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Maize and soybean intercropping in Nepal

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Maize and soybean intercropping in Nepal

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DEDICATION

This thesis is dedicated to my late father
Udit Raut

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Abstract

The productivity of the maize/soybean intercropping system in Nepal has been declining compared to the past, as reported by many farmers. To understand the constraints and to overcome this problem, field experiments and a survey of farmers were conducted at Deorali VDC (mid hills), in Nepal during 2001 and 2002. One pot experiment at Henfaes Research Centre, University of Wales, Bangor was conducted in 2003.

Two field experiments consisting of a combination of three densities each of maize (26.5, 40 and 53 x 10^3) and soybean (100, 150 and 200 10^3 ha^{-1} in 2001 and 50, 100 and 150 x 10^3 ha^{-1} in 2002) along with their sole crops were studied for two seasons to determine optimum populations for the component crops. In the same seasons, another field experiment was conducted to determine the effect of time of maize thinning at different maize densities on LAI and yield attributes of maize and soybean. A survey of farmers was conducted during 2001 to understand the causes of low productivity of intercrops and existing farming practices. A pot experiment was conducted to compare photosynthetic rates of soybean in open, under artificial shade and intercropped with maize.

In neither season was maize yield affected by presence of soybean but grain yield of soybean was reduced in mixture by 59 % and 53 % during 2001 and 2002, respectively. The interception of PAR by the maize canopy increased with increasing maize density and was greatest at highest maize density of 53 x 10^3 plants ha^{-1} due to greater LAI and dry weight of maize at recommended maize density. LAI and dry weight of intercropped soybean increased as maize density was reduced from 53 to 26.5 x 10^3 plants ha^{-1}. Biomass and grain yield of maize were greatest at 53 x 10^3 plants ha^{-1} and least at lowest maize density, whilst conversely biomass and grain yield of soybean increased. The numbers of cobs/plant and grains/cob were highest at low maize density and reduced as maize density increased (except for cobs/plant in 2001) but these did not compensate fully for reduced grain yield due to low density. In soybean, a greater number of pods/plant at low maize density contributed to higher grain yield of intercropped soybean, compared to when grown with recommended maize density. In 2001, grain yield of soybean was not affected by soybean density but in 2002 soybean density of 50 x 10^3 produced a lower biomass and grain yield than 100 and 150 x 10^3 plants ha^{-1} but the differences between these densities were not significant. In both seasons, land equivalent ration (LER) of all treatments was greater than unity indicating higher efficiency of intercropping compared to sole crops.

In the time of thinning experiment, leaf area index (LAI) of maize increased with increasing plant population but the difference between 53 and 66 x 10^3 plants ha^{-1} was not significant. The recommended maize density produced the highest grain yield and declined to lowest at highest maize density of 66 x 10^3 plants ha^{-1} but it did not differ from maize density of 38 x 10^3 plant ha^{-1}. Thus, the population density response was parabolic. Grain yield did not differ significantly between recommended maize density and 38 x 10^3 plants ha^{-1} during the second season. The greater number of cobs/plant and grains/cob at low maize density compensated for the reduced grain yield due to decrease in plant population. However, biomass, yield and pods/plant of intercropped soybean were greatest under low maize density and were reduced as maize density increased. In

the second season, wide maize rows at 50 x 10^3 plants ha^{-1} a produced lower grain yield of maize but increased grain yield and pods/plant of intercropped soybean compared to the recommended maize density. In both seasons, thinning of maize beyond 30 DAS reduced biomass, grain yield and grains/cob of maize significantly while biomass, grain yield and harvest index of soybean increased in the second season only. LER of all treatments in both experiments were higher in the second season which had less rainfall than the first season, favouring higher grain yield of soybean which contributed to the higher LER. In both seasons, delayed thinning reduced LER but this was more pronounced in first season, and reduced the LER to one, indicating no advantage of intercropping over sole crops if thinning was delayed.

A survey of farmers showed that intercropping is predominant (41% of maize area) in this area due to limited mean size of landholding (0.75 ha). Mixed cropping of maize and soybean was advantageous over growing them separately because maize yield was not affected by soybean, and this provided additional output as a bonus crop. In addition, it provided security against crop failure; helped in maintaining soil fertility and gave an income to farmers due to high market price. About 95 % respondents claimed that productivity of intercropped soybean has been declining from the past. The reasons given by them were the introduction of high yielding competitve maize varieties and application of urea as a topdressing to maize. Crop sampling results indicated that low plant populations of both crops at harvest contributed to low yields. Continuous thinning of maize for security against drought, and insect/pest damage and livestock fodder was the main cause of poor plant population at harvest. Other constraints leading to low productivity as indicated by farmers, were poor crop management, drought during germination, sub-optimal ratios and densities of component crops, untimely weeding, excessive rainfall and wild rabbits.

The net rate of photosynthesis in maize (C_4 carbon pathway) was double that of soybean (C_3 pathway) at the same levels of incident PAR. Net photosynthesis rate in soybean increased with increasing PAR up to 500 µmol $m^{-2}s^{-1}$ but leveled off thereafter. Net photosynthetic rate in soybean was significantly greater in the open than under artificial shade and when intercropped. Interactions between slopes of regressions for the three treatments was non significant indicating that soybean does not adapt to shade, although specific leaf area (SLA) of soybean was greater under shade than in open and when intercropped.

It is suggested that soybean could be grown successfully as an intercrop with maize by increasing row spacing of maize from 75 to 100 cm with reduced populations of around 40 x 10^3 plants ha^{-1} which would provide better light penetration to the soybean canopy resulting in increased grain yield. This would compensate for reduced grain yield due to decrease in maize density.

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Acronyms and abbreviations

%	percent
*	significant at the 5 % probability level
**	significant at the 1 % probability level
/	per
@	at the rate of
’	minute
<	less than
>	greater than
&	and
$\mu m^{-2}s^{-1}$	micro mol per square metre per second
10^3	thousand
10^{th}	tenth
6^{th}	sixth
A	Aggressivity
ADB	Agriculture Development Bank
ARS	Agriculture Research Station
ATER	area time equivalent ratio
AVRDC	Asian Vegetable Research Development Centre
B	bean
C	cowpea
CGR	crop growth rate
CIMMYT	International Maize and Wheat Research Institute
cm	centimetre
cm^2g^{-1}	centimetre squared per gram
CR	competitive ratio
cv	cultivar
DAS	days after sowing
DFID	Department for International Development
df	degree of freedom
DOS	Disc Operating System
E	east
e.g.	for example
ELER	effective land equivalent ratio
FYM	farm yard manure
g	gram
$gm^{-2}d^{-1}$	gram per metre square per day
HMGN	His Majesty’s Government of Nepal
HARP	Hill Agriculture Development Project
ha	hectare
i.e.	that is
IRGA	infrared gas analyser
IRRI	International Rice Research Institute
K	potassium
K_2O	potassium oxide
kg	kilogram
km	kilometre
LA	leaf area

LAI	leaf area index
LAR	leaf area ratio
LER	land equivalent ratio
LRMP	Land Resource Mapping Project
lsd	least significant difference
M	maize
m	metre
m.e.	milli equivalent
m^2	square metre
MA	monetary advantage
MC	moisture content
mg	milligramme
mm	millimetre
NMRP	National Maize Research Programme
N	nitrogen
no	number
NAR	net assimilation rate
NARC	Nepal Agriculture Research Council
NH_4^+	ammonium ion
NO_3^-	nitrate ion
ns	non-significant
^{o}	degree
^OC	degree Celsius
P	phosphorous
P_2O_5	phosphorous pentaoxide
PAR	photosynthetically active radiation
ppm	part per million
q	quintal
r	correlation coefficient
RCA	research command area
RCB	randomized complete block
RCC	relative crowding coefficient
RGR	relative growth rate
Rs	rupees
RYT	relative yield total
S	soybean
S*	sorghum
SLER	staple land equivalent ratio
Spp	species
T	tall fescue
Tg	Teragramme)million tonnes
TT1	time of thinning after germination
TT2	Time of thinning after 30 DAS
TT3	Time of thinning after 60 DAS
TT4	Time of thinning after 30 + 60 DAS
t	ton
VDC	Village Development Committee
vs	versus
WDR	Western Development Region
$x 10^3$	thousand

CHAPTER ONE

GENERAL INTRODUCTION

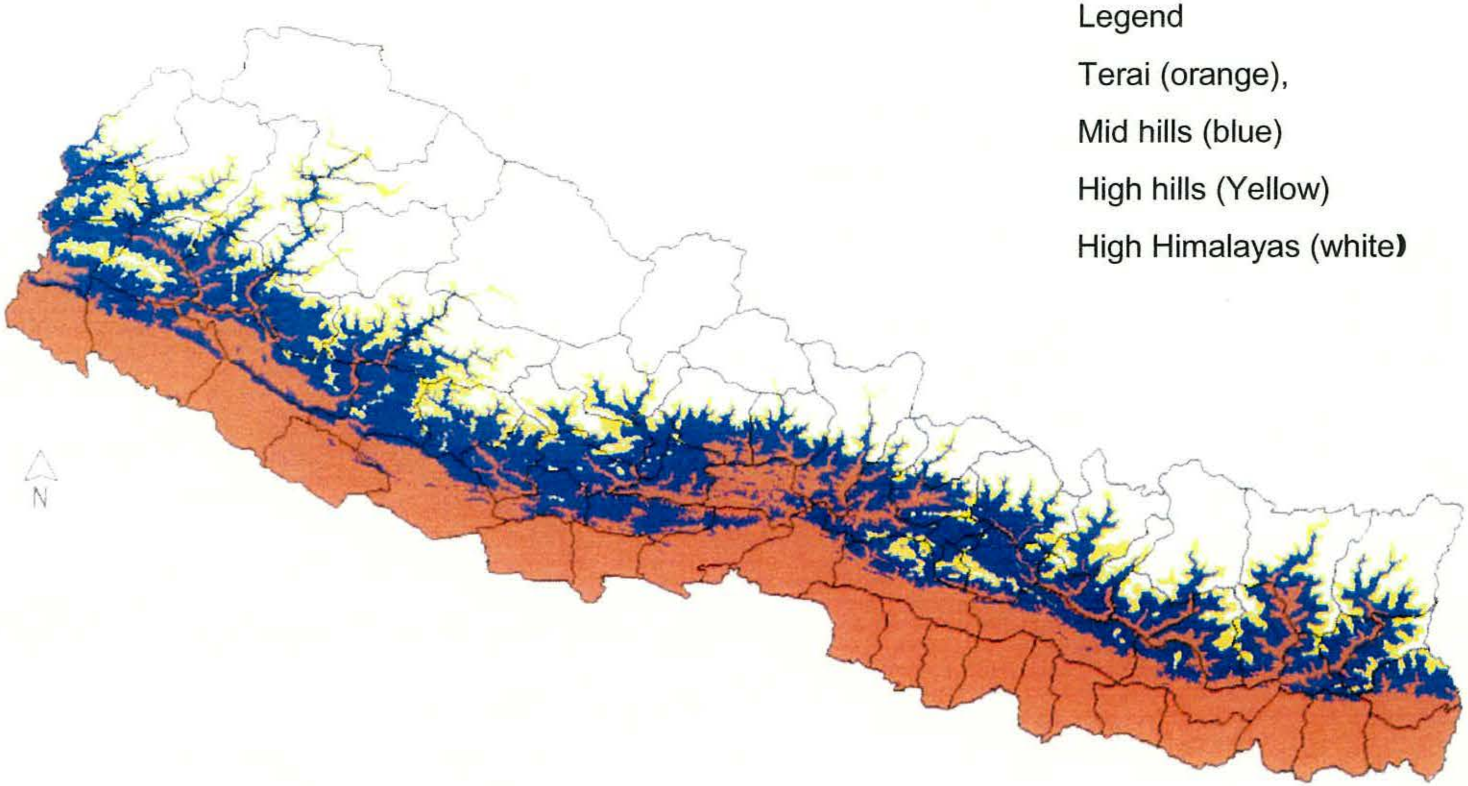
1.1 Background and context

Maize (*Zea mays* L.) is the second most important staple food after rice for the Nepalese population, especially in the hills (Anonymous, 1998a). It is grown on 819,010 hectares with an average grain productivity of 1.76 t/ha. About 61.5 % of the total maize production (1,445,440 t) is produced in the mid and high hills and is used for direct human consumption at farm level and the ratio of human consumption to total production is higher in less accessible areas (Paudel *et al.*, 2001). Of the total maize area, the mid hills (1000-1600m asl) occupies 69.8 % in area and 53.3 % of production (Anonymous, 2000). Paudel *et al.* (2001) reported that although maize yields in the hills have increased slightly over the past five years, there has been very little yield improvement when compared to nationwide yields 30 years ago. This is probably due to a combination of the expansion of maize cultivation into less suitable terrain, declining soil fertility and sluggish adoption of improved management practices. Considering the population growth in the country, during next two decades demand for maize is expected to increase by 4 % per year for direct human consumption as well as for livestock feed. There is an urgent need to increase productivity of the hill farming system in a sustainable way without depending too much upon external inputs.

1.1.1 Brief Description of Nepal

Nepal is a small, landlocked, constitutional monarchy, lying in the lap of the highest mountains of the Himalayas (Fig. 1.1). It is situated between two giant countries, China and India, at latitudes 26^0 22' N to 30^0 27' and longitudes 80^0 04' to 88^0 12'E. It lies on an east-west axis, having a length of 885 km whereas the south to north width of the country varies from 130 to 240 km with an average of 193 km. The total area of the country is 147,181 sq km in which only 20.2 % is suitable for cultivation. A great variation in topography, which ranges from 60 m above sea level to over 8000 m asl, causes a wide variation in climate, from subtropical to alpine. Major rivers originate from the Himalayas and run in a north to south direction, which creates barriers for

Figure1.1. Map of Nepal showing distribution of land on the basis of topography



transportation and communications. About 23.2 million people live in this country with a population density of 158 per km and an annual growth rate of 2.27 % (SINA, 2001). Physically the country can be divided into five regions, namely Terai (plain), Siwalik hill, mid hills, high mountain and High Himalayas (Figure 1.1).

Terai region: This is a narrow, warm sub-tropical belt comprising the foot hills of the Himalayas and extends from east to west along the south side of the country and is continuous with India. It is an extension of the Gangetic plains of India, and forms low, flat land and has an altitude ranging from 60 m to 310m. It includes most of the fertile land and dense lowland forest areas of the country. This region occupies 23.1 % and 41.5 % of the total and cultivated areas of the country, respectively (SINA, 2001). However, it supports 46.7 % of the population. Water resources and fertile land permit the cultivation of a wide range of crops like paddy (rice), maize and wheat.

Siwalik hills and Mid hills: These are located in the middle part of the country and also run from east to west. The climate is generally subtropical and temperate with considerable variation in micro-climate, created by the rugged topography which changes according to elevation. Siwalik hills and mid hills occupying 13 % and 30% of the total land and 13.7 % and 27.5 % of cultivated areas respectively. They support 45% of the population. *Bari*[1] land is dominant in mid hills where maize is a major crop during the summer season.

High Mountain: It occupies 20% land area with an alpine climate. Only 8.5% land is suitable for cultivation. Because of high altitude and cold climate, this area is thinly populated. Sheep and yak grazing are the main occupations of the mountain people. It supports only 5 % of the population.

High Himalayas: It is mainly characterized by high peaks, steep slopes and narrow valleys. The climate is predominantly arctic, with permanent snowfields and many glaciers. Only

[1] *Bari* lands are mostly located on the steep slopes of the hills and characterized by terraced land or non-terraced rolling landscape, unbunded and usually subject to erosion. (Anonymous, 1998a).

0.2 % of the land area is suitable for cultivation. The population of Nepal residing in this region is less than three percent.

1.1.2 General Background of the western region

The research reported in this thesis was located in the mid-hills of the Western Development Region (WDR). It is one of the five development regions of the country, which lies to the west of Kathmandu, the capital of Nepal (Fig.1.2). There are 16 districts, which include 885 Village Development Committee and six Municipalities. Out of the 16, three districts are situated in the south and are categorized as terai and two districts which are located on the north side of Himalayas fall under high Himalayas regions. The remaining 11 districts, the shaded areas of the map, represent the western hills and fall into mid and high mountain classifications and come under the Research Command Area (RCA) of Agriculture Research Station (ARS), Lumle, near Pokhara.

Climate, Area and Population

The WDR has an area of 29,398 sq. km with a population of 4.57 million and mean household size of 5.25 persons (SINA, 2001). The climate is monsoonal with at least 70% of the total annual rainfall occurring during June to September and the maximum and minimum temperatures occur during May-June and January, respectively. However the actual temperature depends on the altitude. The rainfall varies from 6,000 mm at Lumle and the lowest is 1500 mm, at Palpa, located in the southern district of the mid hills, characterized by low rainfall. Agricultural production is determined by a combination of altitude (300-2500m), rainfall (1500-6000mm) and aspect. As result, climate varies from sub tropical to alpine within tens of kilometres and the range of possible crops and other farm enterprises reflects this variability (Floyd, 1997). On the basis of altitude, the western hills are classified as river basin (300-600m), low hill (700-1000m), mid hill (1100-1500m) and high hill (>1500m).

1.1.3 Farming systems in the western hills of Nepal

The western hills contain diverse farming systems where farmers depend upon complex mixtures of crops, livestock and forest for a living. About 78 % households live in low and

LOCATION MAP

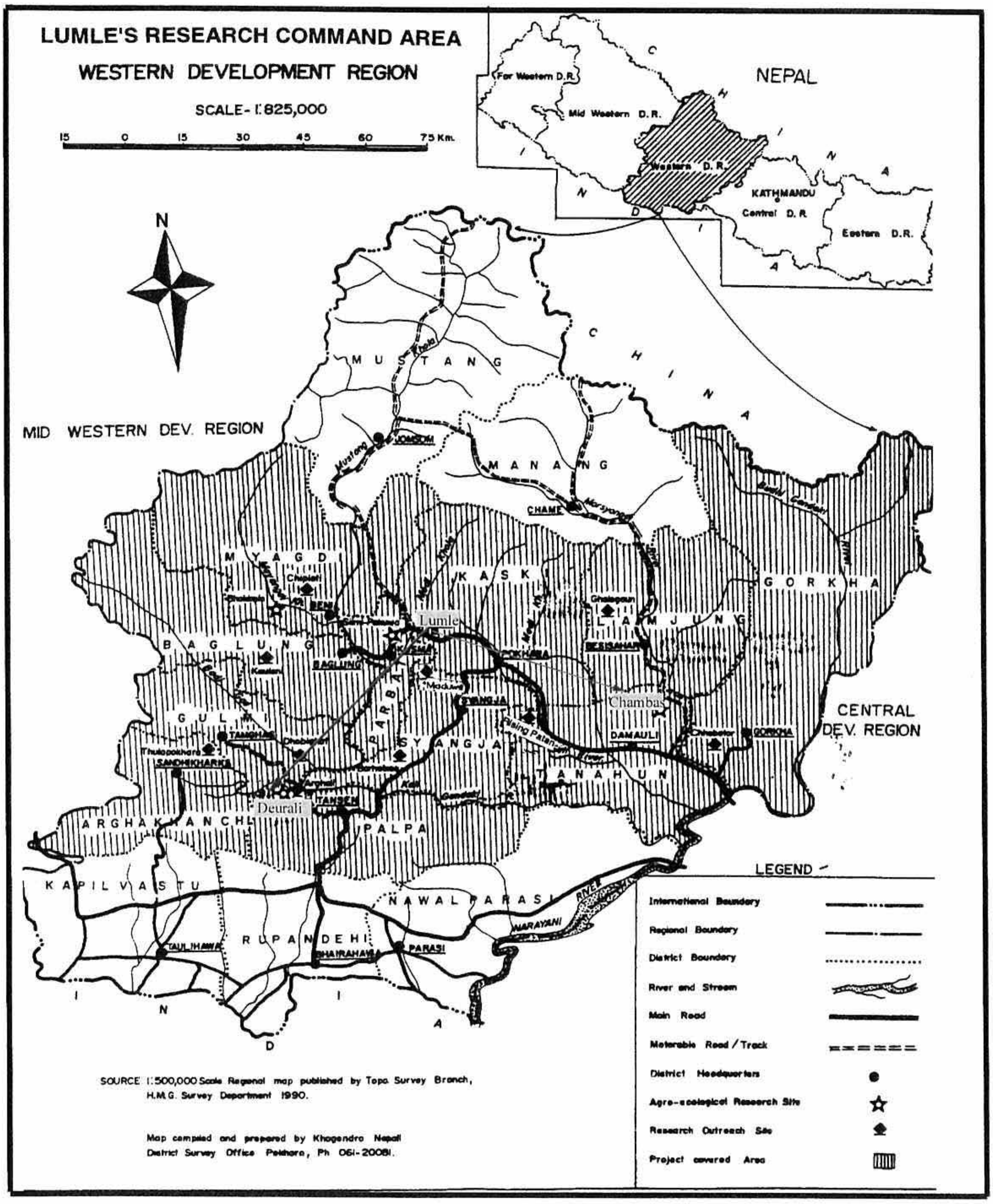


Figure 1.2 Location map of research site in Western Development Region

mid hills followed by 14 % in river basins, 9 % in high hills and less than one percent in high mountains (Vaidya and Floyd, 1997). Hill farming in Nepal is dominated by subsistence farmers (Subedi, 1990) with small land holdings (<0.5 ha) associated-with rainfed cultivation, low external inputs and integration of crops and livestock (Subedi, 1997). The term "small farm" is defined by Sanchez (1976) as one based primarily on only family manual and animal labour and where a considerable proportion of farm output is consumed directly by the family and a significant portion is sold or bartered. A socio-economic survey conducted by Vaidya and Floyd (1997) in nine districts of the western hills of Nepal showed that the poor groups (46% households) owned on average only 0.28 ha of land, which included 0.09 ha of *khet* land compared to 0.36 ha and 0.59 ha of *khet* [2] land for medium and rich groups, respectively. Only 20 % households produced enough food for more than 12 months, whereas over 46% households produced enough food only for less than six months. Small farm size and fragmented land holdings are major constraints to agricultural development especially in the hills (Subedi, 1997). Similarly, Allen and Obura (1983) reported that small farmers in many countries are seriously constrained by low productivity and limited land resources.

In Nepal, most of the crop production activities are concentrated between 300 to 1500 m asl. In river basins and low hills, *Khet* land is dominant, where three crops per year are grown successfully at lower warmer altitudes. A rice-wheat cropping system is predominant in *khet* land. *Kalomato* (black soil) was the most common soil type reported in *khet* (53% respondents) followed by *rato mato* (red soil, 37 %) *balaute* (sandy soil, 28%) (Vaidya and Floyd, 1997). *Khet* land is a major indicator of wealth and social prestige in hill societies. As the altitude increases to mid hills (1100-1500m), two crops per year are grown. On *bari* land, a maize based cropping is predominant. Subsistence farmers are largely dependent on *bari* land where maize is an important crop during the summer and monsoon season. This land is usually fallow during the winter months although wheat or mustard (*Brasica* spp) may be grown. At higher altitudes, above 1500m, one crop a year is

[2] *Khet* land is that which is leveled and bunded to impound water and is partially or fully irrigated especially during rainy season. It is generally more productive than *bari* land

grown. Livestock enterprises are the main source of living and farmers keep yak and sheep. Above 2000m, potato and barley are the main crops.

On *bari* land, intercropping systems are usually practiced to maximize the use of available resources, particularly moisture during the rainy season (Subedi, 1990). Besides this, the long duration of maize at high altitudes makes it difficult to grow sequential crops. Therefore, farmers usually grow more than two crops together as intercrops to make efficient use of the short duration of the monsoon from June to September. The primary objective of these hill farmers is to grow cereals as staples usually maize (Subedi, 1997; Siame *et al.*, 1998). Willey (1979) also emphasized that many subsistence farmers put their main effort into raising cereals because they provide their staple food and yield more than non-cereal grain crops. However, maize alone will not meet the dietary requirement of a family so more than one crop is often grown simultaneously. In addition, farmers grow more than one crop to spread labour peaks and to reduce marketing and production risks (Mead and Willey, 1980).

Approximately 80 % of the maize growing area of the mid hills falls within the eastern and central wet agro-ecological zone characterized by relatively high rainfall with a long duration of monsoon rainfall (Anonymous, 1998a), where maize is often grown as an intercrop or relayed with finger millet (*Eleusine coracana* Gaertn.). Other intercropping systems include maize with soybean (*Glycine max* L Merr.), other legumes (e.g. beans *Phaseolus* spp), and rice bean (*Vigna umbellate* Thumb), radish and upland rice (Anonymous, 1997). The combination of crops depends upon rainfall and food requirements of the farmers. The maize/millet system is a common practice in northern districts of the mid hills, having a wet regime, whereas growing of soybean is a common practice in southern districts of the mid hills, a relatively dry region, to avoid the risk of crop failure due to moisture stress. In the north of Kathmandu Valley, hillside maize was reported to be intercropped with amaranth and several kinds of legumes and flat lands were devoted to monocrop rice (Innis, 1997). Similarly, Rerkasam *et al.* (1988) reported that mixed cropping using legumes and non-legumes (e.g. maize and bean, cowpea or soybean grown together in the same field for at least part of their growth cycle) is common in small land holdings in South Asia, particularly under rainfed systems in Pakistan and Nepal.

1.2 Importance of maize in the Nepalese economy

Maize is the most important food grain crop both in term of area and production in the hills of Nepal. It plays an important role in human diet of hill farmers as well as animal nutrition. It occupies about 30 % of the total cultivated area and comprises 27 % of the cereals production in Nepal (Anonymous, 1997). Maize comprises 38 % and 33 % of cereal grain production in mid and high hills, respectively. The most common preparations of maize grain in the hills are *Aato/Bhat* (cooked maize grit), *Dhindo* (Porridge), *Pitho/Puwa* (maize flour fried in ghee or oils), boiled and popped maize (Jaiswal and Subedi, 1997). The per capita maize consumption in Nepal increased from 140 g/day in 1971/72 to 174.4 g/day in 1995/96 (Anonymous, 1997).

In the mid hills context, maize is a multipurpose crop. It provides green fodder for animals during the growing season. Farmers sow maize seed densely and start thinning after one month and continue up to silking when they thin out the barren plants to feed to their animals (Subedi, 1990). In the hills, ruminants are important components of farming systems and provide milk, meat, animal traction and manure (Paudel *et al.*, 2001). Besides this, farmers strip lower leaves of maize at the tasseling stage and sometimes detop the upper portion of maize plant at the brown husk stage and feed this to animals. After harvest, dry stalks are also used for animal feed. Grains are used as feed ingredients for milking animals and poultry feed.

Women are directly involved in maize production and in many communities provide up to 90 % of the labour for cultivation and harvest, since most able-bodied men are away during the season seeking off-farm employment (Anonymous, 1998a). Maize is also emerging as an industrial crop and is used for extraction of corn oil, animal feed ingredients, glucose and corn flakes.

1.3 Importance of soybean in the Nepalese economy

Plant sources satisfy up to 80 % of dietary needs in much of the tropics and subtropics (Kinzig and Socolow, 1994 quoted in Graham and Vance, 2000). Grain legumes have become increasingly important in supplying protein for farmed animals and humans. They are grown on approximately 250 million ha globally and fix about 90 Tg of N per year (cited by Graham and Vance, 2000). Soybean is a rich source of plant protein (45-50 % crude protein content in the seed). Soybean is the fifth most important legume crop of Nepal, covering 19,759 ha with an average grain yield of 849 kg/ha (SINA, 2001). About 75 % of the soybean area is in the mid hills and this contributes 77.7 % of the total production. A further 10 % of the area falls in the high hills and contributes 12 % of the total production.

Green pods and seeds of soybean are used as a vegetable whereas dry seeds are either cooked whole or split or used as thick soup (*Dal*) or ground or mixed with rice flour for making bread. They are also valued as high protein fodder and high quality feed concentrates for animals. Vaidya and Floyd (1997) reported that among eleven types of grain legume, soybean was the most widely grown and consumed (70% of total produce) in mid and high hills of the Research Command Area of Agriculture Research Station, Lumle. It is also grown as a cash crop in the hills because farmers sell their surplus produce in markets and it fetches a good price. Besides protein, the soybean seed also contains 20 % oil (Anonymous, 1998b). But there is a negative relationship between protein and oil content of soybean (INSOY, 1986). The protein and oil of soybean are used as raw materials for making soymilk, vegetable ghee and cooking oils.

Soybean is intercropped with maize in every agro-ecology area in the hills but more commonly in the western and mid western region characterized by low rainfall (Paudel *et al.*, 2001). Intercropping of soybean with maize provides some security against crop failure (Vandemeer, 1989; Rao and Singh, 1990 and Fukai, 1993), increased land use efficiency (Mandal and Mahapatra, 1990), maintenance of soil fertility (Chatterjee and Bhattacharya, 1986; Banik and Bagchi, 1993) and supply of protein to mankind and feed to animals. Soybean plants withstand drought to some extent and produce a satisfactory yield and demand small amounts of soil nutrients (Willey, 1979). It can fix atmospheric nitrogen (N_2) in root nodules (Thurlow and Hilbold, 1985), contributing part of the fixed N to the associated crop and enriching the soil as claimed by Wahua and Miller, (1978b); Palaniappan, (1985) and Liang *et al.* (1996). On sloping land, it also reduces soil erosion due to run off during rains by covering the ground with a canopy (Fukai, 1993).

1.4 Declining soil fertility

Productivity of rainfed uplands (*Bari* land) is decreasing due to declining soil fertility resulting from continuous growing of the same cereals crops (maize/finger millet) which deplete plant nutrients in the soil, nutrient leaching and soil erosion (Emuh and Agboola, 1999). Without adequate nutrient replenishment, land productivity declines over time. Mathema *et al.* (1999) conducted a survey in hill districts of Nepal and reported that the main cause of low productivity is declining soil fertility. The rate of decline of soil fertility is relatively greater in the rainfed upland (*bari)* land than in the lowland (*khet* land). Insufficient use of animal manure based compost reduces soil organic matter, also resulting in a decline in soil fertility. Declining soil fertility and limited farmyard manure (FYM) are major constraints leading to low productivity of crops in the hills of Nepal (Subedi, 1998). Farmyard manure is still the major source of plant nutrients for maize crops in the hills. The availability of bedding materials, fodder for feed and other leaf litter is rapidly decreasing because of the decline of forest area (Tripathi *et al.*, 1998), and the Government's policy to restrict the collection of forage in community forests and the limited supply of labour (Mathema *et al.*, 1999).

In the absence of sufficient compost, farmers are forced to use chemical fertilizer, especially urea as topdressing in maize. Continuous use of urea increases acidity in the soil (Subedi, 1998). Tripathi *et al.* (2001) conducted long term experiments to assess crop productivity after continuous cropping of maize/finger millet in highly acidic soil and reported that there was a significant yield reduction of maize (57%) and finger millet (23 %) due to continuous growing of same crops from 1997 to 2000, without addition of organic manure to the soil. In addition, available phosphorous, exchangeable K and organic carbon in the soil were reduced from 5.67 to 1.55 ppm, 0.21 to 0.14 me/100g soil and 3.28

to 2.39 % respectively. Similarly, continuous application of only chemical fertilizer at the rate of 90:30:30 kg NPK/ha reduced maize yield by 74 % after four years and the productivity of the system was not sustained without application of compost on highly acid soils.

Soil erosion by heavy rainfall on steeply sloping *bari* land is another serious problem in the hills, also exacerbating the decline in soil fertility. Kowal and Kassam (1976) also reported that erosion by water is a serious problem in some parts of the tropics where both intensity and drop size of rain are greater than in temperate areas. Similarly, Gardner and Jenkins (1995) reported that sustainable soil loss rates are estimated to be in the range 10 to 11 t/ha/year and therefore suffering greater losses that can not be maintained in cultivated land. The areas considered to be more at risk are the marginal *bari* lands at high elevations that are mostly the farmed by the poor farmers. Erosion risk can be minimized by intercropping, which provides a more rapid ground cover, preventing rain drops hitting bare soil when they tend to seal surface pores, and prevents water from infiltrating and increasing surface erosion (Innis , 1997).

The Agriculture Perspective Plan (1995) produced by the Ministry of Agriculture has identified declining soil fertility and the limited availability of fertilisers as key constraints to increasing crop productivity and has given priority to soil fertility research. Therefore, the tenth five years plan in 2002 of His Majesty's Government of Nepal has emphased the need to implement the Agriculture Perspective Plan and develop technologies for sustaining soil fertility in the future. The intensification of agricultural practices based on high inputs has created both economic and environmental problems. The use of indigenous agricultural knowledge and practices plays an important role for maintaining sustainable agriculture for longer periods (Innis, 1997). It has been suggested that inclusion of legumes with cereals adds nitrogen to the soil by fixing atmospheric nitrogen in the root nodules, which helps in maintaining soil fertility. It saves expensive use of chemical fertilizer and increase productivity of the system.

1.5 Inappropriate crop management

Low production of soybean in the maize/soybean system is due to the introduction of high yielding, leafy maize varieties, which require more plant nutrients from the soil and depress the growth of intercropped soybean by intercepting more solar radiation. Khadka (1992) reported that recommended varieties of maize were not suitable for intercropping or relay cropping due to their high leaf area index. The tall stature, large amount of foliage and large tassel size of most improved maize varieties available in Nepal also reduces the yield of finger millet grown as a relay crop (Baniya, 1990; Subedi, 1990). This indicates a need to find a suitable variety of maize that does not provide too much shade to intercropped soybean. Additionally, a significant variation in grain yield of soybean genotypes tested under maize was observed (Prasad *et al.*, 1998).

Plant density and spatial arrangement have a great influence on the performance of crops in mixture due to the need for optimum utilization of above and below ground resources resulting in higher combined yields of the systems. The amount of light intercepted by components in an intercrop system depends on the spatial geometry of the crops and foliage architecture (Trenbath, 1982). In the system being examined, the taller maize shades the soybean and its high density causes reduced growth and yield of soybean as also found by Ofori and Stern (1987). Optimum plant densities will be different for intercropping compared to sole crops; for example, a reduced density of maize should provide more light for intercropped soybean and the yield reduction in maize may be compensated by increased yield of soybean. Planting of maize in wider rows or pair-rows, keeping the same plant population within the rows provides more space for the intercrop. Pandey *et al.* (1999) reported that pair planting of maize at 30 cm and using the interspace for growing two rows of soybean significantly increased production compared to standard planting of maize at 60 cm inter row spacing.

Many farmers have reported that the productivity of soybean intercropped with maize has decreased from the past. The one reason given by farmers is the increasing use of urea as top dressing on maize. Mineral nitrogen will generally depress both nodulation and N_2 fixation (IRRI, 1976). Plant population of both crops varies from farm to farm depending on germination, seed quality, soil moisture, and suppression by excessive growth of weeds and losses during hoeing and weeding of maize. Paudel *et al.* (2001) also mentioned that the main causes of low productivity were low plant population (often caused by drought after planting), excessive rains, weeds and insect damage. Generally, plant populations of both crops are higher at the time of germination. Farmers start thinning of maize one month after sowing and continue up to silking stage. The final plant stands of both crops are low at harvest, which is a major cause of low production in the system. It is necessary to investigate the causes of low plant population and to determine the optimum population of both crops for maximum yield of the whole system.

The maize/soybean intercropping system was chosen for this detailed study because it is important for those subsistence farmers of mid hills who are dependent on erratic rainfall. Such a study on the maize/soybean system has not been carried out in these areas before. The majority of work on maize and soybean has been done on varietal selection of both crops in isolation by separate commodity programmes. It was thought important, therefore, to gain better understanding of the possible causes of competition and complementarity between these two crops.

1.6 Research rationale

The highest yield of maize is obtained at optimum plant population (53 x 10^3 plants ha^{-1}). Any deviation from optimum plant population (above or below) has a negative effect on grain yield of maize but a low density of maize has a positive effect on soybean by allowing more light to the companion crop.

1.6.1 Overall Research Objective:

1. To identify the constraints of maize/soybean intercropping system under farmers' conditions.
2. To study the effect of varying plant population on the growth and yield of maize and soybean plants when grown as intercrops.
3. To study the effect of maize removal at different times (as practiced by local farmers) on growth and yield of maize and soybean grown as intercrops.

1.6.2 Expected Research Output:

1. Constraints of low productivity in the maize/soybean intercropping system under farmers' managed condition identified.
2. Optimum plant populations of both crops (maize and soybean) grown as intercrop identified to obtain highest land use efficiency.
3. Information helpful for designing future research on maize and soybean intercropping system.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction to Intercropping

Intercropping may be defined as the growing of two or more crops simultaneously in the same field, thus resulting in crop intensification in time and space (Andrews and Kassam, 1976). The crops are not necessarily sown at the same time but they are usually 'simultaneous' for a significant part of their growing period (Willey, 1979). This distinguishes intercropping from 'relay cropping' in which the growing period only briefly overlaps. Intercropping is further classified into row intercropping, mixed intercropping and strip intercropping. In row intercropping, different crops are grown simultaneously in separate rows whereas in mixed cropping, crops are grown randomly with no distinct row arrangements (Haizel, 1974; Andrews and Kassam, 1976). In strip cropping, crops are grown simultaneously in the different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically (Vandermeer, 1989).

Intercropping is a traditional form of agriculture in many developing countries (Wijesinha *et al.*, 1982) and is popular with small-scale farmers (Wahua and Miller, 1978a). It is the main production system in subsistence agriculture in the tropics and subtropics (Willey, 1979; Santella *et al.*, 1994) where crop production is often constrained by limited available moisture due to low and short distribution of rainfall and by low soil fertility or sloping land. In rainfed agriculture where full irrigation is not economically possible, the extent of crop growth is limited by the duration of wet season and residual moisture stored in the soil. Therefore, many farmers aim to maximize production by growing more than two crops simultaneously on the same land. For example, about 70% of the small scale farmers of Nigeria are involved in growing groundnut intercropped with cassava to earn income (Ikeorgu and Odurukwe, 1990).

Various types of intercropping system are practiced in different countries. For example, farmers grow annual crops under immature perennial plantation crops to utilize resources during early establishment. In addition, cocao needs the protection of temporary shade during transplanting. For this purpose, many food crops such as maize, pigeonpea, cassava and banana can be grown as intercrop. Among various food crops intercropped in a young rubber plantation on the Atlantic cost of Costa Rica, maize and cassava gave the best economic and agronomic results (Pinchinat *et al.*, 1976). Hence, annual crops perform better under tall crops grown at wide spacing. However, intercropping of annual crops is the most common practice in many parts of the World. The combination of crops is primarily determined by the length of growing season and adaptation of crops to particular environments. In low rainfall areas, between 300 to 600 mm, simultaneous cropping is practiced with crops of similar maturity (Andrew and Kassam, 1976) whereas, areas with annual rainfall greater than 600 mm, cereals and legumes of varying maturity are used, e.g. maize, sorghum, millet, rarely upland rice, and legumes such as cowpea, groundnut, soybean, chickpea or pigeonpea (Ofori and Stern, 1987).

Inclusion of legumes with cereals is the commonest intercropping system in Africa and Asia (Siame *et al*, 1998). The cereal, being the staple, is regarded as the crucial component and the farmer's primary objective is to produce a high yield of this crop. At the sametime, the legume has importance as a high protein food crop, or as a high value cash crop. Legumes do not compete with cereal plants for most nutrients especially nitrogen, because nitrogen fixation occurs in their root nodules which fulfills their own requirements and is partly available to the succeeding crop after decomposition of nodules and leaf litter into the soil after harvest (Wahua and Miller, 1978b; Banik and Bagchi, 1994; Hungria and Vargas, 2000).

Intercropping with legumes confers many advantages. Intercropping of legumes with pasture crops improves the quality of pasture by increasing percentage of protein content (Vandermeer, 1989). Intercropping with legumes is also used to avoid an application of expensive N fertilizers and is one way of increasing land productivity. Myers and Wood (1987) reported that the amount of nitrogen fixed by legumes could range between 50 and 300 kg N/ha per season. Spreading habits of legumes help in suppressing weeds and controlling pest and disease and increase the capacity for nutrient recycling (Howieson *et al*, 2000). Inclusion of legumes in intercropping is also reported to have a residual effect on succeeding crops. Wheat yield was increased significantly when grown after sorghum intercropped with cowpea (both fodder and grains) or with groundnut compared with sole sorghum in the previous crops (Waghmare and Singh, 1984). Jellum and Kua (1996) emphasised that intercropping is a viable alternative to conventional maize culture for forage production because it saves application of N fertilizer. Intercropping of legumes reduced the amount of N fertilizer application from <90 kg N/ha in the first year of rotation to <40 kg N/ha in the second year of rotation to produce the same yield of maize. This is known as nitrogen 'sparing' (Vallis *et al.*, 1967 in Giller and Wilson, 1991), indicating that the legume component removes only a small amount of soil N, therefore more is then available for use by the companion crop.

2.1.1 Importance of Intercropping

Farmers in developing countries practice intercropping for several reasons; perhaps the most important is that it is regarded as more efficient and productive than growing crops separately because of higher combined yields and better resource use efficiency. Component crops compete less for the same growth resources as they may require those at different growth stages and different layers of soil. They also make more efficient use of light, water and nutrients (Weil and McFadden, 1991). Planting of tall cereals like maize at wider spacing provides sufficient space for growing companion crops, because maize plants do not utilize all available growth resources at early growth stages. Companion crops grown as intercrops may utilize those growth resources more efficiently. For example, better use of light is a major cause of yield advantage of mixtures (Govinden, 1984). In Tanzania, a maize and bean mixture captured 13% more light than monocropped maize and 6% more than monocropped beans (Fisher, 1976).

Maize, being tall and sturdy, is a dominant crop and is but slightly affected by the companion crop but in turn it usually has a major influence on the growth of companion crop. Total yield of the intercrops is higher than for sole crops when grown separately, because interspecific competition for growth resources is usually less than intraspecific competition (Willey, 1979). Looking at maize and soybean intercrop specifically, Rajbhandary (1991) reported that the presence of soybean with maize had little effect on the performance of intercrop maize, however, soybean yields were significantly reduced. Intercropping of cowpea, blackgram and soybean gave highest maize equivalent yield (Yield of maize + Yield of intercrop x price of maize/price of intercrop)

(35.28, 33.5 and 30.7 q/ha, respectively) than sole maize (28.0 q[1]/ha) (Khola *et al*, 1999) and a 41% higher land use efficiency was found by timely planting of soybean and maize (LER[2] = 1.41). Similarly, Heremath *et al.* (1994) reported that the highest productivity came from maize planted at 90 x 20 cm spacing with soybean, which was higher than sole cropping of maize or soybean. Intercropping of cowpea with maize did not affect yield of maize whereas cowpea yield was depressed with presence of maize (Haezel, 1974). Intercropping reduced the yield of maize by 7.9% and of pigeonpea by 63.8% compared with their respective sole crops (Rafey and Prasad, 1992). They found that association of both component species at recommended level of nutrients resulted in the greatest land equivalent ratio (1.35) together with grain yield (4.11 t/ha) and highest monetary advantages (Rs[3]2728/ha).

Intercropping also helps mitigate risks associated with crop failure (Norman, 1971; Subedi, 1997) and market instability. In intercropping, component crops with different morphological and physiological characters are grown which make more efficient use of light, water nutrients than grown separately. In addition, if one crop fails or grows poorly from whatever causes, the other crop can compensate (Rao and Willey, 1980a; Rao and Singh, 1990) and provides security against crop failure. Over-production of one single component may saturate the demand of local consumers, which results reduction of profit to the farmers.

Intercropping has been shown to increase total yield by reducing pest problems. It reduces the effect of insect attack by dispersing them in the mixture, which may reduce the exposure of a target species to attack by pests and disease and subsequent spread of pest and disease may be retarded when target plants are mingled with a non-susceptible species (Fukai, 1993). For examples, Francis (1978b) reported that fall armyworm (*Spodoptera frugiperda*) attack on maize was less in a mixed cropping system with beans than in a monocrop. Similarly, farmers of Gambia planted groundnut with sorghum which reduced weevil attack on sorghum reportedly due to a confusing effect of groundnuts (Vandermeer, 1989).

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[1]. 1 q = 100 kg,
[2] LER = Land Equivalent Ratio
[3] Nepal Rs 120 = 1 £

Intercropping increases the rate of ground cover and so suppresses weed populations in the field. Midmore (1993) reported that intercropping of cassava with bean controlled weeds as effectively as application of pre-emergence herbicide. Premalal *et al.* (1994) reported that all intercropping treatments (maize + soybean) had fewer weeds compared to sole crops. Similarly, a maize field (monocrop) produced 4 t/ha of weeds after 40 days of sowing but maize intercropped with soybean produced only 0.5 t/ha of weeds (Moody and Shetty, 1979), because the inter-row spaces in the sole crop provide room for weeds to flourish.

Intercropping also reduces soil erosion by achieving full cover quickly, which prevents raindrops from hitting the bare soil. Aina *et al.,* (1976) reported that intercropping of cassava and maize reduced erosion and runoff more than sole cassava. In intercropping, tall erect growing species also provide support for intercropped climbing species such as common bean (*Phaseolus vulgaris*) and serves as windbreaks for companion crop.

Intercropping has become economically more attractive in areas where farming is both capital and labour intensive due to high population and absolute land shortage (Andrew and Kassam, 1976). Besides higher yield of intercrops, it provides diversified food to the poor hill farmers of Nepal in remote area and supplies feeds to their animals.

2.2. Conceptualization of Intercropping

Many advanced methods have been developed to evaluate monocrop yield by different researchers in different situations. But methodologies developed for assessing advantages of combined yield of intercropping and sole crop together are limited. It has been suggested that more than one analysis should be applied for the analysis of intercropping data (Mead and Stern, 1979). When two species are grown together in association, the presence of one species may alter the growth of the other by changing micro-environments. It may be positive for one another, called complementarity, or negative, called competition, where both species compete for same growth resources resulting in poor growth compared to when grown separately.

The combined yield of intercrops is usually greater than that of sole crops because inter-specific competition is less than intra-specific competition (Willey, 1979). Various indices for advantages of intercropping have been proposed by different researchers and some are extensively used in intercropping competition studies. Relative Crowding Coefficient (RCC), one of them, is extensively used in ecological research and was proposed by De Wit (1960). It is based on the assumption that intercropping treatments are in replacement mixtures (where the space that was occupied by one component is occupied by the other). Each species has its own coefficient (K), which gives a measure of whether that species has produced more or less yield than 'expected'. Expected yields are those that would be obtained if each species experienced the same degree of competition in mixture as in pure stand, i.e. interspecific competition was equal to intraspecific competition (Willey, 1979). For species in a 50:50 mixture with species a and b, it can be written thus:

$$K_{ab} = \frac{Yab \times Zba}{(Yaa - Yab) \times Zab} \text{..........................} \textit{Equation } 1$$

where, Kab, relative crowding coefficient of crop 'a' intercropped with 'b'

Yab = mixture yield of species a, Yaa = pure stand yield of species a,

Yba = mixture yield of species b, Ybb = pure stand yield of species b,

Zab is the sown proportion of species a, Zba is the sown proportion of species b.

If a species has a coefficient less than, equal to or greater than one it means it has produced less yield, the same yield or more yield than 'expected', respectively. The component crop with the highest coefficient is the dominant one. The product of coefficient (K), having greater than one indicates a yield advantage in mixture. However, this index is not used in the intercropping experiment described in this thesis because both types of treatment models (Additive and Replacement) are included.

2.2.1 Aggressivity

This index was proposed by McGilchrist (1965) and may be used in replacement mixture. It provides a simple measure of the relative yield increase of species over others. It indicates those components which are dominant and more competitive compare to others and denoted by A. For any replacement series treatments it can be written: -

$$A_{ab} = \frac{\text{Mixture yield of crop a}}{\text{Expected yield of crop a}} - \frac{\text{Mixture yield of crop b}}{\text{Expected yield crop of b}} \text{........} \textit{Equation} \; 2$$

$$A_{ab} = \frac{\text{Y ab}}{\text{Yaa x Zab}} - \frac{\text{Y ab}}{\text{Ybb x Zba}}$$

where, Aab is aggressivity of species 'a' on species 'b'. An aggressivity value of zero indicates that the component crops are equally competitive. The positive value component is considered to be aggressive and dominant over the negative value component. The greater the numerical value, the greater the difference between actual and 'expected' yield. Willey and Rao (1980) questioned its value for meaningful interpretation of intercrop comparisons that give different levels of yield advantage due to fact that it is based on simple difference between the extent to which both component crop species vary from their respective expected yield. Willey and Rao (1980) presented it as a ratio and termed it the 'Competitive Ratio' (CR). It is the ratio of two partial LER's adjusted for their proportion in the mixture

2.2.2 Competitive Ratio (CR)

$$CRa = \frac{La}{Lb} x \frac{Zba}{Zab} \text{.....................} \textit{Equation} \; 3$$

or

$$CRa = \frac{Yab/Yaa}{(Yba/Ybb} x \frac{Zba}{Zab}$$

where, CRa is the competitive ratio and La and Lb are partial LER of crop a and crop b. This index determines the competitiveness of one species over the others. It has been proposed for evaluating the competitive balance in intercrop combination subject to treatment effect. The strong point of CR over A is that the former gives the exact degree of competition by indicating the number of times one crop is more competitive than other. Since, CR values of the two crops are the reciprocal of each other, it will often be sufficient to consider the values of only one of the crops.

2.2.3 Land Equivalent Ratio (LER)

Different methods of assessing yield advantages of intercropping have been proposed on different occasions by various researchers in competition studies under intercropping systems. However, LER has been used extensively by many researchers to evaluate the advantage of productivity in intercrop combinations in relation to the sole crop. It is also convenient to use in both additive and replacement mixtures. This index is used in this thesis to assess the advantages of intercropping and sufficient to meet the objectives of this study.

Land equivalent ratio is defined as the relative land area under sole crops that is required to produce the yield achieved in intercropping (Willey, 1979). It can be written in the following form:

$$LER = La + Lb = \frac{Ya}{Sa} + \frac{Yb}{Sb} \text{..................} \textit{Equation } 4$$

where, La and Lb are the LER's of individual crops and also termed the partial LER of component crops. Ya and Yb are the individual crop yields in intercropping and Sa and Sb are their yields as sole crop. Partial LER of each component crop is the ratio of intercrop to sole crop and also known as relative yield (RY). LER is similar to the Relative Yield Total (RYT) proposed by De Wit and Van den Bergh (1965) who were primarily interested in replacement series experiment and developed their index in terms of proportion of sole crop yield achieved by the intercrop. Similarly, Andrew and Kassam (1976) mentioned that both are similar in replacement mixture. LER is the sum of the fraction of the yields of the intercrops relative to their sole crop yields. According to Willey (1979), comparison between partial LER (La and Lb) can indicate competitive effects of the two crops in the mixture. In the intercropping mixture, the species with higher partial LER is considered to be more competitive for growth limiting factors than the species with lower partial LER. Total LER can be taken as a measure of the relative yield advantage in intercropping. For example, a LER of 1.3 indicates a yield advantage of 30% or in other words, 30% more area would be required for sole crops to achieve the same yield as obtained by intercropping. LER is considered to be the most efficient general function to determine the efficiency of intercropping systems because different crops whatever their type and levels of yield, are put on a relative basis and compared directly.

The LER has several advantages over other indices. Willey (1979) compared RCC, A and LER values from an experiment conducted at ICRISAT in 1977 in which four genotypes of pearl millet were tested in all combination with four genotypes of sorghum as 50:50 intercrops. For any combination, all the indices indicated which was the dominant and which the dominated genotype. The RCC and LER values showed the same pattern of yield advantage or disadvantage whereas the aggressivity value A failed to show this. However, a major drawback of the relative crowding coefficient is that it does not provide an indication of actual magnitude of yield advantage. Therefore, Willey (1979) argued that LER is the most useful index and also has the merit that it can be applied to any intercropping situation and not just replacement models.

Use of LER is the most appropriate index to assess advantage of intercropping in Nepal, because it takes account of land use. Subsistence farmers in the hills of Nepal have limited land resources especially in '*bari*' land where it is a common practice to grow different crops mixed with maize during the rainy season. Farmers want to maximize total yield from the system to meet their food requirements from limited land, by growing different crops together to utilize the short rainy period.

In spite of the various merits of using LER in evaluating advantage of intercropping there are some weaknesses. Firstly, LER is defined as the ratio of intercropped and sole crop yields. Larger values can be obtained not only because of higher yield in intercropping but also due to lower yield of corresponding sole crops. Secondly, LER is based on land area only and does not take duration of component crops into consideration. However, production is a function of both crop duration and land area (Ofori and Stern, 1987). Land occupancy by a given intercrop system is frequently of longer duration than for sole crops. This problem is solved by the concept of Area Time Equivalent Ratio (ATER) proposed by Hiebsch (1980) and Mc Collum (1982) as a modification of the LER. This takes into account the duration of the crops; i.e. the time it occupies from planting to harvest. It also permits an evaluation of crop on a yield per day basis (Hiebsch and Mc Collum, 1987). It can be written as:

$$ATER = (L_i t_i + L_j t_j)/T \quad \text{.........................Equation 5}$$

where, L_i and L_j are relative yield or partial LERs of component crops i and $_J$; t_i and t_j are the duration (days) for crops i and j and T is the duration (days) of the whole intercrop. ATER is only appropriate in systems with component crops of contrasting maturities. In the experiments described in this thesis, the duration of maize and soybean differed by three weeks only. Therefore, there is no practical advantage in calculating ATER.

The third difficulty in using LER as measure of biological efficiency is that the LER is based on harvested products and not on desired (i.e. by farmers) yield proportion of the components predetermined at sowing (Mead and Willey, 1980; Mead and Stern, 1980 in Ofori and Stern, 1987). They argue that a farmer can not predict exactly what area of sole crop can be used to get the desired yield proportions. The exact areas of sole crops involved in the comparison are determined by the final intercrop yield whereas farmers have to decide crop areas at sowing time. In practice, after long experience, farmers can adjust the sown area of each crop to obtain the proportion of required yields, which they need at harvest.

Many researchers have reported that LER gives an accurate assessment of the greater biological efficiency of the intercropping situation. LER is used even though the yield proportion obtained from crop mixtures is not always the same as that desired by farmers. For example, an intercrop system giving an LER of 1.53 may be considered to be better than one giving only 1.47, but in practice farmers may actually prefer the latter one because the yield proportion of a crop that farmers prefer may be higher in the combination with lower LER. To solve this problem, Mead and Wiley (1980) proposed a further modification in LER which is termed the 'Effective LER' (ELER) that takes into account the different yield proportion of the intercrops and can relate these to the farmer's requirements. A general method of obtaining the proportion of intercropping (K) for a required proportion (P) of crop A can be written:

$$K = \frac{(1 - P)}{PLb - (1 - P)La + (1 - P)} \text{.....................} \textit{Equation } 6$$

Once this proportion is known, the ELER can be calculated as

$$ELER = \frac{(Lb)}{(1 - La) + (LER) - 1)P} \text{.....................} \textit{Equation } 7$$

The ELER must be less than the LER and it progressively decreases as the required yield ratio departs further from that produced by growing only the intercrop. Relay (1984) criticized the effective LER stating that it only takes in to account a combination of an intercrop and single sole crop area. She put forward a new proposal called 'General' form of LER, which encompasses several intercropping systems.

In subsistence farming, farmers need to have certain amounts of some critical crop like cereals, which fulfill their basic requirements as a staple food. They do not want to lose it but also want to have some bonus crop by intercropping. LER fails to consider such circumstances. To overcome this problem, Reddy and Chetty (1984) proposed a concept of 'Staple' LER. They argued that the SLER concept allowed the interpretation of yield data from intercrop treatments based on the assumption of a basic requirement for a minimum supply of staple food. It is estimated as

$$\text{SLER} = \frac{\text{Yi}}{\text{Yii}} + Pij\,\frac{\text{Yji}}{\text{Yjj}} \ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation}\ 8$$

where Yi/Yii is the desired standardized yield of staple i. Pij is the proportion of land devoted to intercropping. Yji and Yjj is the relative yield of crop j. SLER is only applicable when it is desired to attain a specific yield of a staple cereal crop and yield from the secondary component is a bonus.

In the recent era, many farmers are evaluating advantages of intercropping compared to equivalent yield of main crop by adjusting the price difference between two crops (Rezende and Ramalho, 1994). Farmers can purchase the equivalent amount of required crops (main crop) using the amount received from the sale of second component. It can be computed as follows:

$$\text{Main crop equivalent (A)} = \text{Yield(A)} + \frac{\text{Price of cropB (Rs/kg)}}{\text{Price of crop A (Rs/kg)}}\, x\text{Yield(B)}..\textit{Equation}\ 9$$

This method is used to compare yield advantage achieved through different crops combinations in intercropping systems in terms of equivalent yield of main crop as grown in sole crop. In absence of marketing constraints, farmers can replace a required commodity (main crop) by purchasing of main crop using money received through sale of the secondary crop, provided they are easily available in local market.

LER is an efficient index in evaluating biological efficiency but fails to evaluate intercropping advantage in economic terms. Farmers are interested in economic advantage because the price of some crops is very high compared to others in spite of their lower yield. It is a common practice to assess intercropping advantage by expressing yield in monetary terms, which puts different crops on a comparable basis. But an LER based on monetary values would give the same figure as an LER based on yield. To calculate the absolute value of the genuine yield advantage, Willey has suggested:

$$\text{Monetary advantage} = \text{Value of combined intercrop yield} \times \frac{\text{LER - 1}}{\text{LER}} \ldots\ldots \textit{Equation}\ 10$$

This economic assessment of intercropping should be in terms of increased value per unit area of land. This method of assessing intercropping advantage has been used in this study.

The LER value is determined by several factors including density, competitive ability of component crops in the mixture, crop morphology and duration and management variable that affect individual crop species (Natarajan and Willey, 1980a). There are different opinions about the use of standard sole crop for calculating LER. Mead and Willey (1980) suggested that sole yield of component crops can be regarded as standardizing factors and it may sometimes be sensible to define sole yield of component crops as the maximum or average of sole crop for the set of treatments in the experiment. According to Mead and Stern (1980), most of the intercropping reported in the literature has included large proportion of sole crop plots, often up to 50 % of the total experiments and some times even more. Inclusion of large number of sole treatments seems to be intended for asking whether mixed cropping is better than sole cropping at the expense of investigating agronomic problems of intercropping.

For an experiment with different plant populations and spacing, Huxley and Maingu (1978) suggested that yield should be compared with the sole crop at the optimum population and spacing. However, Fisher (1977b) suggested that sole crop yields in each block should be averaged separately rather than taking mean of sole crop yield over the whole experiment. Mead and Willey (1980) recommended that the selection of sole treatments should be based on the aim of the experiments. They suggested that in intercropping experiment with different level of fertility, intercrop yields should be compared with the sole crop yield at the same fertility level. For this study, optimum plant population and recommended spacing of maize and soybean were selected for sole crops in each replication because they produce maximum grain yield when grown separately.

2.3 Principles of Intercropping

The main reasons for yield advantage in intercropping system are (a) an efficient absorption of resources by component crops from different niches, (b) complemenarity use of growth resources in space and time; i.e. mutual cooperation and (c) modification of micro-climate suitable for companion crops. Sometimes, it is difficult to distinguish the effect of niche differentiation and spatial complementarity. They are discussed in detail separately.

2.3.1 Niche differentiation

In intercropping, component crops exploit environmental resources by occupying different niches, resulting in lowered competition (Trenbath, 1974) among them either above or below ground. Component crops with contrasting habits, with respect to height, branching, leaf and root distribution, mineral uptake or other morphological characters will together able to exploit the total environmental resources more effectively than monoculture (Donald, 1963). A multistorey cropping system is a good example of this. Innis (1997) explained this with an example of coconut palm intercropped with cacao and other companion crops in Kerala, India. Coconut plants are planted at a spacing of 7.7 x 7.7 m in which the leaf crowns of the coconut occupy all the area above ground but the roots occupy one quarter of this area, which means that there is ample room for small farmers to grow secondary food crops for food or to get additional income. As the leaf canopy allows 50% of light to get through, shade tolerant plants can grow beneath it. Nair (1977) also reported that cacao intercropped with coconut gave excellent returns. In the tropics, multistorey plants harvested in sequence can utilize the sun's energy on a year round basis (Sebostiani, 1981), the lower leaves must, of course, be adapted to lower light intensity. In combinations of tall cereals with short species, a combined leaf canopy which increased the amount of radiation intercepted due to fast development of canopy cover (Ramakrishna and Ong, 1993) may make better use of light (Chatterjee, *et al.*, 1993). Incoming solar radiation is not fully utilized by the canopy of tall crops under monoculture. Growing of short species at the base of tall crops can utilize wasted sun's energy resulting in complementary use of light for higher combined yields. The inclination of the leaves greatly influences the amount of light which is intercepted by the canopy of taller intercrop component e.g. one unit of LAI of prostrate-leaved white clover (*Trifolium repens*) intercepted 50% of the incoming light whereas the same LAI of erect leaved perennial rye grass (*Lolium perenne*) intercepted only 26% (Brougham, 1958). Combinations of erect leaves of tall plants such as cereals and horizontal leaves of lower storey plants make more efficient use of light. Ojomo (1976) reported that combination of cereals with legumes utilize twice as much solar energy with intercropping. Similarly, combining crops which have different inherent response of light, can utilize incoming solar radiation more efficiently resulting in higher yields in intercropping. The top canopy could consist of a component with a high light requirement combined with a bottom component with a low light requirement (Chatterjee, *et al.*, 1993). Mixing of tall C_4 plants with short C_3 plants which differ in efficiency in use of tropical sunlight (Midmore, 1990) utilizes solar energy more effectively and results in higher productivity of the intercropping system. In the experiments described in this thesis, combination of a tall C_4 maize plant with short C_3 soybean (legume) at different spatial arrangements was studied to evaluate complementary use of resources.

Harper (1977) reported that when growing of *Lotium perenne* (aggressor) and *Phalaris tuberosa* (suppressed species) in mixture, the yield of *Phalaris* per plot was depressed by 32% when its shoots were intermingled with *Lutium* (aggressor), 75% when its roots were intermingled and 93% when both roots and shoots intermingled. Snaydon and Harris (1979) also mentioned that plant interactions below ground are normally more intense than those above ground. The difference in root system, depth of rooting, lateral root spread and root densities are factors in competition for water and nutrients between component crops. Innis (1997) found that there were more soil nutrients lost when one crop was grown than when two crops were grown. He further explained that soluble nutrients are always being leached down through the soil whenever rain falls. Planting of cowpea and green gram as intercrops helped in reducing nutrient losses because their roots were able to retrieve K and P which would otherwise have been lost, and return them to the upper layers of soil. Growing of crops with differing root system morphology absorbs plant nutrients from different layers of soil, also minimizing the degree of competition for water (Ofori and Stern, 1987). In a mixture of *Avena strigosa* and *A. fatua*, Harper (1977) also reported that the roots of *A. strigosa* were more strongly developed in the upper layer of soil profile but *A. fatua* contributed most of the root system deep in the soil. The presence of shallow rooted component crops in a mixture can force the deep rooted component to forage the nutrients in even deeper soil horizons (Govinden, 1984). In multistorey cropping systems, Harper further added that trees extracted nutrients from the deeper layers of soil where they are usually out of reach of annuals and return them to the surface in leaf litter. Similarly, in cereal-legume intercropping systems, Innis (1997) reported that when the leaves and roots of the legume die, the recovered nutrients released by decomposition were returned to the surface layer of the soil and supplied plant nutrients to companion crops. In a mixture of maize with soybean, soybean has many roots below the root system of maize where they capture nutrients, which have slipped past the maize root hairs (Beets, 1975; Greenland, 1975).

2.3.2 Complementarity of use of resources

When plants are grown together in association as intercrops, interaction between the component species occurs which is essentially a response of one species to the environments as modified (Harper, 1977) by the presence of another species (Palaniappan, 1985). Yield advantages in intercropping systems occur because component crops utilize growth resources in such a way that they are able to 'complement' each other and make better overall use of resources than when grown alone (Willey, 1975 in Govinen, 1984; Chatterjee *et al.*, 1993) which is also known as mutual cooperation or facilitation (Vandermeer, 1989). For example, component crops extract soil water from different zones of soil profile and times due to difference in their root systems that avoids a direct zone of conflict (Harper, 1977). On the other hand, component crops may compete for the same resources and interact in such a way that one exerts a negative effect on the others (Vandermeer, 1989) resulting lower yield than expected due to competition for growth resources among them, which is termed mutual inhibition or plant inference. 'Complementarity' is the avoidance of competition between component species by sharing of environmental resources in time or space (Trenbath, 1976). Complementarity of resources use by component crops is attributed to differences in response need during different growth stages. In other words, component crops are not competing for exactly same overall resources and thus intercrop competition is less than intracrop competition. Therefore, it is essential to maximize the degree of complementarity between component crops and minimize intercrop competition for higher intercropping advantages (Steiner, 1984). Midmore (1993) explained that the stage at which complementarity evolves into competition for resources is manipulated through agronomic management e.g. delay in the crossover points between complementarity and competition is the main goal of improved agronomic practices. For high yields in intercropping, the component crops should compete minimally with one another for the same resources in space or time. Complementarity is of two types: temporal and spatial.

Temporal complementarity

Complementarity in time means that the component crops make their major demands on growth resources at different times, which is also known as temporal complementarity (Govinden, 1984). Ofori and Stern (1987) explained that growing of component crops of contrasting maturity is the main source of temporal complementarity because they demand the resources at different times resulting higher combined yield. Andrews and Kassam (1976) supported this in their reports that a low intercrop competition between more rapidly growing early maturing and slow growing late maturity component crop in space or time is the prime cause of yield advantage. Natarajan and Willey (1980b) found a 62% yield advantage with 82 days duration sorghum and 173 days duration pigeon pea. In the maize/finger millet relay cropping system found in the mid and high hills of Nepal, they are not planted at the same time and so utilize resources at different times. Maize is planted early and utilizes resources earlier while finger millet is planted at a later stage and utilizes resources after harvest of maize.

In tree plantation crops, trees, which grow slowly, are planted at wider spacing and utilize a minor part of the available growth resources such as light, water and nutrients during their early establishment period (Govinden, 1984). This principle also applies in mixtures of annuals and biennials such as sugarcane, pigeonpea and cassava which grow slowly during the first few months. At normal density, they do not establish a full ground cover until 3-4 months. Fast growing companion crops may therefore be successfully mixed without detriment to the main crops. Similarly Dalal (1974) has demonstrated the effect of temporal complementarity in mixture of two crops in which pigeonpea started flowering and had peak nutrient demand after harvest of maize.

The temporal use of irradiance within intercrops of contrasting development and phenology (i.e. peak demands for the same resources do not overlap in time due to difference in phonology or planting date) is a prime example illustrating the more efficient use of naturally available resources by intercrops (Midmore, 1993). Shade tolerant cowpea and greengram with a tree (*Casuarina equisetifolia*) would optimize the complementarity between tree and arable species over a 3-year period. The duration of the main crop in a mixture has great influence on the growth and yield of companion crops. For example, in cowpea intercropped with three contrasting cultivars of maize, all the intercropped maize gave a full yield; the yield of cowpea dropped progressively with lateness of maturity in the main crop (Baker, 1981). He observed 84% yield reduction in the legume due to 45 days delayed maturity in maize.

Spatial complementarity

Spatial arrangement is defined as the distribution pattern of the plants over the ground, which determines the shape of the area available to the individual plant (Willey and Rao, 1981; Steiner, 1984). In intercropping, the positioning of plant of one component relative to that of the other component crop(s) and planting density of component crops offers the greatest scope to maximize interspecific complementarity (Midmore, 1993). Alteration of spatial arrangement; i.e. changing from square to rectangular patterns in the crop geometry of the main crop, allows wider inter-row spacing which provides more penetration of light to shorter crops for longer periods before canopy closure (Steiner, 1984) and resultant increased efficiency of the intercrop (Ofori and Stern, 1987). For example, planting of double rows of maize gave higher yield than the same number of plants per ha uniformly spaced (Innis, 1997).

Spatial geometry has great influence in intercropping of tall C_4 cereals with shorter legumes, the cereal is usually the aggressor and depending on plant population, causes large yield reductions in the associated crop (Gupta and Singh, 1988). Chui and Shibbles (1984) also reported that crop mixtures in which components vary in plant height are amenable to manipulation of spatial geometry, principally to provide more space (i.e. irradiance) for shorter (under storey) crops through reduction of space for the taller (dominant) crop. Similarly, row ratio of component crops has great influence on the use of growth resources, especially light, resulting in higher yield in the intercropping system. For example, planting of rice and soybean under a paired-row combination (2:2) gave greater plant height, branch/plant and dry weight of soybean than 1:1 and 1:2 combinations (Sarawgi and Tripathi, 1998). In the light of these reports, in this thesis, spacing between maize rows was increased from 75 cm to 150 cm to provide wider inter-row space to accommodate soybean rows and penetration of more light to the soybean canopy.

2.3.3 Modification of micro-environments

Growing of component crops in mixture modifies the growth environment compared to sole cropping, which has a significant impact on growth and yield of companion crops. Shading reduces the temperature and favours the growth of some under-storey crops (Fukai and Trenbath, 1993). Midmore (1993) reported that relayed planting of potato in to maize in a warm climate enhanced early emergence of potato due to shading caused by maize. The micro-climate is also affected in a mixture of crops of different heights. Intercropping of tomato with pigeonpea modified the environmental conditions and enabled the production of off-season tomato during summer with a hot dry wind and low humidity (Govinden, 1984). Shade tolerant crops can survive at the bottom of mixture in multi-story cropping systems (Norman, 1979). The beneficial effect of shading in cocao, coffee and tea has been attributed to a reduction in leaf temperature (Willey, 1975 in Govinden, 1984).

In many parts of the tropics, water is the most limiting factor. Water deficits of several months characterize wide expanses of the semi-arid and arid tropics, where intercropping is widespread. Mixture of crops with contrasting demand and root extraction zones are able to utilize soil water reserves (Midmore, 1993) more effectively. In a mixture of maize and beans in Kenya, it was observed that rapid extraction of surface water by bean forced maize to root in deeper soil layers (Fisher, 1976). De (1980) reported an increased water use efficiency of intercropping system with maize, the water use was 10.3 g/kg for sole maize increasing to 16.8 and 19.4 g/kg in intercropping system with soybean and mungbean respectively, possibly due to a wind break effect and an increase in humidity and reduction in transpiration. Reddy and

Willey (1981) also reported that an intercrop of millet/groundnut used water more efficiently in producing biomass because millet has a high photosynthetic rate and groundnut provides dense ground cover resulting in low soil evaporation.

2.4 Agronomic management for intercropping advantage

Higher intercropping advantage is attributed to various agronomic management procedures such as manipulation of component densities, spatial arrangement, alteration of planting time and choice of component genotypes. This section will review the influence of agronomic factors affecting on the combined yields of maize and soybean grown as intercrop.

2.4.1 Component population density

Plant population can be defined as the number of plants per unit area that determines the size of the area available to the individual plants (Willey and Rao, 1981). Subedi (1990) explained that crop yield is a function of yield per unit area (***Y***) and number of plants per unit area (***P***). An optimum plant population, therefore, is one, which maximizes ***Y***. Any shift from optimum population decreases ***Y*** because in cereals, grains per plant increases if population is lowered and *vice versa*. When two crops are grown as an intercrop, plant interactions may result in mutual inhibition, co-operation and compensation. One standard method of measuring plant interaction is to compare the growth of the intercrop components with their growth in sole crops. The type of interaction is highly dependent on the ratio of the density of each component (Rajbhandary, 1991). In intercropping, plant population is a complex concept, as it not only involves the total population but also involves the component populations. Both types of competition (inter or intraspecific) exist. In such situations, the crops are not comparable on a plant to plant basis, in term of their pressure on resource use. To overcome this problem, Willey and Osiri (1972) used the concept of "plant unit" in which they considered one plant unit to be equal to one maize plant or two beans plants. This equivalence was calculated according to the ratio of their optimum populations in a pure stand.

The combinations of component densities are based on 'replacement' and 'additive' models (De Wit, 1960). In the replacement series, mixture treatments are formed by replacing a given proportion of one species with the equivalent proportion of the other while keeping the total population constant (Harper, 1977; Willey, 1979). For example, in 50:50 mixture, the ratio of component populations are decided on the basis of optimum density of respective sole crops and arrangement of rows and plant spacing are adjusted accordingly, keeping total population constant. In the additive model, however, the mixture is achieved by adding together the populations used in pure stand. In this model, the density of first crop, called the indicator, is maintained constant and that of other is varied and used to compare the relative aggressiveness of a group of species to indicator (Ellen *et al.*, 1970 in Harper, 1977). Total populations in mixture can be more than 100%, meaning that the total population can be higher than either component optimum population. Steiner (1984) reported that the optimum total population for the intercropping system was higher than for the sole crop due to complementary use in resources and compensation by component crops. In the experiments reported in this thesis, combinations of different densities of maize in different spatial arrangements with soybean were evaluated to determine the optimum plant densities for higher yield advantages and land use efficiency.

Fukai and Trenbath (1993) mentioned that in intercrop components with similar maturity, their peak demand for growth resources occurs at about the same time; thus competition for limiting resources is intense. In such a situation, the replacement type of intercropping gives some advantage. The farmers aim for a plant population pressure that is usually not much higher in the intercrop than in the sole crop. On the other hand, where there are component crops with different growth durations, their peak requirement for resources occurs at different times reducing competition for growth resources. In such conditions, the additive model becomes effective where population densities of component crops have adjusted, resulting in higher total yield.

When two crops differ in competitiveness; manipulation of the suppressed species has little effect on the performance of the dominant species. Mostly cereals are dominant and lower storey species are dominated in intercropping. For example, maize dominated potato under high maize density, and change of potato density had no effect on yield of the dominant maize but change of maize density had a large effect on both components (Ifenkwee *et al.*, 1989). The effect of component densities on total productivity under intercropping system, reported by different authors, are summarized in Table 2.1

Table 2.1 Summary of the effect of component densities on maize and companion crops in experiments conducted by different researchers.

Densities (plants/m^2)	Effect on yield, growth of maize and associated crops	LER	Authors/location/ if known
M (1-10) S (3-24)	Soybean density did not effect maize yield but grain yield of soybean increased with increasing density. Each unit increase of maize density reduced soybean yield by 20% for cv. Cobb. and 47% for cv. Davis	1.1-1.4	Heibch, *et al.* (1995)
M (2.2-4.4) S(11.1-2.2)	Maize yield at 100% density less affected by bean compared to when maize density was 50%.	1.21-1.68	Siame *et al.* (1998)
M (3-4) B (8-64)	Maize yielded similarly under mono and intercropped with different bean densities		Francis e*t al.* (1978b)
M (5.3), B(100,75 & 50%)	Blackgram yield reduced with decreasing population of blackgram but maize yield was similar in mono (4.32) and intercrop (4.04-4.14t/ha)		Singh *et al.* (1995), India
S* (2-8) C (2-8)	Cowpea yield decreased as cereal plant density increased whereas cereal and total intercrop yield increased with increasing density		Craufurd (2000) UK
M (2-5) S (20)	Soybean yield reduced under intercropped maize and yield reduction greater with increasing maize density		Weil and McFadden (1991),
M (4-18.4) S(12. -86.6)	Soybean yield suppressed (17-37%) by high maize density but maize yield increased with increased maize density.	1.48	Putnam *et al.* (1985), USA
M(1.8-5.5) C (2-7)	Maize yield increased in pure and intercrop as maize density increased, cowpea yield reduced by 52% in mixture. Optimum density for maize and cowpea were 2 and 3.3 plants/m^2, respectively		Tariah and Wahua 1985). Ibadan, Nigeria
M (3.4-7.4) S (22.3-38.6)	Maize yield increased in sole (6.3-8.2t/ha) and decreased under intercrop (7.4 t/ha) with increasing soybean density while yield of soybean increased from 1.04 to 1.16 t/ha. Optimum density for maize and soybean were 6-7.4 and 24.3 plants/m^2.		Qinglu *et al.* (1996), China
M (N) S (8-16)	The biomass of intercropped maize decreased with increase in soybean density.	1.3	Marchiol *et al.* (1992)
M (1.6-8.3) B (2.3-12)	Maize yield per plant yielded less (30%) at 8.3 plant/m^2 than at 1.6 plant/m^2. Intercropped bean yield reduced by 48% with increasing plant density.		Fisher, (1977a), Kenya
M (2-8) B (2-8)	Bean yield decreased with increasing maize density. Optimum density for maize and bean were 2 & 24 plants/m^2)		Salomon (1990)
M (2.2-3.3), B (N)	Maize density did not effect on bean yield, but maize yielded high at higher density.		Robinson (1997)
M (2.4-3.7) S (1.1-2.2)	The change in maize density from 2.4 to 3.7 m^2 increased maize yield by 28 & 39% and reduced bean yield by 11 & 18%, respectively.		Mutungamini *et al.* (2001), Zimbabwe

Densities (plants/m^2	Effect on yield, growth of maize and associated crops	LER	Authors/location/ if known
M (7.2) S (22-67)	Light penetration and leaf area decreased with increasing plant density while plant height increased		Foroutan-Pour, *et al*, (1999)
M (2-12) T (6)	Maize leaf area index increased linearly with plant density. Grain yield increased linearly up to LAI 4.2 . Yield of tall fescue reduced (30%) due to low light interception (24%).		Harper *et al.* (1980), USA
S (1.38-33) S* (N)	Grain yield of sorghum increased with increased plant density while intercropped soybean yield reduced by 75 and 17% with tall FS-16 and dwarf BR-44 sorghum varieties, respectively.		Wahua and Miller (1978a), USA
M(1.8-5.5) B (4.9)	Bean received 50% light at low density (1.8 p/m^2) and reduced to 20% at high density (5.5 p/m^2) of maize		Gardner and Craker (1981)

Note: Letter M, C, S, S*,B T & N denotes maize, cowpea, soybean, sorghum, bean & tall fescue, normal density respectively, figure in parenthesis are densities (plants/m^2)of respective crops

2.4.2 Spatial arrangement

Planting the dominant crop in double rows, orientation of rows in an east-west direction, increasing leaf inclination of dominant crops and the growing of shade tolerant plants are the main agronomic management strategies to avoid competition for light and to increase complementary use of light by component crops. Alteration of spatial geometry of tall crop increases the resource capture by the understorey crop, causing over-yielding (Midmore, 1993). Over yielding herein refers to yields of component intercrops, which surpass the sum yield of monocrop of the same species. For example, the use of double rather than single alternate row arrangement of component crops improves the yield and light penetration to the lower canopy. The effect of spatial arrangement under different intercropping system, reported by different authors is summarized in Table 2.2

Table 2.2. Summary of the effect of spatial arrangement on component crops grown as intercrop (results of different experiments)

Intercrops	Effect on component crops	Authors and location (if known)
Pair rows		
Sunflower + greengram (30/60 cm)	Higher sunflower equivalent yield (18.78q[2]/ha), monetary advantage (IRs[3]3885/ha) and net return (IRs 7549/ha.	Sarkar and Chakraborti (1997), India

[2] q = quintal = 100 kg
[3] IRs. = Indian rupees

Intercrops	Effect on component crops	Authors and location (if known)
Maize + blackbgam (30/90 cm)	Increased production of maize (24.9q/ha) and blackgram (3.3 q/ha) compared to standard planting of maize (19.2q/ha).	Rathore (1980), India
Sunflower + groundnut	Greater harvest index and yield compared alternate row planting under same density.	Dayal and Reddy (1991)
Pigeonpea +soybean	Similar result from pair row (net return Rs 7319/ha) and alternate row (Rs 8074/ha), which was not significant)	Prasad and Shriwastawa (1999), India
Pigeonpea + soybean	Alternate row planting gave highest monetary advantage (Rs 7311/ha)	Joshi *et al.* (1997), India
Sorghum + soybean	Higher sorghum equivalent (52.79q/ha) LER (1.49) and net profit (Rs 10,817/ha) by pair row compared to single and mixed line sowing or broadcasting	Dubey *et al.* (1995), India
Pigeonpea + soybean (60/150 cm)	Paired row planting of pigeonpea with 4 row of soybean gave highest soybean equivalent yield (1,984 kg/ha) and LER (1.56) and benefit cost ratio (2.58)	Rani and Kodanaramalah (1997), India)
Sorghum + soybean	Soybean yielded higher when intercropped between wider row (60 cm) of sorghum compared to 45 cm.	Gupta and Singh (1998), India.
Row ratio		
Maize + soybean	2:2 row ratio (maize:soybean gave highest grain yield of both crops and monetary return	Vyas *et al.* (1995), India
Pigeonpea + Sunflower	1:2 row ratio (pigeonpea:sunflower) gave higher yields of components crops and LER (1.61)	Reddy and Venkateswarlu (1992)
Cereals + groundnut	2:3 row ratio (cereals:groundnut) gave balanced yield of cereals and groundnut and higher LER	De (1980)
Maize + soybean	2:3 row ratio (maize:soybean) yielded 26 & 50% higher yield than sole crop in 1992 & 1993	Premalal *et al.* (1994), India
Maize + soybean	Light interception by soybean was greater in pair row than single row	Sharma *et al.* (1994), India
Maize + soybean	2:3 row ratio (maize : soybean) gave highest yield of soybean and land equivalent ratio	Mondal *et al.* (1998), India
Maize + soybean	1:2 row ratio (maize : soybean) when spaced at 90x20 cm gave highest return	Hiremath *et al.* (1994), India
Maize + soybean	4:2 row ratio (soybean: maize) with 100% maize and 67% soybean of respective sole crop densities gave highest yield and LER (1.20-1.23)	Doubey *et al.* (1996), India
Maize + soybean	Soybean plants intercepted more light in 4:2 row ratio (soybean : maize) compared to 2:2.	Behairy (1994), India
Pigeonpea + soybean	1:2 row ratio (pigeonpea : soybean) yielded highest with LER of 1.43 and benefit cost ratio of 3.02	Tomar *et al.* (1987), India
Pigeonpea + soybean	1:3 row ratio (pigeonpea : soybean) gave higher LER (1.39), monetary advantage (Rs (6,712/ha) and benefit cost ratio (2.8)	Nimje (1995), India
Pigeonpea + groundnut	1:3 row ratio (pigeonpea : groundnut) gave balance yield, net return (Rs24,728/ha and highest benefit cost ratio (3..9)	Shinde *et al.* (1990), India

Intercrops	Effect on component crops	Authors and location (if known)
Wheat + Chickpea	2:2 row ratio (wheat : chickpea allow more light interception to lower canopy and gave higher yield (4155 kg/ha wheat equivalent)	Ali (1993), India
Pearl millet + groundnut	1:3 row ratio (groundnut : pearlmillet) gave highest LER (1.53), monetary advantage (Rs 6825/ha) and benefit cost ratio (2.39)	Kaushik *et al.* (1998), India

2.4.3 Time of planting

Adjustment of planting time of component crops helps ensure full utilization of growth factors because crops occupy the land throughout the growing season (Willey, 1979). A long growing season may be under utilized with sole crops when it is longer than the duration of one annual crop but too short for a sequenced crop. Intercrops may use the season more efficiently. Difference in length of growing period of the component crops can lead to a yield advantage in intercropping. When the earlier component matures, conditions become favorable for the remaining component due to removal of competition. For example, in Uganda, Osiru and Willey (1976) found a month's delay in planting of bean in a mixture of 85-day bean with 120-day maize led to a decrease in the yield advantage from 20 % to only 2 %. Similar results were derived from potato/maize relay system in high hills of Nepal (Chand, 1997). Potato matures in July and conditions become more favorable to maize after the harvest of potato until maize is harvested in late September. Maize/ finger millet relay system is another example that occurs in mid and high hills of Nepal. Finger millet is planted under maize at the time of tassel initiation and both crops utilize resources fully, but at different times, resulting in higher total production (Khadka, 1992).

In a spring planted soybean-cassava mixture in Australia, Tsay *et al.* (1985) reported that soybean sowing could be delayed until five weeks after cassava planting without reduction in soybean yield, but under tropical conditions in Colombia, even simultaneous planting of soybean and cassava resulted in less soybean yield relative to sole crop yield (Thung and Cock, 1979). Similarly, soybean planted after 25 days of sowing of maize performed better in northern high hills of Nepal (Prasad *et al.*, 1998) where maize takes 160-180 days for maturity. On the other hand, simultaneous planting of maize and soybean is practiced by farmers of southern mid hills in the western region of Nepal where maize matures within 125 to 135 days. If planting time of soybean is delayed, the vigorous growth of dominant maize suppresses the growth of companion soybean by reducing light penetration.

Wein and Smithson (1981) reported that at Ibadan, Nigeria, as the planting date of intercropped cowpea was delayed from zero to 40 days after maize, yield of intercropped cowpea declined from 40 to 10 % of sole crop cowpea. Similarly, Francis *et al.* (1978a) reported that planting of bean 19 days before maize sowing caused a 26 % yield reduction and gave an early competitive advantage whereas 58% reduction in bean yield was observed when both crops were planted at the same time. Francis *et al.* (1976) also found that sowing of beans 5-15 days before maize did not reduce yield of the both crops compared to simultaneous planting whereas maize sown 5-15 days earlier than beans reduced bean yield resulting in lower LER but maize yield was not affected.

2.4.4 Effect of varieties

Another factor which influences the productivity of intercropping systems is the genetic constitution of component crops. Careful selection of varieties that minimize competition and maximize efficient use of the limiting resource is a key factor for obtaining higher yields in intercropping particularly when genotype strongly influences phenotypic growth habit, such as stature, degree of spread of canopy or life cycle duration. For example, association of maize varieties with different growth duration has a marked effect on the performance of any companion crop. Khadka (1992) conducted an experiment on the maize/finger millet relay cropping system and evaluated the performance of finger millet under short duration Arun-2 and a full season maize, Hetauda composite. He found that finger millet yielded higher under Arun-2 compared to Hetauda composite. Arun-2 maize variety matured earlier and allowing more light penetration and reduction of the overlapping period in comparison to Hetauda composite. Similarly, Baniya and Adhikari (1989) reported that a tall and full season maize variety reduced finger millet yield by up to 80% whereas a short season variety of maize reduced yield of same millet variety only by 40%. Introduction of high yielding leafy maize has been reported to suppress the finger millet yield primarily because of its shading effect (Subedi, 1991). Many farmers reported to the author during field visits that the soybean under an improved maize variety performed worse than with a farmers' maize variety due to greater leaf area in improved maize.

Ssekbembe (1986) reported that combinations of cereals that differ widely in maturation time gave a high yield advantage. SB 65, a short and early (110 days) sorghum gave highest yield advantage (130 days) when combined with WC 30, a long maturity millet (140 days) whereas a tall sorghum of long maturity, Namateera (140 days) gave no yield advantage with millet cv Severe 1 (110 days). Some cultivars perform better under shade as they require a low amount of light. Jaiswal and Amatya (1994) reported that Dare variety of soybean was superior to Sathiya under mixed cropping with maize in both mid and high hills of Nepal. Similarly Passed *et al.* (1998) evaluated ten genotypes of soybean under Arun-2 maize variety in high hills and found that genotypes SB0065 and GC- 822-32-22 produced the highest grain yield of 1649 and 1671 kg/ha with LER of 1.64 and 1.54 respectively.

2.5 Services rendered by intercropping

Intercropping provides indirect benefits to the farmers by various ways like suppression of weeds, controlling insects/disease, helping maintaining soil fertility, and reducing leaching of nutrients and soil erosion as discussed in the following separate sections.

2.5.1 Effect on weed suppression

Weeds become a very serious problem whenever monocropping is practiced because the inter-row space provides room for weeds to flourish (Gahlot, 1978). Weeds compete with crops for growth resources (light, water and soil nutrients) and cause a reduction in grain yield (Bantilan *et al.*, 1974). It is well established fact that intercropping helps in suppression of weeds because it provides additional cover to inhibit weed seed germination and reduce weed populations in the field. Midmore (1993) mentioned that early canopy cover smothers weeds and reduces weed/crop competition, particularly for soil nutrients and water. Low growing intercrops with a spreading canopy can smother weeds in tall, widely spaced crops. For example, Govinden (1984) reported that mungbean (*Vigna radiata*) was observed to be more effective in controlling weed in maize than groundnut. Magnitude of reduction in weed growth in intercropping systems depends largely on the nature and properties of component crops, total population and spatial arrangement of the plants (Moody and Shetty, 1981).

Intercropping with a fast growing smother crop as the intercrop, which shades the ground surface early in the season can effectively control weed growth (Chatterjee *et* *al.*, 1988). For example, in maize/soybean intercropping, presence of soybean substantially reduced the weed growth and saved plant nutrients removed by weed plants, consequently used by maize plants (Furoc *et al.*, 1977). A monocropped maize produced 4.0 t/ha of weed 40 days after sowing, but when intercropped with soybean produced only 0.5 t/ha (Moody and Shetty, 1979). Effect of intercropping in suppressing weed control, reported by different authors is summarized in table 2.3.

Table 2.3 Summary of the effect of intercropping on suppression of weed control (results of different experiments)

Intercrops	Effects on weed suppression	Authors
Maize + soybean	Fewer weeds compared to sole crop	Premalal *et al.* (1994), India
Wheat + lentil	Weed production reduced by 96 and 86 % in 1990 and 1991 compared to sole crop lentil	Carr *et al.* (1995), India
Pigeonpea + cowpea	Cowpea suppressed weed growth, arrested nutrient depletion and increase in yield attributes and yield of pigeonpea in the both years.	Patil and Pandey (1996), India
Pearl millet + groundnut	Weed infestation reduced by 50-75% in pearl millet with groundnut	Shetty and Rao (1981)
Cassava + bean	Controlled weeds effectively as application of pre-emergent herbicide on the sole cassava plot.	Midmore (1993)

Plant density and spatial arrangement of component crops are factors which influence effectiveness of controlling weeds. High plant density and complete crop cover caused severe competition with weeds and kept weeds under check (Rao and Shetty, 1977). For example, intercropping of soybean with maize, consisting of 56,800 maize plants/ha, suppressed weed by 39% as compared to the maize crop alone (Moss and Hartwing, 1989). Paired-rows of pigeonpea and soybean at 30 cm + 90 cm row spacing reduced weed infestation by 71.3 % compared to sole cropping. Similarly, planting of one row of pearl millet with three rows of groundnut gave the highest yield advantage and weed control at ICRISAT (Anonymous, 1978)

2.5.2 Effect of intercropping on controlling insects and disease

Intercropping reduces pest damage because the host-plant-finding behaviour of insects may be disturbed by close juxtaposition of the two plant species (Emdon, 1989).

Intercropping helps in controlling insects/pests by various mechanisms. There are two main hypotheses proposed for this, namely 'disruptive' and 'enemies'.

Taking the disruptive hypothesis first, Trenbath (1976) explained about the "fly paper effect" in which a specialized pest is deterred from attacking its host through the disruptive effect of an associated species of plant in which host plants are more widely spread in an intercrop; i.e. a dilution effect; secondly, one species may serve as a trap crop to deter the pest from finding the other crop, and thirdly one species serves as a repellent to the pest. The intercropping of non-susceptible hosts along with a susceptible one creates both dilution and barrier effects. Intercropping of a tall crop with a short one may also affect the movement of flying insect pests within the field. For example, fall armyworm (*Spodoptera frugiperda*) attack on maize was less in a cropping system associated with beans than a monocrop (Francis *et al.,* (1978b). Sorghum is an attractive trap crop for stem borer, *Chilpertellus* spp., in India (Sarup *et al.*, 1977). Ezuech and Taylor (1984) reported that planting of cowpea at 12 weeks after the establishment of maize significantly controls *Maruca testulalis*, *Cydia ptychora* and thrips compared to sole crop because cowpea plants serve as a trap crop. Certain intercrops are believed to repel pests by virtue of the volatile substances they emit. Thus reduced attack of sugarcane intercropped with coriander (Singh, 1961, cited by Govinden, 1984).

The enemies hypothesis states that reduction of pests in an intercrop is due to attractiveness of the intercrop for predators and parasites presumably because of the greater availability of habitats or resources as compared to a monocrop (Trenbath, 1976). For example, spiders were more effective against maize borer in an intercrop of maize and groundnut than in a monoculture of maize (Gavarra and Raros, 1975). Crop diversity is likely to promote the activity of beneficial organisms such as predators or parasitoids. For example, the fewer corn borers observed in intercropping of maize with groundnut was attributed to higher numbers of predators, especially spiders (IRRI, 1973).

Manipulation of a cropping system provides an ecological base front line of defense, which can serve to discourage herbivore build up (Innis, 1997). For example, Rosset *et al.* (1986) reported that army worm (*Spodoptera sunia*) totally destroyed a monoculture of tomato while an intercrop of bean with tomato was effective in reducing the attack to virtually zero. Similarly, Muralibaskaran (1991) reported that sesame in association with pearl millet or groundnut reduced the infestation of the shoot-webber (*Antigastra catalaunalis* Duponchel) on sesame and increased net income. The pure stand of sesame recorded 23 % shoot webber damage compared with 7.8 and 12 % when intercropped with pearl millet and groundnut respectively.

Intercropping provides a buffer against disease losses by delaying the onset of the disease, reducing spore dissemination or modifying micro-environmental condition such as temperature, humidity, sunlight and air movement (Altieri and Liebman, 1986). Reddy (1996) reported that bean planted simultaneously with two maize rows and one bean row gave reasonable yield in addition to reducing disease. Inclusion of resistant species in intercropping provides a barrier to the spread of inoculums and reduces the density of the susceptible pure stand resulting in lower incidence of disease (Steiner, 1984). Natarajan *et al.* (1985) reported that there was substantially less wilt (*Fusarium* spp.) incidence in pigeonpea when intercropped with sorghum than when it was grown alone. The incidence of the beetle-transmitted cowpea yellow mosaic virus was markedly reduced when cowpeas were intercropped with maize or when they were sprayed with insecticide (IITA, 1976). In summary, exploitation of diversity in spatial arrangements, physical and temporal barriers, microclimate modification, olfactory effects and colour and trapping effect amongst intercrop components affects pest or disease development or that of their natural enemies.

2.5 Soil fertility effects

Another service rendered by intercropping operates by reducing soil degradation. Intercropping has been shown to influence soil fertility by more efficient use of plant nutrients, addition of organic matter, and biological nitrogen fixation through inclusion of legumes and conservation of soil by reducing erosion.

2.5.1 More efficient use of plant nutrients

In intercropping systems, soil nutrients have been reported to be utilized more efficiently by different root systems of component crops; this may be attributed due to zonation of root systems, which may lead to effective use of nutrient uptake from different layers of soil (Trenbath, 1974) and reducing nutrient losses. Innis (1997) reported that there is more nutrient loss through leaching and erosion in single crops than with two root systems. When the second root system lies partly underneath the first, nutrients can be captured which would be lost through leaching if only the first root system existed. The extra nutrients recovered are brought back up to the surface by longer-rooted crops. In the case where intercrops have similar root properties, the mobile nutrients in the root zone are shared in proportion to the root length of the components present in that volume (Andrews and Newman, 1970).

Intercropping has been reported to reduce the quantity of fertilizers needing to be applied compared to sole cropping. Kushwaha and Chandel (1997a) reported that maize equivalent grain yield (combined yield of maize and soybean) increased with N application up to 50 kg N/ha in the intercrop of soybean with maize and was equal to a sole crop receiving 120 kg N/ha. The requirement of nutrients varies according to combinations of crops used in mixture. In intercrops of legumes with non-legume species, the legume obtains much of its N by the fixation of molecular nitrogen in its nodules whereas other components exploit the NO_3 and NH_4 in the soil solution (Trenbath, 1976). Cereal roots are concentrated in the uppermost horizons of the soil and may be subjected to drying out while legumes tend to produce new roots deeper in the soil profile where they follow the retreating wetting front. Such differences are likely to impact on the rate of uptake of mineral N, particularly nitrate (Unkovich and Pate, 2000). Some legumes make significant contributions in availability of phosphorous. For example, soybean and cowpea are more efficient in extracting available phosphorous from poor soil which reduces the need of additional application of P. Similarly, Agboola and Fayemi (1971) reported that the cowpea and green gram (*Vigna radiata* L.) roots are able to retrieve K and P which would otherwise have been lost and return them to the upper layers of the soil.

2. 5.2 Addition of nutrients

The inclusion of legumes in crop mixture has been suggested as a possible soil fertility sustenance strategy (Agboola and Fayemi, 1972). Legumes depend mainly on their own N fixation while cereals use mineral N from the soil (Ofori and Stern, 1987). Kessel and Hartley (2000) mentioned the importance of biological nitrogen (N_2) fixation as an important aspect of sustainable and environmentally friendly food production and long term crop productivity strategy. The cereal depletes soil nitrogen and produces carbohydrate while legumes fix atmospheric nitrogen and produce protein. Thus, a cereal-legume mixture improves the diet of tropical farmers as well as the soil of their farms. Patra *et al.* (1999) reported that a combination of soybean with maize gave the highest yield because of reduced competition, whereas combination of maize with sesame recorded the lowest combined yield due to severe competition between two non-legume crops. In addition, farmers who are not rich enough to set aside fields for the whole season to grow a green manure in rotation with another crop, can grow a green manure as intercrop which helps in maintaining soil fertility. For example, sunnhemp (*Crotolaria juncea*) was grown as green manure intercropped with sugarcane, in Uttar Pradesh, India (Innis 1997).

Many leguminous crops are efficient N-fixers. They increase the soil N status through fixation, excretion and decomposition of their own residues. Rhizobium bacteria are able to live in symbiosis with suitable host leguminous plants; they form root nodules and fix atmospheric nitrogen, thus adding significant amounts of N_2 to the system (Stern, 1993). The amount of nitrogen fixed by the legume depends on the phenology and morphology of the species or cultivars, legume density in the intercrop mixture, crop management and competitiveness of the rhizobia symbiosis (Ofori and Stern, 1987; Rerkasem and Rerkasem, 1988). For example, Mayers and Wood (1987) reported that the amount of nitrogen fixed by the legume ranged between 50 and 300 kg N/ha. Unkovich and Pate (2000) in their report mentioned that soybean was efficient in N_2 fixiation and it ranged from 0-450 kg/ha (Toomsan *et al.*, 1995) while *Phaseolus vulgaris* is poor in N_2 fixation which ranged from 0-165 kg/ha (Herridge and Danso 1995). N_2 fixation in soybean depends on being inoculated with the correct strain of rhizobium. Stern (1993) reported that legumes of indeterminate growth are more efficient, in terms of N_2 fixation, than determinate types. Eaglesham *et al.* (1982) found that in one season, soybean fixed more nitrogen than cowpea but soybean used a greater amount of the N_2 fixed to produce seed. Maskey *et al.* (2001) reported that soybean fixed a total of 59 kg N/ha and more than 60% of their N requirements was derived from fixation of atmospheric nitrogen.

High levels of mineral N in the soil will generally depress both nodulation and N_2-fixation (Streeter, 1988) and thereby push the legume towards dependence on soil N (Unkovich and Pate, 2000). An application of N in a cereal/legume intercropping system increased the vigour of cereal components which had an adverse effect on the legume components due to severe competition and shading (Trenbath, 1976). In an experiment reported by Reddy and Chatterjee (1973), nodulation was better at low levels of nitrogen; at low levels (20 kg N), the legumes grew better than at high levels of N (80 kg N) and there was a greater advantage of mixed cropping and nitrogen economy at low level of N than at high level of N. Similarly, Choudhury and Rosario (1992) reported that application of N above 30 kg N increased the dry matter and grain yield of maize but reduced that of associated mungbean. In maize/soybean intercropping trials in the Philippines, the LER value fell from 1.47 at 0 N to 1.11 at 120 kg N/ha. A nitrogen application of 60 kg N/ha stopped N fixation resulting in a lower LER value (Libon and Harwood, 1975). Singh and Guleria (1979) reported that maize/soybean system gave a yield advantage of LER 1.91 when no nitrogen was added while it was reduced to 1.82 when N was added.

There is little evidence reported in the literature that in legume/cereal intercropping systems, any direct transfer of N from the legume to the cereal component occurs in the same season. However, there is evidence that nitrogen fixed by legumes is available to the succeeding crop. Nair *et al*., (1979) reported that between 30 and 40% increases in wheat yields were observed after maize-soybean and maize-cowpea intercropping, compared to pure cereals and yield increased with increasing proportion of legumes. Giri and De (1981) estimated that 40 kg N/ha was fixed by fodder legumes and utilized by a subsequent crop of barley under dry land conditions. Waghmare and Singh (1984) reported a reduction in the need for fertilizer nitrogen by wheat in the range of 30 to 37 kg/ha when the crop was sown after a legume/cereal intercrop.

2.6.3 Controlling soil erosion

Intercropping serves as an effective tool in controlling soil erosion on sloping land, as in the hills of Nepal. Inclusion of fast growing crops in intercropping that develop a full canopy rapidly, help to control soil erosion and run off. Ground cover by intercrops reduced soil erosion by preventing direct rain drops hitting bare soil, which otherwise seal the surface pores, reduce infiltration and increase surface erosion (Innis, 1997). Combined root systems of intercrops hold soil firmly and add higher amounts of organic matter to the soil resulting in increased water holding capacity. It also provides dead mulch on the ground by shedding of old leaves. For example, in Gujrat, India, growing groundnut as a cover crop in cotton fields reduced 50 % of soil losses from sole cotton fields (Joshi and Joshi, 1965). Similarly, Singh and Chand (1980) reported that a dense canopy of soybean intercropped with maize can reduce soil losses even on sloping land in Himanchal Pradesh, India.

2.7 Disadvantages of intercropping

In spite of the several advantages from intercropping systems reported for subsistence farmers with small land holding in tropics, there are some disadvantages, which are discussed here.

2.7.1 Low scope for mechanization

Low cost of production of any commodity is a major factor when competing with others in the global market. There is a great scope for commercial farming through the use of improved farm equipment which reduces the cost of production because of increasing costs for manual labour. The use of farm equipment in different cultural operations is difficult in intercropping systems due to the presence of different crops. It also requires much manual labour to perform different farm operations which may increase the cost of production.

There is a technical problem with use of pesticides on intercrop. It was observed that an application of a broad-spectrum insecticide reduced the benefits of insect pest control by predators in a maize- groundnut mixture (IRRI, 1974). It is necessary to select insecticides more carefully in intercropping and to maximize biological control. Fertilizer application becomes difficult if farmers want to optimize fertilizer for each crop, and they have to split and localize small quantities of fertilizers. Similarly, application of herbicides also becomes difficult when controlling weeds in intercropping, as the majority of herbicides are selective for particular crops and it is also difficult in synchronizing the time of applications.

In case of polyphagous pests, intercropping can also increase pest problems when the component crops have common major pests. For example, thrips (*Megaluro-thips sjoestedti*) is a common pest of pigeonpea and cowpea and is highly attracted by pigeonpea. The cowpea crop was more infested with thrips when it was grown in the vicinity of pigeonpea (Rosing, 1980 in Steiner, 1984). Similarly, the infestation of rootknot nematodes on citrus may increase when the orchard is intercropped with susceptible vegetables (Batra, 1962).

2.7.2 Allelopathy

Some crops cannot grow together because they compete too strongly for the same resource which is a competitive effect. However, in mixture, some crop species or varieties may produce toxins into the local environment that causes an adverse effect on the companion crop resulting in poor growth, and this is called an allelopathic effect. Rice (1974) defined this as "any direct or indirect harmful effect that one plant has on the other through the production of chemical compounds that escape into the environment". For example, when rice seedlings were transplanted immediately after harvest of wheat (Kimber, 1973), decaying stubble produced organic compounds in the soil which caused adverse effects on establishment of rice seedlings. Similarly, *Agropyren repens*, a perennial grass weed that produces toxic substances, adversely affected the growth of maize. The presence of every 1 kg of the weed species reduced yield of maize by 2.74 kg compared to a yield reduction of 0.27 – 2.0 kg in the presence of annual weeds (Butch-Haltech, 1971 in Harper, 1977)

However, there are no reported allelopathic effects of soybean on maize or *vice versa.* Others ways in which an intercropping system does harm to companion crops are by sheltering pests, carrying pathogens, encouraging foraging birds and animals and sheltering slugs and snails.

2.8 Conclusion

In the mid and high hills of Nepal, farmers have practiced intercropping of maize and soybean for a long time, sowing seeds of both species densely together. They start to thin maize plants one month after sowing and continue until silking when they thin out barren plants. Recently, many farmers have reported that the production of intercropped soybean has been decreasing compared to the past, possibly due to inappropriate proportions and densities of component crops, and adverse effects of nitrogenous fertilizer application to maize. Most research on intercropping has concentrated on the effects of plant populations and their arrangements on the yield and yield components of associated crops and this literature review reflects that emphasis. In summary, plant densities below optimum lead to inefficient utilization of resources by plants resulting in sub-optimal grain production. On the other hand, excessive plant stands can result in over-use of limiting resources and may lead to weaker plants and lower productivity. Optimum plant density and proportions in mixed cropping may generally help to facilitate and ensure penetration of more light to the companion crop of the system resulting in higher combined yield (Singh and Chauhan, 1991). Many reports showed that a high density of maize (aggressor) caused a yield reduction of companion soybean by reducing light penetration to the soybean canopy.

Many studies on combination of maize and soybean have been carried out to determine optimum populations for maximum land use efficiency in various countries but such types of study are of limited applicability in the mid hills of Nepal due to its particular agro-ecological conditions. Nevertheless, this review has shown that there is great scope for manipulation of plant population and spatial arrangement of maize, which provides intercropping space for growing soybean. The experiments reported in this thesis, both additive and replacement series are used in designing treatments. The optimum density of maize (53,000/ha) and soybean (200,000/a) were used for the respective monocrops. Combination of different densities (reduced up to 50 %) of both crops were evaluated to determine optimum plant densities to obtain highest land use efficiency and monetary advantage, along with progressive thinning of maize crop, as practiced by farmers.

CHAPTER THREE

SURVEY OF MAIZE/SOYBEAN INTERCROPPING SYSTEMS

3.1. Introduction

Growing of soybean with maize in a mixed cropping system is a common practice on *bari* land in mid and high hills of Nepal. That productivity of soybean in intercropping systems has been decreasing from the past, has been reported by many farmers. Plant populations of component crops at harvest make a major contribution to total intercrop yields. Generally plant populations of both crops, especially soybean, are far below the optimum. Subedi (1990) reported that plant population of maize at harvest was less than 40,000 plants per ha due to progressive thinning for animal fodder throughout the season. Higher plant population of maize at an early stage reduces light penetration to the soybean canopy causing high mortality of soybean plants resulting in a poor plant stand at harvest, causing low production. In addition, application of nitrogenous fertilizer such as urea as a topdressing to maize inhibits nodulation, resulting in poor yield of soybean.

Maize/soybean intercropping system is a common practice in *bari* land of southern mid hills of Nepal where the annual rainfall is limited ranging from 1000-1500 mm. The performance of soybean is poor in those areas having higher rainfall such as the northern hills, where finger millet is commonly grown as a relay intercrop with maize. In the southern hills, the distribution of rainfall is concentrated from May to September with the peak in July and August. Farmers cannot grow both crops in rotation due to the short duration of the rainy season. Therefore, farmers grow soybean as an intercrop with maize to obtain at least some yield of soybean and to avoid the risk of total crop failure due to drought, because soybean can withstand drought to some extent. This system is mostly practised in mid altitudes due to the longer growing period of maize compared to the low hills, where these crops become sequential crops because maize requires less than 120 days to mature, and because maize has a higher yield potential at mid-hill altitudes.

In the first season (2001), a limited study was conducted to determine plant populations of maize and soybean under farmers' management in maize/soybean intercropping systems around Deorali.

3.2. Objective

The objective of this survey was to quantify the actual plant population of maize and soybean grown together as intercrops under farmers' management and to determine the factors associated with manipulation of density of both crops. Farmers were interviewed to determine reasons for growing soybean as an intercrop with maize and to identify constraints associated with the reported low production of soybean in such systems.

3.3. Material and methods

The survey was conducted at Deorali VDC of Palpa District of Nepal during the summer cropping period in 2001.

3.3.1. Plant population and yield

A total of 20 farmers' fields, where soybean was grown as an intercrop with maize, were selected randomly to study plant populations of maize and soybean at different stages of crop growth during 2001. It was explained to farmers what the objectives of this study were before they were selected. The common practice is to sow maize and soybean at the same time. Farmers consider maize as the staple crop and perform major cultural operations according to its requirements not those of soybean. Farmers first broadcast soybean seed in the field and then drop maize seed in furrows opened by a plough at approximately 30 cm intervals. Finally, clods are broken and land is levelled.

Twenty to twenty five days after seeding, a 20 m^2 area was selected in the centre of each farmers' field and demarcated with rope and pegs at four corners. Plant stands of maize and soybean from the demarcated area were counted and recorded for each farm separately. Farmers were allowed to perform all cultural operations according to their own normal practices. After first and second weeding of maize, plant populations of both crops within the demarcated area were counted separately and recorded. At maturity, plant stand of maize within the demarcated area was counted, and then harvested. Cobs were separated and dehusked. The number of cobs and field weight of cobs were recorded. The moisture of grain was taken. The plot yield was adjusted to 14 % moisture and 80% grain recovery for rachis was assumed. Similarly, the plant population of soybean was counted and plants were harvested at ground level with a sickle. All harvested soybean plants were dried in the sun for four to five days and threshed. Grains were separated from pericarps and weight of grain was measured for each plot separately. The grain yield of soybean was adjusted at 12% moisture. To confirm the results of the first year, another seven farmers' fields were selected randomly during 2002 to record plant stand and yield of both crops (maize and soybean). A 15 square metre area was selected from the centre of each plot in each farmers' field and other procedures were followed as mentioned above in this section.

3.3.2. Questionnaire

A formal survey was conducted using a questionnaire to determine farmers' perceptions of the maize/soybean intercropping system in the mid hills and their views of the constraints that cause low productivity of the system. The details of questionnaire are presented in table 3.1. The questionnaire was first piloted with five farmers in Lumle VDC and was modified accordingly.

Table 3.1. Format for formal survey of maize/soybean intercropping system at Deorali VDC in Palpa District of Nepal.

1. Farmer's name VDC Ward no Altitude
2. Total land holding (Ropani or $500m^2$): a. Khet b. Bari
3. Area under maize cultivation: a. Khet b. Bari
4. Area under maize/soybean intercropping: a. Khet b. Bari
5. Other crops used as intercrops with maize:

   Crops Area in ropani ($500m^{2)}$

   a. Finger millet
   b. Beans
   c. Ginger
   d. Others

6. Reason for intercropping
    a. Traditional culture
    b. Increased total production
    c. Risk of crop failure
    d. Improve soil fertility
    e. Food diversity/ requirement
    f. Others
7. Uses of soybean as different food items
    a. Roasted
    b. Vegetables
    c. Animal feeds
    d. Others
8. Response of succeeding crops to soybean
    a. Positive
    b. No difference
    c. Negative influence
9. Variety of soybean used:
10. Additional cost of cultivation for intercropping compared to sole maize

	Sole maize	Intercrop
a. Seed		
b. Weeding		
c. Harvesting and threshing		

11. Productivity (kg/ropani)

	Sole maize	Intercrop
a. Maize		
b. Soybean		

12. Price (Rs/kg) at harvest: a. Maize b. Soybean
13. Productivity trend of soybean under intercropping:
    a. Increasing b. Decreasing c. Constant
14. Reason for low productivity of soybean under intercropping
    a. Lack of suitable variety
    b. Lack of appropriate technologies
    c. Use of chemical fertilizers to maize
    d. Problems of disease/insect infestation
    e. Others abiotic and biotic factors

15. Where do you sell soybean?

a. Farm   b. Barter   c. Market

16. Do you have any problem in marketing?:

3.3.3. Survey Procedure

All farmers selected for the crop sampling survey were also involved in the questionnaire survey. Selected farmers were consulted individually in advance and an appointment was arranged to conduct the survey. Before conducting the survey, farmers were introduced to and briefed about the objective of survey. The survey was used as a guideline, and the format of the interview was semi-structured. The details of farmers' perception were also noted. Responses were reviewed in the evening of same day and triangulation of suspect information was carried out by the next day.

3.3.4. Statistical Analysis

Data were analysed by using descriptive statistics.

3.4. Results

3.4.1. Land holding under different intercropping system

The mean land holding of surveyed households and areas devoted to different intercropping systems are presented in Table 3.2. The mean total land holding per household was 0.8 ha with a range of 0.2 to 2.0 ha. *Bari* land was dominant (93.6%), meaning that these lands are upland and less fertile and mostly allocated to growing maize during the summer. *Khet* land is characterised by being lowland, irrigated and more fertile land and is generally used for cultivation of rice and wheat. *Khet* land was limited to a few farmers, and had an average area of 0.05 ha, ranging from zero to 0.65 ha per household. A higher holding of *khet* land is an indication of wealthier farmers in the hills. Though data are not presented here, 80% of surveyed households lacked *khet* land and were solely dependent on *bari* land.

Maize is a major staple crop in the hills and farmers give higher priority to cultivation of maize than soybean. Farmers start sowing maize as the first intermittent monsoon showers start during April. Not all farmers have bullocks and so depend on hired bullocks. Sowing of maize was often delayed to due to unavailability of bullocks to cover all fields in a timely manner, resulting in depletion of soil moisture. Farmers broadcast soybean seed at a mean rate of 19 kg /ha before ploughing the land. Maize seed was then sown in furrows opened with a wooden plough drawn by a pair of bullocks and seed was dropped in furrows approximately 30 cm apart. Farmers used a higher seed rate of maize, 40 – 50 kg/ha, which was double the recommended seed rate of 20 kg/ha, to avoid low germination and risk of poor plant stand, damage caused by insects/pests and other natural calamities like excess rainfall or drought. The average land allocated to maize cultivation in the surveyed households was 0.53 ha with a range of 0.1 to 1.2 ha per household, which accounted for 71 % of total *bari* land. Mixed cropping of maize and soybean is a major cropping pattern in the surveyed area with slight variations depending upon location, soil type, diverse socio-economic groups and different market opportunities. Some respondents reported that mixed cropping of ginger with maize resulted in benefits to farmers in the past because ginger gave a good yield and a better price in the market, but the high susceptibility to rhizome rot disease restricted the cultivation of ginger in this area. Besides the foregoing combinations, farmers were also growing finger millet and other legumes like rice bean (*Siltung*), bean

Table 3.2. Land holding (hectares/farmer) of surveyed farmers under different cropping systems at Deorali VDC of Palpa District of Nepal (average of 20 farmers).

Land area under different system	Land holdings (ha)	Standard deviation
1. Total land holding (n = 20)	0.80 (0.2 – 2.0)	0.51
a. *Bari*	0.75 (0.2 – 2.0)	0.15
b. *Khet*	0.05 (0 – 0.65)	0.47
2 Area under maize cultivation	0.53 (0.1 – 1.1)	0.27
3. Area under maize/soybean intercropping	0.22 (0.05 – 0.5)	0.15
4. Area under maize/millet intercropping	0.03 (0.0 -0.15)	0.05
5. Area under maize/other crops intercropping	0.07 (0.0 – 0.5)	0.14
6. Percent of maize/soybean intercropping	41.1	
7. Percent of maize/millet intercropping	5.8	
8. Percent of maize/other crops intercropping	13.6	

Note: Figure in parenthesis indicates ranges, *Khet* land is terraces with binds.

and cucumbers on a small scale. The average areas occupied by maize/soybean intercropping in surveyed households was 0.22 ha with a range of 0.05 to 0.5 ha per household, which accounted for 41 % of total maize area. Farmers with smaller land holdings allocated more land to growing soybean mixed with maize than larger farmers (data not presented). The reason given by respondents for not adopting intercropping by large holding farmers was the scarcity of family labour for weeding and harvesting because intercropping is a labour intensive system. Small holding farmers performed all operations using their own family members and this can be sustained on a small area of land. Intercropping of soybean was limited by the presence of wild rabbits which destroys germinating seedlings of soybean. Therefore, areas near to forest are not suitable for growing soybean as an intercrop.

About 0.03 ha per household was allocated for maize/finger millet relay intercropping which was only 5.8 % of total *bari* land. Wheat followed maize/finger millet grown provided there was winter rain. Some communities used finger millet for preparation of liquor. Besides this, about 13.6 % of the land area per household (mean of 0.07 ha) was used for growing other crops such as rice bean, bean, cowpea and cucumber. Farmers reported that they required these vegetables and pulses in addition to cereals for their daily home consumption, because they could not afford to buy vegetables daily due to their limited income.

3.4.2. Farmers' perceptions regarding maize/soybean intercropping

Out of 20, only four respondents (20 %) reported that growing of soybean mixed with maize was practised traditionally by their parents (Table 3.3). The term "tradition" means "learned from my father" and is often used by young farmers (Steiner, 1984), because they had lacked their own indigenous knowledge. About 70% of respondents replied that mixed cropping of maize and soybean maximized total productivity compared to growing them separately. They also knew that maize yield was not affected by presence of soybean but growing of soybean mixed with maize provided additional soybean as a bonus crop. Farmers earned cash by selling excess produce, because soybean fetches a higher price than maize.

30 % of respondents from the surveyed households answered that intercropping of maize and soybean was practised to minimize risk crop failure due to natural calamities like excess rainfall, drought and damage by insect/pests. They also believed that normal or excess rainfall favoured the production of maize while irregular and reduced rainfall favoured production of soybean. Thus yield reduction in one crop is compensated by increased production of other crop. 70 % of respondents reported that growing of soybean with maize improved soil fertility and soil became easier to work while ploughing the land than after sole maize. They assessed soil fertility by comparing the growth of the succeeding crop of mustard or wheat grown after intercropped and sole maize. They also asserted that mature and dry leaves of soybean that fall on the ground increased nutrient content of soil after decomposition when mixed with soil after ploughing. Some farmers also reported that nodules formed by roots of soybean also helped in increasing soil fertility. It was recognised that large amount of nutrients are removed through harvest of grains and straw.

About 50% respondents expressed their view that soybean provided a more diversified diet, and explained that they required pulses and vegetables besides cereals as basic requirements. This was only possible by growing different crops simultaneously on their limited available land whilst not reducing maize grain yield. Soybean is consumed by all farmers in various forms which supplements plant protein in their diet, where the supply of animal protein is limited. Soybean haulm and grains were also used for animal feed. 20 % farmers also gave other reasons for the practising of growing soybean with maize. They reported that in spite of low productivity of soybean compared to maize, it gave higher income due to a good market price. Secondly, it utilized the short rainy season more efficiently, because there is a gap between harvest of maize and planting of a winter crop. Besides this, farmers also perceived that the presence of soybean suppressed weed growth and reduced the cost of second weeding in maize and helped indirectly in higher grain production of maize.

Table 3.3. Reasons given by farmers for growing soybean as intercrop with maize at Deorali VDC of Palpa District of Nepal (n = 20).

Reasons given by farmers	Number	Percent of total
Traditional culture	4	20
Increased total production	14	70
Reduce risk of crop failure	6	30
Improve soil fertility	14	70
Food diversity/requirement	10	50
Other	4	20

Note: some farmers gave multiple responses.

3.4.3. Effect of maize /soybean mixed cropping on succeeding crops

The response of surveyed respondents regarding the residual effect of growing soybean on succeeding crop is presented in Table 3.4. A great majority of respondents (95 %) believed that growing of soybean along with maize had significant beneficial effects on the growth and yield of the succeeding winter crop. Only one respondent (5%) reported that there was no effect of intercropped soybean on growth of succeeding crop compared to sole maize. No one mentioned any adverse effect on the succeeding crop.

Table 3.4. The response of surveyed farmers regarding the effect of growing soybean on succeeding crops in relation to soil fertility improvement (n= 20).

Response of farmers	Number	Percent of total
1. Positive effect on succeeding crop	19	95
2. No effect on succeeding crop	1	5
2. Adverse effect on succeeding crop	0	0

3.4.4. Productivity, gross and net return from maize/soybean intercropping

The mean productivity of maize and soybean, and gross net returns from maize soybean mixed cropping are given in Table 3.5. The average production of sole and intercropped maize were 2565 and 2506 kg/ha with a range of 1395 to 4176 kg/ha, respectively, productivity of intercropped maize being only slightly lower than sole maize. Yields of intercropped soybean was 322.7 kg/ha with a range of 99 to 792 kg/ka. The reason given by farmers for such low productivity of soybean was excess rainfall during cropping period as well as a low plant population. They reported that high rainfall favoured vegetative growth but reduced grain yield. Similarly, low moisture during sowing time reduced germination resulting in low initial plant populations.

Table 3.5. Average gross returns from sole and intercrop maize with soybean and additional benefit from growing soybean as intercrop in surveyed farmers' fields at Deorali VDC of Palpa district of Nepal.

	Sole maize	Intercrop	
		Maize	Soybean
Grain yield (kg/ha)	2565 (861))	2506 (821)	322.7 (160.2)
Gross returns (Rs/ha)	20443.05	19972.82	8506.37
Gross returns (Rs/ha) (combined)	20443.05	28479.19	
Difference in intercrop vs sole crop(Rs)		8036.1	
Additional costs for soybean cultivation			
Seed (kg/ha)		18.98 (7.01)	
Weeding (Man day /ha)		25 (15.39)	
Harvesting and threshing (manday/ha)		29 (13.73)	
Total costs (Rs/ha)		3740.31	
Net benefit from intercrop (Rs/ha)		4295.83	

Note: Figure in parenthesis indicates standard deviation. Price of maize, soybean and manday were calculated at the rate Rs[1]. 8.00, 26.36/kg and Rs 60/day, respectively.

In spite of low productivity of soybean, gross returns from intercropping was higher (Rs. 28479.19/ha) than sole maize (Rs. 20443.05/ha) and a difference in gross return of Rs. 8036.1 per ha was obtained. Farmers reported that intercropping with soybean required additional expenses in seed, labour for weeding, harvesting and threshing. Women labourers were mostly used in these operations which cost less per manday than male labourers, the daily wages of male and female labourers being Rs. 100 and 60/manday, respectively. On an average 25 additional female labourers per farm were needed for weeding of intercropped maize, a high number because they had to protect

[1] Rs 115.00 = £ 1.00

soybean plants from accidental damage while weeding. About 29 mandays were needed for harvesting and threshing operations. Total variable cost involved in cultivation of soybean as an intercrop was Rs. 3740.31/ha. After deduction from gross return, a total net return of Rs. 4295.83/ ha was obtained by growing soybean mixed with maize.

3.4 5. Use of soybean

Responses of surveyed households regarding different uses of soybean are presented in Table 3.6. All farmers in the hills consume soybean in their regular diet but in different forms. Green pods are used as vegetables, because farmers need vegetables along with rice (*Bhat*) and pulse soup (*Dhal*). Green pods are also consumed after boiling. Mature grains are dry roasted in an oven and mixed with puffed maize grains and consumed for breakfast. This was also given to agricultural labourers for breakfast while working in the farmers' fields. Mature grains were also used as '*Biraula*', a special preparation of breakfast, in which dry grains are soaked in water overnight and fried in the oven with oil. Straw and grains are used for animal feeds. 85% of respondents reported that soybean was consumed as mature grains either with lunch or dinner. Only 25 % respondents mentioned that soybean was used to feed milk cattle. Due to the high price of soybean, only the food surplus category of farmers used soybean as animal feed. A few farmers (5%) reported that it was used as *Satuwa*, a grounded flour of roasted grains of soybean and consumed as a semi-liquid by making *Litho* mixed with water.

Table 3.6. Uses of soybean in different food preparation by the farmers of Deorali VDC of Palpa District of Nepal (n = 20).

Uses of soybean	Number	Percent of total
1 Roasted (matured seed)	17	85
2. Vegetable (green pods)	13	65
3. Animal feeds	5	25
4. Others	1	5

Note: farmers gave multiple responses.

3.4.6. Varieties of soybean

Seto (white) and *khairo* (brown) were the two main varieties reported. These varieties were adopted a long time ago. *Khairo* produced the higher grain yield and has a good taste. However, it took longer to mature and so escaped from losses due to any heavy rains at harvest, but delayed maturity of this variety restricted early planting of a winter crop like mustard. On the other hand, *seto* variety matured earlier and facilitated early entry of mustard. Sometimes, there was a heavy loss by rotting due to heavy rains at maturity.

3.4.7. Farmers' perception on productivity trend of intercropped soybean

The Table 3.7 shows that out of 20 surveyed farmers, 19 farmers (95%) claimed that the productivity of soybean had decreased from the past. They reported that in the past they were selling large amounts of surplus soybean in the markets to earn cash, but production of soybean has since declined abruptly and now is not sufficient for their own consumption. The reason given by the farmers was the introduction of a high yielding, leafy maize variety which requires chemical fertilizers in large quantities. Compost made with livestock manure is used wherever possible, but quantities made have declined due to reduced numbers of livestock. This is because restrictions imposed by community forest management has reduced the availability of fodder collected from forests. Most farmers apply urea as a topdressing to maize by broadcasting, because of random plant population of maize. They perceived that application of urea to maize might be the cause of excessive vegetative growth of soybean plants resulting in low production. Only one farmer reported that yield level of soybean had not changed.

Table 3.7. The response of surveyed farmers for productivity trend of soybean grown as intercrop with maize at Deorali VDC of Palpa District of Nepal (n = 20).

Response of farmers	Number	Percent of total
1. Increasing from the past	0	0
2. Decreasing from the past	19	95
3. Stagnant	1	5

3.4.8. Farmers' perceptions on low productivity of intercropped soybean

15 % of respondents mentioned lack of high yielding varieties as a cause of low productivity of soybean (Table 3.8). They perceived that the two varieties mentioned in section 5.4.5 have been cultivated from the very beginning and have deteriorated like maize. They requested the introduction of new high yielding genotypes of soybean in this area. 20 % farmers replied that there was a lack of knowledge regarding improved

technologies such as correct time of planting and appropriate proportion and density of component crops. Farmers' own experience showed that soybean grown on sloping land gave higher grain yields than on level land. Generally, level land is more fertile with a high moisture content, whereas sloping land has lower fertility and water stress forces soybean roots deeper into the soil to extract water, and nutrient stress resulted in soybean plants becoming independent from soil nitrogen and so fixed atmospheric nitrogen through their own root nodules, resulting in reduced competition. Out of 20, 18 respondents claimed that application of urea as a topdressing to maize was a major cause of low productivity of soybean. They also expressed the view that a short plant growth habit of soybean is ideal for higher grain yield, while application of urea increased plant height, with consequent lodging and thinner plant stems resulting in low yield. Only one farmer reported that infestation of insects/disease might cause reduced productivity, although 25 % respondents reported that other abiotic and biotic factors caused yield reduction of intercropped soybean. They further explained that drought during sowing time had adverse effect on germination resulting in a poor plant stand. On the other hand, heavy rainfall during vegetative growth increased vigorous growth of soybean plants and caused lodging, also resulting low grain productions, and post harvest losses. Secondly, wild rabbit was a major pest in reducing plant stand near

Table 3.8. Reasons given by farmers for low production of soybean grown as intercrop with maize at Deorali VDC of Palpa District of Nepal.

Reasons given by farmers	Number	Percent of total
1. Lack of suitable variety	3	15
2. Lack of appropriate technologies	4	20
3. Use of chemical fertilisers to maize	18	90
4. Problem of disease/insect infestation	1	5
5. Others abiotic and biotic factors	5	25

Note: Some farmers gave multiple responses.

forest areas, which destroy the plumule of germinating seedling of soybean. Thirdly, farmers performed cultural operations according to the requirements of maize, not soybean. Due to a delay in first weeding, small seedlings of soybean were suppressed by weeds and many plants were uprooted during weeding due to their low visibility, resulting in a poor plant stand.

3.4.9. Marketing of soybean

Farmers were interviewed to identify marketing constraints influencing the marketing of soybean. All respondents reported that there was no problem in selling soybean. Farmers sell their produce to local buyers or retailers, depending upon quantity and the need of individuals. For example, they may sell to local buyers in small quantities and purchase another commodity needed immediately for daily use. Some farmers sell a large quantity to retailers. Farmers had to transport this to market. There was a variation in selling price between local buyers and retailers because of differences in quantity and transportation cost. Price of soybean also fluctuates, being lowest during harvest (October-November) and highest during the off season (June to August)

3.4.10. Plant population of component crops during growing period

The trend of plant population of maize and soybean at different growth stages in different farmers' field at Deorali during 2001 are presented in Appendix 3.1 and Figure 3.1. In both crops, initial plant stand of maize and soybean were higher at 20 to 25 days after germination and gradually declined after first (45 DAS) and second (75 DAS) weeding to lowest at harvest. The trend of reduction in plant stand of maize was higher compared to soybean. The magnitude of reduction in plant population were 17.5, 22.2, 40.3% in maize and 11.7, 15.3, 19.5% in soybean after first and second weeding and at harvest. In all farmers' fields, populations of both crops had declined by harvest, and in no cases was the recommended plant population was retained at harvest. In second season, final plant populations of maize and soybean were 3.51 and 6.74 plants/m^2, respectively (Table 3.9). Plant population of both crops were higher in second season. In a few cases in this season, recommended population of maize was retained at harvest. Thinning of maize was the main cause of reduction in plant population. Farmers perceived that high plant population of maize reduced grain yield of both crops. Generally, two thinnings were reported, mainly at first and second weeding between 30 and 60 DAS. Farmers thinned maize plants gradually to secure against drought and insect damage, to remove lodged plants and to obtain a supply of fodder. In addition to thinning, plant population continued to decline further because of removal of barren, smutted, lodged and wind damaged plants. There was strong wind after tasseling during July which caused a significant reduction in plant population during the first season. At the initial stage of the crop, insect such as shoot fly (*Atherigona* spp) field cricket

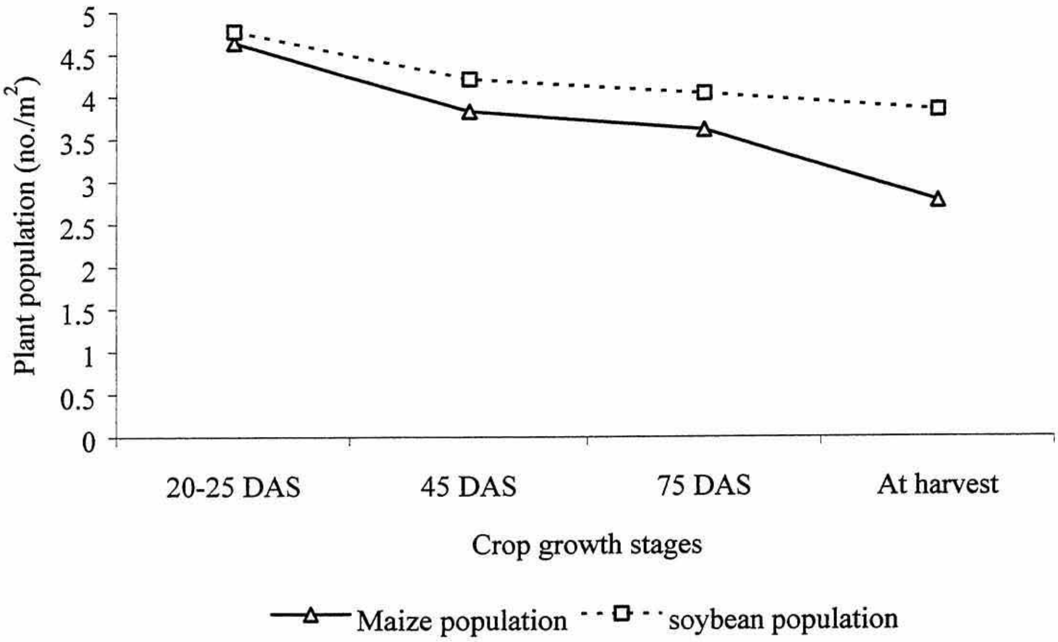


Figure 3.1. Mean plant population (no./m^2) of intercropped maize and soybean at different growth stages, observation taken in different farmers' fields at Deorali VDC of Palpa District during 2001.

Table 3.9. Mean plant population (number/m^2) and grain yield (g/m^2) of intercropped maize and soybean at harvest from crop cutting taken in different farmers' fields at Deorali VDC of Palpa District during 2001 and 2002.

Crop growth stage and yield	2001		2002	
	maize (n = 21)	Soybean (n = 21)	Maize (n = 7)	Soybean (n = 7)
Plant population at harvest(no./m^2)	2.77 ± 0.66 (1.80 - 3.80)	3.84 ± 0.78 (2.0 - 5.80)	3.51 ± 0.85 (2.60 – 5 00)	6.74 ± 2.08 (4.73 - 11.27)
Grain yield (g/m^2)	324.8 ± 108.2 188.5 - 364)	20.23 ± 0.98 (11.53 - 8.0)	281.8 ± 85.6) (198.5.-.459.5)	68.85 ± 22.2 (53.80.- 110.30)

Note: Figure in parenthesis is range of observation

(*Acheta assiusmilis*) and stem borer (*Seamia inferens* and *Chilo partellus*) also caused considerable plant losses. Immature cobs also damaged by rodents were reported in some places.

3.4.11. Grain yield of maize and soybean

Grain yield (g/m^2) and plant population of maize and soybean at harvest from the crop sampling survey conducted in 21 farmers' field during 2001 and from seven farmers' field during 2002 are given in Table 5.9. In the first season, grain yield of maize was 324.8 g/m^2 with a range of 188.5 to 364 g/m^2 whilst mean grain yield of soybean was 20.23 g/m^2which ranged from 11.53 to 48.0 g/m^2. The grain yield of soybean (Table 3.9) was lower (20.23 g/m^2) during first season than reported by respondents (32.27 g/m^2) whereas maize grain yield was higher (324.8 g/m^2) than the survey report (250.6 g/m^2). Farmers also perceived that high rainfall favoured better production of maize but had a negative effect on the production of soybean whereas reverse trend was obtained under low rainfall.

In the second season, in spite of a higher plant population of maize, grain yield from seven farmer's fields was only 281.8 g/m^2, which was lower than previous season. This showed that low rainfall during the second season had an adverse effect on maize yield.

3.5. Discussion

3.5.1. Practise of intercropping

Limited land holding (<0.5 ha) is major constraint in hills of Nepal which enforces farmers to grow multiple crops as mixed crops on the same land to obtain diversified food for their daily use and to utilize soil moisture more efficiently, for higher total yield. Additionally it provides employment to family members, because of poor employment opportunities in other sectors. In this agro-ecozone, crop production is limited by the duration of the monsoon (June to September), furthermore, there is no guarantee of winter crops due to unreliable rainfall. The majority of farmers have only *bari* land which has low poor fertility and is rainfed. This combination of small holdings, low fertility and short duration of rainfall causes farmers to adopt mixed cropping. Norman (1977) reported that land shortage was a major reason given by farmers for adopting intercropping in Northern Nigeria. In Nepal, some farmers with larger land holdings use less of the area for intercropping due to scarcity of labour and having other sources of income, while small farmers mostly use their family labour in cultivation of intercrops.

Maize, being the staple food in the hills, is accorded first priority in cultivation. Secondly, selection of crops depends on the rainfall pattern, altitude and household food requirements. For example, in the high hills with high rainfall, potato is mostly grown as an intercrop with maize, whereas finger millet is relayed with maize in the mid altitude northern hills with high rainfall. However, the production of finger millet is restricted in southern mid altitude hills, because of the prevailing limited short duration rainfall (<1500 mm over four months). Water stress during flowering causes yield reduction in finger millet. Soybean is more common in the Deorali area because it can tolerate drought and can extract water from deeper layers of soil, having a deep root system. It provides insurance against crop failure due to uncertain rainfall and other natural events. Steiner (1984) reported that intercropping is more pronounced in areas with unpredictable rainfall. Intercropping is generally regarded as a subsistence farmer's technique to reduce risk of catastrophic failure. Reddy and Chatterjee (1973) demonstrated that intercropping of soybean with rice provided security against crop failure. The poor yield of soybean in years of heavy rainfall was compensated by good yield of rice taken as intercrop. Besides this, in Nepal, all farmers consume pulses in their daily diet in different forms and in Deorali, soybean is the pulse most suited to this agro-ecozone. They treat it as an essential commodity, which forces them to grow soybean as an intercrop, as they are limited by land scarcity.

3.5.2. Constraints to low productivity

3.5.2.1. Crop improvement

The survey report indicated that productivity of soybean is decreasing. Farmers are mostly cultivating only two varieties of soybean, namely *seto* and *khairo*, Since soybean cultivation began. The Nepal National Legume Improvement Program has given a low priority to crop improvement of soybean and has not introduced varieties suitable for intercropping with maize. This limitation of varietal diversity is one causes of low productivity. Priority should be given to develop and introduce shade tolerant, high yielding genotypes of soybean to increase varietal diversity in these areas. Farmers' experiences suggest that existing genotypes are highly influenced by variation in rainfall pattern. Soybean crop suffers more due to high rainfall resulting poor grain yield. This specific problem suggests that there is lack of soybean germplasm tolerant to heavy rainfall.

3.5.2.2. Crop establishment

Soil moisture during sowing time is a critical factor to obtain optimum plant population. Generally, farmers start sowing maize and soybean immediately after the start of initial showers in April. Sowing operations are often then delayed due to limited availability of bullocks and labour resulting in a decline in soil moisture if rain does not continue. Maize seed germinates at low moisture while soybean requires high moisture for germination. Smith and Circle (1972) reported that a minimum of 50% moisture in the seed is required for germination of soybean seed whereas maize requires only 30 %. Secondly, delayed weeding increases weed growth which suppresses young soybean seedlings causing poor plant stand. Paudel *et al* (2001) reported that low plant population (often caused by drought after planting) was ranked highest among various constraints such as excessive rains, weeds, insect damage identified by farmers. To overcome these constraints, it is suggested that there should be investigation into sowing soybean at first maize weeding (20-25 DAS), when moisture content in the soil has been already improved by succeeding rains.

Good yield potential with stability of performance is the ultimate objective of any crop improvement programme (Sthapit., *et al* 1991); but specific objectives vary with production system and region. The present indigenous variety of soybean adopted by farmers is a low yielder which needs to be addressed in the long term to improve and sustain soybean yield.

On the other hand, introduction of the existing high yielding, leafy maize variety has also had adverse effects on soybean yield by imposing higher shade. The development of maize varieties is totally based on monocropping without taking in to consideration any intercropping practices. Farmers' varieties (landraces) are early maturing and have less foliage, so allow more light penetration to the soybean canopy, but are being replaced by new high yielding maize. There is a need to develop maize varieties with less foliage, erect leaves and so which are more suitable for intercropping. A slight reduction in maize grain yield may be compensated for by an increase yield of the intercrop.

3.5.2.3. Agronomic practices

The findings of the survey suggest that farmers' manipulations of populations of component crops is a major constraint to productivity, especially soybean. The initial plant population of maize is higher than recommended for sole crops but lower than optimum by harvest. Thinning is a major cause in maize while poor germination of seed is in the case of soybean. Farmers retain a high plant population of maize up to a late stage of crop growth to secure against plant damage by insect, drought and rainfall then thin. The presence of high plant population for a long period increases competition for plant nutrients and water and causes poor growth of maize as well as in soybean, by inter and intra-specific shading. This could be improved by early thinning and weeding with secured insect/pest management. The plant density of maize could be reduced to a at slightly lower density of 40 x 10^3 plant ha^{-1} rather than the recommended density of 53 x 10^3 plants ha^{-1}. The slight yield reduction in maize could be compensated for by an increase yield of soybean. However, it should be borne in mind that for the farmers, maize is a multi-purpose crop. Thinnings are all fed to livestock or sold for fodder, and this is an important source of food for stock during a fodder scarcity period.

The results of field observation shows that the trend of plant population changes from emergence to harvest. Farmers used a high seed rate which gave an average of 4.64 and 4.77 plants ha^{-1} for maize and soybean, respectively in 2001. But the final plant stand of maize and soybean were 2.77 and 3.84 plants ha^{-1} reduction by 40.3 % and 19.5 %, respectively. In the second season, the final plant stand of maize and soybean were 3.51 and 6.74 plants ha^{-1}, which were greater than the previous season. Variation in environment plays a major role in variation of plant stand of both crops. Drought during sowing and strong winds after tassel initiation lowered already poor plant population in both crops in the first season while sufficient moisture in the soil during sowing favoured better germination and a good plant stand in the second season. This finding is in agreement with results obtained in surveys conducted by Subedi and Dhital (1997) in the western hills of Nepal, that plant stand of maize at harvest was 37,300 ± 1700 plants ha^{-1}, a 46 % reduction from the initial plant stand. Similarly, Tiwari (2001) reported that initial population of maize was 102 % higher the national recommended population and was reduced by harvest to 45 % of the recommended population of 53 x 10^3 plants ha^{-1}, in eastern mid hills of Nepal. Gurung and Rijal (1993) also found in their survey report that plant population of maize was about 30% lower than the national recommendation, in mid and high hills in eastern Nepal.

Delaying thinning to increase fodder production results in barren plants, fewer ears and grains per ear, which ultimately decreases grain yield (Subedi, 1990). Hallauer and Sear (1969) reported that significant yield reduction resulted from delayed thinning. Adhikari (1990) described how delaying thinning after 30 DAS has a detrimental effect on the final crop. Subedi (1994) observed that the number of barren plants increased significantly with increase in plant population. In the current study, high initial plant population of maize suppressed the growth of soybean by competing for nutrients and water uptake and reduced PAR incident on the maize. At the same time, maize production declined due to high intra-specific competition and reduced plant population caused by self thinning as well as barren plants.

3.5.2.4. Application of chemical fertilizers

Experiences of farmers suggest that application of urea intended for maize is also used by soybean, and this suppresses nitrogen fixation. Reddy and Chatterji (1973) reported that at low levels of N (20 kg N) soybean grew better than at high levels of N (80 kg N) and nodulation was better at low level of N. Planting of both crops in separate rows and placement of fertilizers near the maize row may overcome this problem. Maize could be planted in rows behind the plough by dropping seed within the row but in alternate furrows. This needs to be further investigated.

3.5.3. Grain yield of component crops

The results showed that grain yield of maize was 324 and 281 g/m^2 during the first and second season. Similarly grain yield of soybean was 20.23 and 68.45 g/m^2, during the first and second season, respectively. Maize yield decreased while soybean yield increases in second season. In spite of high plant populations of maize at harvest, grain yield of maize was reduced due to drought at late vegetative and grain filling stages in the second season (863 mm during entire cropping period; section 4.3.5. section of Chapter Four) whereas it favoured grain production of soybean, increasing grain yield by three times compared to the previous season. Additionally, higher plant population at harvest also contributed to higher grain yield of soybean.

3.6 Conclusion

The survey results clearly indicated that the productivity of intercropped soybean has been declining from the past. The reasons given by farmers were the introduction of new, high yielding, leafy maize varieties and application of urea to maize. Crop sampling results indicated that low plant population at harvest was the main cause of low productivity of the intercropping system. Continuous thinning of maize as insurance against drought, insect/pest damage and supply of fodder was the cause of reduced population at harvest. Farmers want to grow soybean due to its high value and it is needed for their dietary requirement, but they are constrained by limited landholdings, so they have to grow it as an intercrop. There is an urgent need to develop suitable technologies to overcome the identified problems and to determine optimum plant populations of component crops for higher intercropping productivity.

CHAPTER FOUR

EFFECT OF VARYING MAIZE AND SOYBEAN POPULATION DENSITIES IN INTERCROPPING

4.1 Introduction

In maize/soybean systems in Nepal, sowing of crops starts from the middle of April to the end of May, as soon as rain provides sufficient moisture in the soil. This is a period of intense activity for farmers to catch soil early moisture. Due to the limited supply of labour and bullocks, firstly farmers usually broadcast soybean seed at a high seed rate and then drop maize seed approximately 30 cm apart in the furrow opened by a wooden plough. In spite of the high seed rate of soybean, poor stands of soybean are achieved, because broadcasting and ploughing in leads to very variable seed depth. Seed placed too deep in soil can not emerge due to the short plumule and seed placed near soil surface also may not germinate due to insufficient moisture. Germination of soybean sometimes is below the optimum due to prolonged drought at sowing time However, maize seed can germinate even at low soil moisture. Soybean seed requires a minimum of 50% moisture in seed for germination whereas maize requires only 30 % (Smith and Circle, 1972). Farmers give more emphasis to maize cultivation as it is their staple food.

The results of survey indicated that the productivity of soybean has decreased over time due to application of urea as topdressing to maize as discussed in Chapter Three. However, survey reports conducted by Subedi and Dhital (1997) indicated that plant populations of maize were too high (69,100 ± 1800) at initial stages but decreased by 46 % at the time of harvest, which was far below the optimum level. Generally, plant population of soybean is also very low at the time of harvest (on the basis of visual observation). Low production of the system is thus due to a combination of low and inconsistent plant populations, low fertility and variable rainfall. Punia *et al.* (1999) mentioned that the yield potential of intercropping depends on optimum populations of components in the system.

Higher density of maize has adverse effects on the growth of soybean by reducing light interception. Weils and McFadden (1991) observed that yield reduction of intercropped

Plates showing research site (above) and farmers' practice of maize/ soybean intercropping (below) soybean was greater with increasing maize density because light penetration and leaf area decreased with increasing maize plant density. Yield of component crops in the intercrop varied significantly with component population density (Pal *et al.*, 1993).

4.2 Objectives

The main hypothesis tested was that lowering of maize density or using wider rows would allow more penetration of light to intercropped soybean and any yield reduction in maize could be compensated by increased yield of soybean. The objective of this experiment was therefore to determine the effects of different plant populations of maize and soybean on growth and combined yields of the component crops, and soil nutrient content.

4.3 Material and Methods

The research was co-ordinated from ARS Lumle. The experiment site was located about 13 km west of Tansen, headquarters of Palpa District, in the southern hills of Western Development Region of Nepal. The experiment was conducted on land hired from farmers of Deorali Village Development Committee (VDC) from April 20 to September 18, during the 2001 rainy season. The land for the experiment was located in farmers' fields at Deorali for three reasons. Firstly, the climate of the Agriculture Research Station, Lumle is not suitable for growing soybean due to high rainfall, whereas low rainfall occurs in the southern hills in Palpa District. Secondly, there is a common practice of growing soybean intercropped with maize in this area. Thirdly, the experiment required large plot sizes, which are not available at Lumle Station. Farmers' fields at Deorali have wide terraces. ARS Lumle has established an agro-ecological site at Deorali, 190 km south from Lumle, representing the mid hills, to generate technologies suitable for mid hill environments. This provides logistical support to conduct off-station experiments.

The location of the experimental site was $27^0 53'39''$ N and $83^0 26'72''$ E and at altitude of 1260 m above sea level. The soil was loam in texture, having 18.2, 45.0 and 36.8 % clay, silt and sand particles respectively. Coarse gravels were also mixed with the soil. Soil pH ranged from 5.5 to 6.1 with low organic matter (1.2 to 2.1%) and total nitrogen percentage (0.082 to 0.120%) and medium available phosphorous (37.7 to 45.3 ppm) and potassium (0.27 to 0.44 me/100g soil) (Landon, 1992).

Soil sampling and analysis

Soil samples from each plot were collected before planting maize and after harvest of soybean. Samples were taken randomly from five to six places from each plot with an auger, after demarcation of layout of the plot, and mixed thoroughly to make a representative sample. About 0.5 – 0.75 kg of soil was collected in labelled plastic bags. Soil samples were dried in shade for 15 days, after which they were crushed and passed through a 2mm sieve for determination of pH, texture, potassium and phosphorous, and 0.5 mm for organic matter and nitrogen. pH was determined in 1:2.5 soil water ratio. Organic matter was analysed using the Walkley method. Nitrogen content was analysed by acid digestion and calorimetric method. Similarly available P and K were determined by applying Bray and ammonium acetate extracts and flame photometer methods, respectively. The particle size of soil was determined by hydrometer method, to determine its textural class.

Treatments

The experiment consisted two mixed cropping factors in addition to sole crop of maize and soybean. Factor A consisted of three levels of maize density (53, 40 and 26.5 x10^3 ha^{-1}) and factor B consisted of three levels of soybean density (200, 150 and 100x10^3 ha^{-1}) arranged in nine treatment combinations. In addition there were two sole crops of maize and soybean at their recommended density of 53 x 10^3 and 200 x 10^3 ha^{-1}. Maize densities were obtained by manipulating row spacing from 75 to 150 cm whilst maintaining a constant interplant spacing of 25 cm. Soybean densities were obtained by planting soybean in two rows between each pair of maize rows and adjusting plant spacing within the row as shown in figure 4.1a and Table 4.1. The varieties used for maize and soybean were Mankamna-1 and CN60, respectively and their varietal characteristics are given in tabular form (Table 4.2) as follows:

Mankamna-1, white grain, full season maize variety, was recommended for the mid hills in 1988 and was widely accepted by farmers. Seed contain 8.18, 5.29 and 73.11 % protein, fat and carbohydrate respectively. CN 60 variety of soybean is an exotic genotype, claimed to be suitable for intercropping with maize, with a potential grain yield of 1550 kg/ha, and of medium maturity (Anonymous, 2000a).

Table 4.1. Details of treatments, spacing of maize and soybean between row and within row in intercropping experiment 1, 2001.

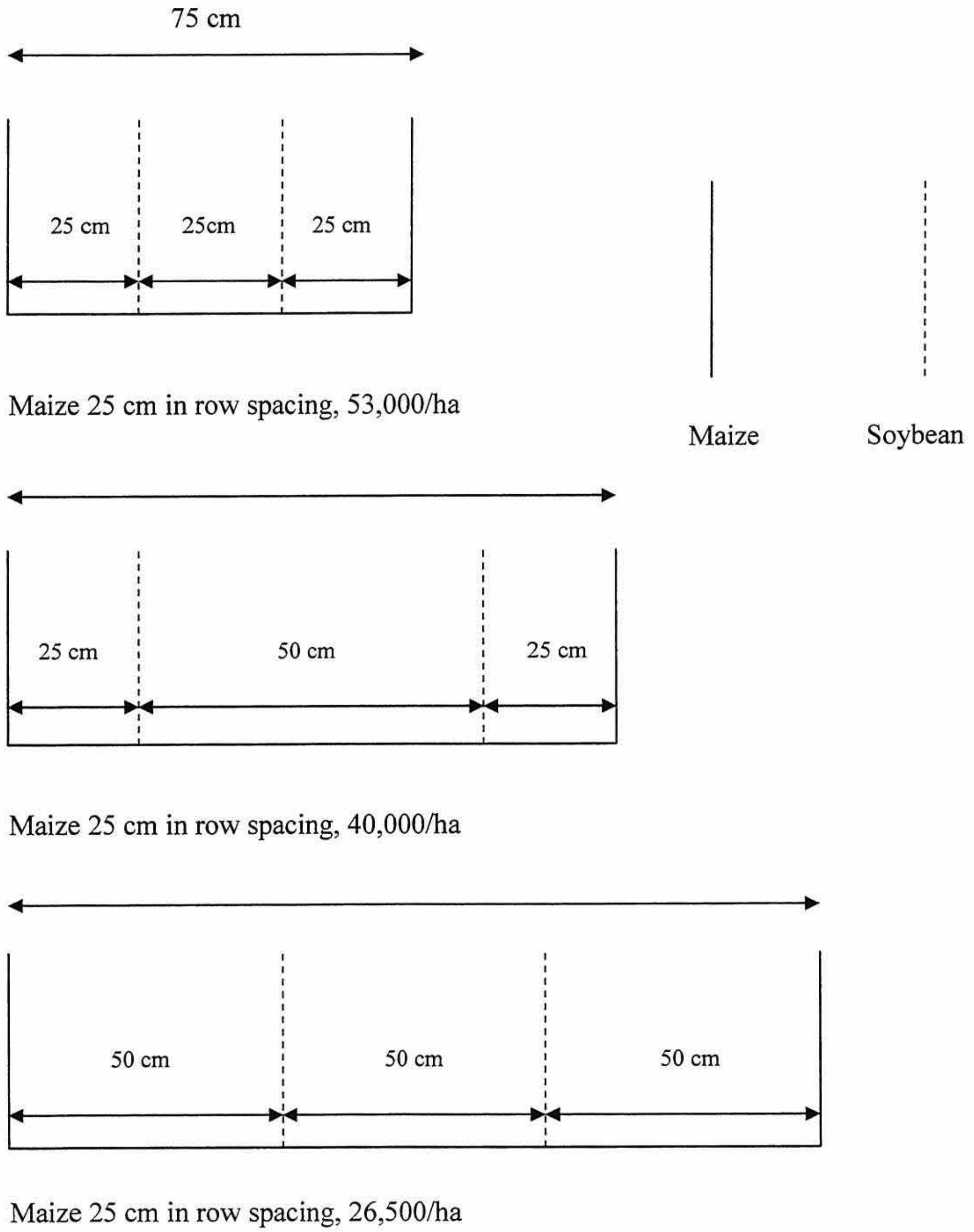
Treatments	Maize			Soybean		
	population	Between row spacing	Within row spacing	populatio n	Betwee n row spacing	Within row spacing
1. D1S1	26,500	150	25	100,000	25	13.2
2. D1S2	26,500	150	25	100,000	25	8.8
3. D1S3	26,500	150	25	100,000	25	6.6
4. D2S1	40,000	100	25	150,000	50	20
5. D2S2	40,000	100	25	150,000	50	13.2
6. D2S3	40,000	100	25	150,000	50	10
7. D3S1	53,000	75	25	200,000	50	26
8 D3S2	53,000	75	25	200,000	50	17.6
9 D3S3	53,000	75	25	200,000	50	13.2
10 Sole maize		75	25			
11 Sole soybean				200,000	50	10

Table 4.2 Characteristics of maize and soybean varieties.

Characters	Maize	Soybean
Variety	Mankamna-1	CN 60
Plant height (cm)	190-215	96
Days to 50% flowering/silking	68-70	60
Parentage	Local x exotic	Exotic
Source	CIMMYT, Mexico	AVRDC Taiwan
Potential grain yield (t/ha)	3.4 to 4.5	1.5 to 2.5
Maturity (Days)	135	126
Grain colour	White	White
Pods/ plant		39
100 seed weight (g)		21.4
Year recommended	1988	
Locations	Mid hills	Mid to high hills

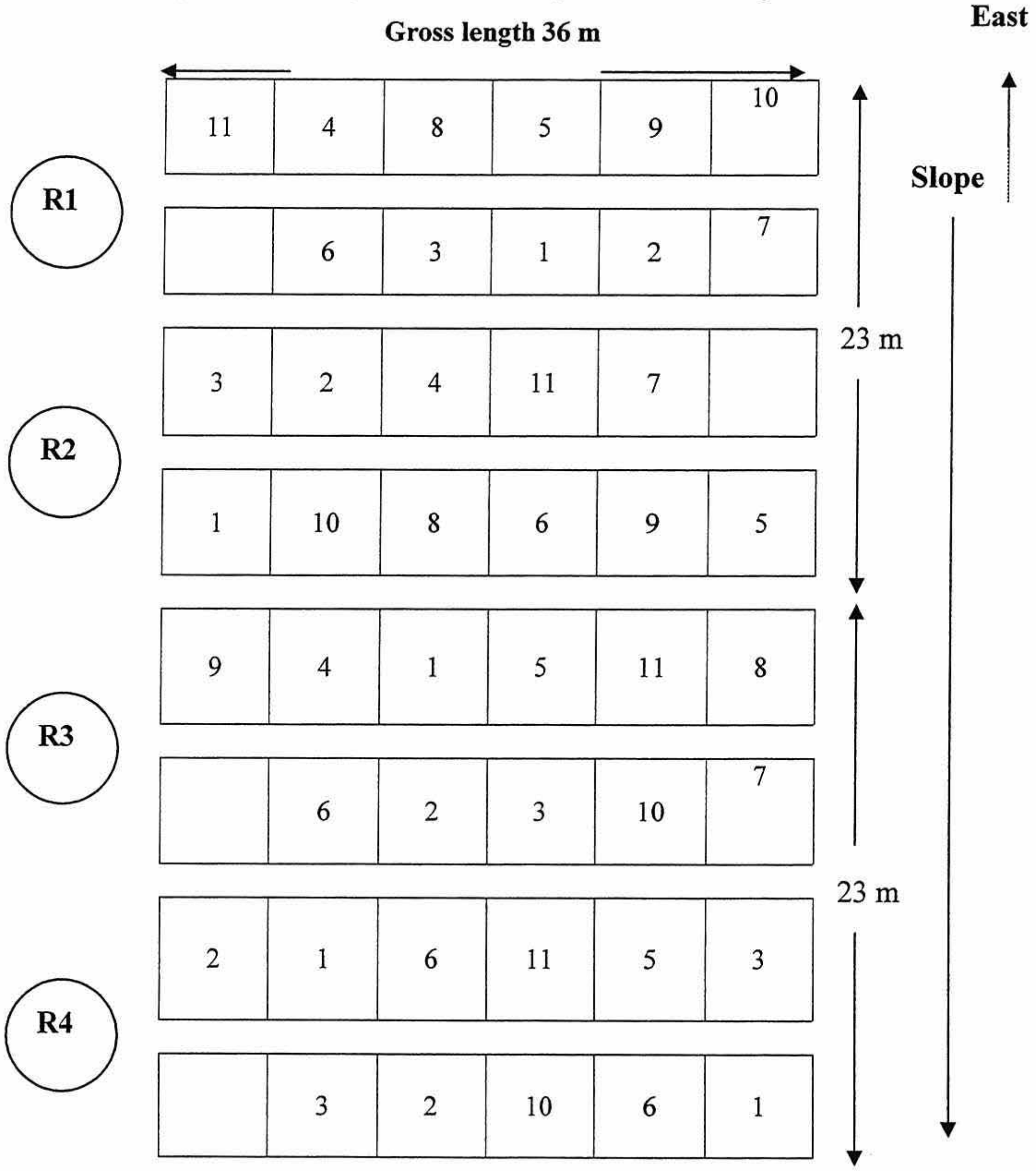
Adopted from Anonymous, (1997) for maize and Anonymous, (2000a) for soybean.
Note: Soybean variety CN 60, tested at Khumaltar under maize, mid hill of Nepal.

Figure 4.1a. Diagrammatic presentation of plant configurations. Experiment 1, 2001.



Soybean populations = 100, 150 and 200 x 10^3 plants ha^{-1}.

Figure 4.1b. Layout for field experiment during 2001



Treatments

Factor A: Maize Density

1. D1 – 26,500/ha
2. D2 – 40,000/ha
3. D3 – 53,000/ha

Factor B: Soybean Density

1. S1 – 100,000/ha
2. S2 – 150,000/ha
3. S3 – 200,000/ha

Treatment combinations

1. D1S1
2. D1S2
3. D1S3
4. D2S1
5. D2S2
6. D2S3
7. D3S1
8. D3S2
9. D3S3
10. Sole maize
11. Sole soybean

Experimental Design

The experiment was laid out in a factorial randomised complete block (RCB) design with four replications (Figure 4.1b). The gross and net plot sizes were 6 x 5 m and 3 x 3 m respectively. One metre spacing was left between each two blocks and there was no space between plots.

Crop establishment

The experimental area was ploughed with a bullock-drawn wooden plough after rainfall when sufficient moisture was present in the soil. The seedbed was prepared by removing weeds and breaking clods inside the experimental areas. The experiment was conducted in two adjacent farmers' fields to accommodate four replications, having two replications in each farm. Finally, plots were demarcated. Maize was sown on 21 April 2001. For sowing maize, furrows were opened at specified row spacing in each plot. Fertilisers were placed in the furrows at the rate of 40:40:40 $N:P_2O_5$ and K_2O kg per hectare as basal applications in the form of urea, diammonium phosphate and muriate of potash respectively. Furadan granules were applied in furrows at the rate of 10 kg/ha to control soil insects. After applying fertilisers, it was mixed into the soils by stirring with wooden sticks in the furrow to avoid direct contact of seed with fertilisers. Three seed were sown at each position to ensure establishment and finally furrows were covered with pulverised soil.

Soybean was sown on 1 May 2001 after additional rainfall, which provided sufficient moisture in the soil for germination of seed. Two shallow furrows were opened between two maize rows leaving 25 cm from the maize row in the case of 75 cm and 100 cm row spacing and 50 cm in the case of 150 cm spacing of maize. Two seeds of soybean were sown at each hill at the specified distance. Finally furrows were covered with soil.

Maize plants per position were thinned from three to two plants/position within 10 days of germination. Finally they were reduced to one plant per position after 30 DAS. Similarly, excess soybean plants were removed from each plot. Vacant spaces were gap filled by transplanting soybean seedlings wherever necessary to maintain the required density. The first weeding was done after 28-36 DAS, manually. Maize was topdressed after 46 DAS with urea at the rate 40 kg N per ha. A shallow furrow was opened besides each maize row and urea was dibbled into the furrow uniformly and was covered with soil. A second weeding was completed after a one month interval. There were strong winds on 6 and 10 July, which caused lodging of some maize plants. Earthing up at the base of maize plants lifted up some of the maize plants. Maize and soybean were harvested on 24 August and 18 September respectively. A diary of operations for this experiment is presented in Table 4.3.

Table 4.3. Diary of operations for intercropping experiment conducted during 2001 summer season.

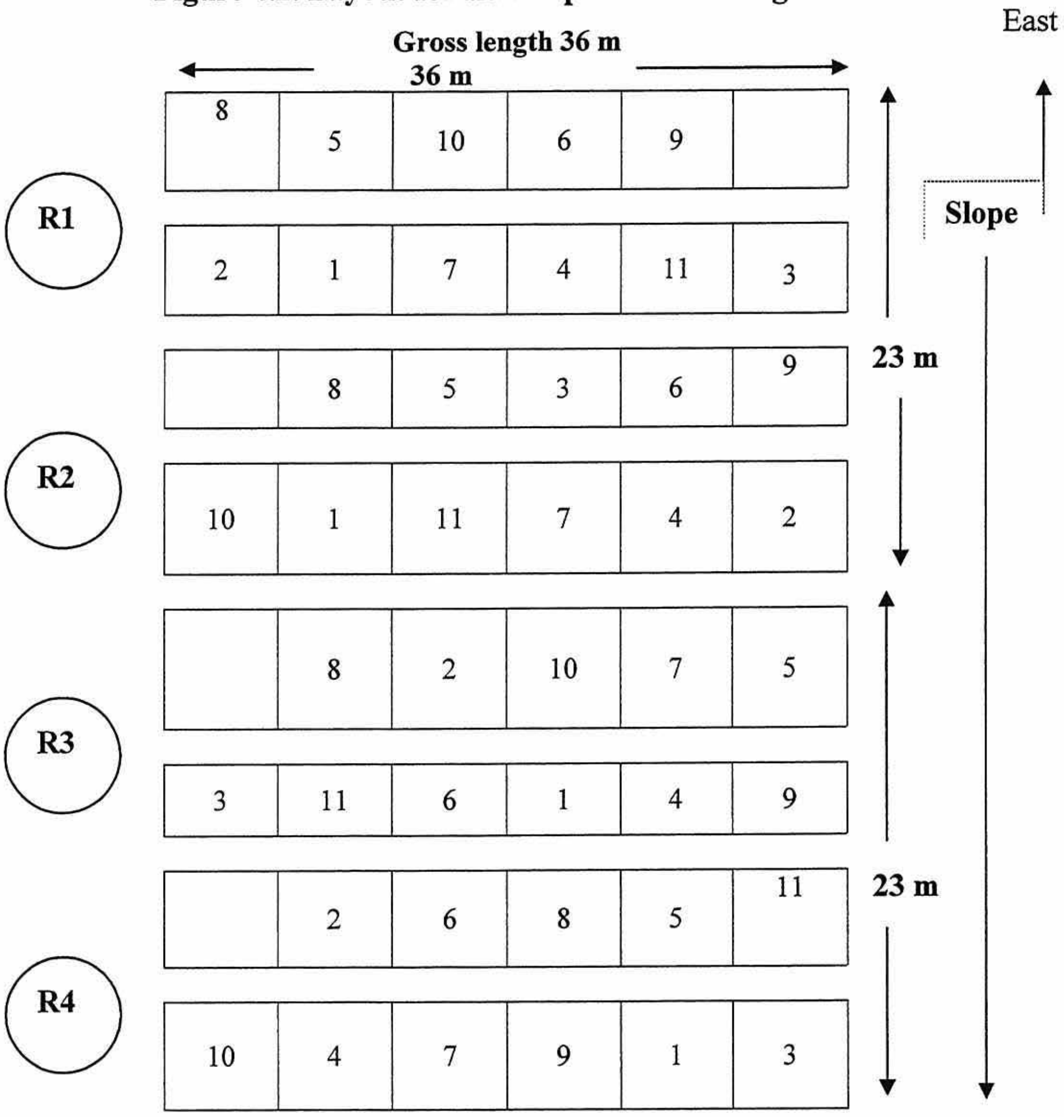
Date	Activities
16.04.01	Demarcation of plots and collection of soil samples
18.04.01	Ploughing of land by bullock, clod breaking and levelling of land
20-21.04.01	Final lay out of experiment, planting of maize
01.05.01	Planting of soybean
11.05.01	Gap filling of soybean
20.05.01	Thinning of maize
03.06.01	First sample collection of maize plants for LAI, plant height and dry wt. measurement. Subsequent sampling at two week intervals
06.06.01	Topdressing of maize with urea
16.06.01	First PAR measurement. Subsequent measurements at two weeks intervals
17.06.01	First sample collection of soybean plants for LAI, plant height dry wt measurement. Subsequent sampling at two week interval
24.06.01	Tassel initiation in maize started
27.06.01	Silk initiation in maize started
29.06.01	Flowering in soybean started
6-10.07.01	Strong wind causing some lodging of plants
24-25.08.01	Harvesting of maize completed
18.09.01	Harvesting of soybean completed

Intercropping experiment in 2002

A modification to factor B (soybean density) was made during 2002 season on the basis of results obtained from the experiment conducted during 2001. All tested densities gave similar yield. Therefore, lower density of 50 x 10^3 included for intercropping instead of highest recommended density of 200 x 10^3 for sole crop. and treatment details are given below. The layout of the experiment is given in Fig. 4.2.

Soybean seed was planted at the specified density in single row between two maize rows planted at 75 cm row spacing (D3) and double rows, planted at 100 and 150 cm row spacing (D1 and D2). All cultural operations and observations were followed as for the previous year mentioned. Maize and soybean were planted on 29 April and 2 May, 2002, respectively. Harvesting of maize and soybean was completed on 2 and 22-23 September, 2002, respectively. A diary of operations for this experiment is presented in Table 4.4.

Figure 4.2. Layout for field experiment during 2002



Plot size of 5 x 6 m

Treatments
Factor A: Maize Density

1. D1 – 26500/ha
2. D2 – 40,000/ha
3. D3 – 53,000/ha

Factor B: Soybean Density

1. S1 – 50,000/ha
2. S2 – 100,000/ha
3. S3 – 150,000/ha

Treatment combinations
1. D1S1
2. D1S2
3. D1S3
4. D2S1
5. D2S2
6. D2S3
7. D3S1
8. D3S2
9. D3S3
10. Sole maize
11. Sole soybean

Plate showing planting geometry of maize and soybean ,wider (above) and standard spacing (below) of maize, 2002.

Table 4.4 Diary of operations for experiment conducted during 2002 summer season.

Date	Activities
18.04.02	Demarcation of plots and collection of soil samples
20.04.02	Ploughing of land by bullock, clod breaking and levelling of land
29-30.04.02	Final lay out and planting of maize
02.05.02	Planting of soybean
17.05.02	Partial thinning of maize (2 plants/position)
22-24.05.02	First weeding of maize
26.05.02	Final thinning of maize
01.06.02	Thinning of soybean
02.06.02	First sample collection of maize plants for LAI, plant height and dry wt. measurement. Subsequent sampling at two week intervals
05.06.02	Topdressing of maize with urea
16.06.02	First sample collection of soybean plants for LAI, plant height dry wt measurement. Subsequent sampling at two week intervals
30.06.02	Tassel initiation in maize started
05.07.02	Silk initiation in maize started
05.07.02	Flowering in soybean started
15.07.02	Nodulation count in sampled soybean plants
18.08.02	PAR measurement. Supervision of experiment by Dr. R.M. Brook.
02.09.02	Harvesting of maize completed
22-23.09.01	Harvesting of soybean completed

4.3.1 Observations

4.3.3.1 Non-destructive measurements of growth

Emergence of maize and soybean were recorded 10 days after sowing. Days to 75% tasseling and 50% silking were recorded by visual estimation. The measurement of incident and intercepted photosynthetically active radiation (PAR) was conducted from 16 June to 12 August, 2001 at two week intervals. A Decagon Sunfleck Ceptometer (Decagon Devices, Pullman, WA, USA) was used to measure PAR within one hour either side of midday above both canopies, the top of the maize and the soybeans canopy and at the base of both canopies by placing the 80 cm probe across the row at 5-

6 randomly selected locations within each plot. Mean value for each plot was then used to calculate the percentage of PAR intercepted by the plant canopy of each treatment as follows (Carr, *et al.,* 1995):

$$\%PAR_i = (1 - PAR_b/PAR_a) \times 100$$

where the subscript $_i$ denotes intercepted PAR, and subscripts $_a$ and $_b$ denotes PAR above and below the plant canopy, respectively. In 2002, data on PAR was not collected because the Ceptometer did not function properly. PAR was recorded on only one occasion, on 18 August 2002, when single cell PAR sensors (Skye Instruments, Liandrinded Wells) became available. As it was close to maturity, recordings were not repeated

4.3.3.2 Destructive (classical) growth analyses

In 2001, samples for destructive growth analysis were taken at two weeks intervals from 3 June to 15 July for maize and from 17 June to 29 July for soybean (Table 3.3). In 2002, dates were 2 June to 14 July for maize and 16 June to 28 July for soybean, respectively. Three adjacent maize plants were selected from one end of a row, leaving one border plant on either side, at each sampling period. These sampled plants were used to measure plant height, leaf area and for dry matter determination. Plant height was measured from ground level to the tip of longest leaf before tassel initiation and up to the tip of the longest tassel branch after tasseling. Similarly, five plants of soybean were selected from the central row of one end of each plot, leaving two border plants between sample zones at each sampling period. Plant height of soybean was measured from base of the plant to the tip of the last fully expanded leaf cluster (Redfearn *et al.*, 1999). Plants were cut at ground surface.

Two leaves of maize from each sampled plant were randomly selected from different positions and separated from the main stem. Selected leaves were cut into small pieces and kept in a cool box by wrapping in labelled polythene bags. Remaining green leaves were separated and cut into small pieces and mixed together thoroughly and fresh weight was recorded. Leaves which had become more than 50% yellow were omitted from the green leaves sample but used for dry weight determination with the stem. A sub sample of 200 g green leaves was taken from each plot and put in paper bags to determine dry weight. Similarly, stems of maize were cut into small pieces and fresh weight was recorded. A sub sample of 500 g was taken from each plot to determine dry weight of each sub sample. All samples were taken to the laboratory at ARS Lumle to measure leaf area of sample leaves and dry weight of the rest of the leaves and stems. Leaf area of sample leaves was measured with a leaf area meter (Delta-T Devices, Burwell, Cambridge) after calibration with templates of known areas. After measuring leaf area, sample leaves were kept in paper bags and oven dried at 70^0C for 3 to 4 days to constant weight. Dry matter of the rest of the leaves was computed from the fresh weight and finally total dry weight of leaves was calculated. Leaf area of sample plants was computed as follows:

$$\text{LA of sample plants} = \frac{\text{Leaf area of sample leaves}}{\text{Dry wt. of sample leaves}} \text{X Total dry wt of leaves}$$

Similarly dry weight of stems was computed from fresh weight and total dry wt of sample plants were calculated by adding dry weight of leaves and stem together. Finally dry weight per plant and m^2 were calculated for each treatment.

In soybean, three leaves from each sampled five plants were selected randomly at different position and separated from the main stem. All leaflets of the sample leaves were separated from the petiole and kept together by overlapping each other in labelled polythene bags. All samples leaves were immediately put in a cool box to avoid wilting. Remaining green leaves were separated from stem and petiole and put in paper bags to determine dry weight. Similarly, stem and petiole were cut into small pieces and put in paper bags to determine dry weight at ARS, Lumle. The leaf area of sample leaves and dry weight of the rest of the leaves and stems were taken as in the case of maize. Finally, total leaf area and total dry weight for sample plants were calculated. This process was repeated at each sampling period for both maize and soybean.

4.3.2 Statistical analysis

The data were entered into a spreadsheet (Excel 97, Microsoft Corp.). This was used for calculating plot means and different growth and yield parameters, from which graphs and tables were created. The data were exported to Genstat 6.0 and analysed as unbalanced analyses of variance as a factorial RCB design with additional control, including sole crop of maize or soybean or both as required. Minitab (v 13.1) was also used in the case of balanced factorial data.

4.3.3 Crop Growth Analysis

The means obtained were used to calculate growth analysis parameters as follows (Hunt, 1990)

4.3.3.1 Leaf Area Index (LAI)

Leaf Area Index is a ratio of green leaf area to the ground area that plants occupy. It estimates leafiness of the plant canopy. However, leaves never form a complete canopy because they are displayed at various angles. It was calculated by dividing leaf area with total area of land occupied by plants.

$$\mathrm{LAI} = \frac{\mathrm{LA}}{\mathrm{A}} \text{ ....} \textit{Equation } 11$$

where LA is the total leaf area of the sample plants and A is the land area occupied by sampled plants.

4.3.3.2 Crop Growth Rate

The crop growth rate of a unit area of a crop is defined as the increase of plant dry matter per unit time, and is usually measured in units of g m^{-2} d^{-1} or $week^{-1}$.

CGR was calculated by the formula proposed by Hunt (1978)

$$\mathrm{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \text{...........} \textit{Equation } 12$$

where W_2 and W_1 are dry wt per m^2 at first and second sampling time, t_1 and t_2.

4.3.3.3 Net Assimilation Rate (NAR)

The net assimilation rate of a plant over period of time is defined as the increase of plant dry weight per unit of assimilatory one-sided green surface area per unit time. It is an estimate of net photosynthesis per unit of leaf.

NAR was calculated by the formula proposed by Hunt (1978)

$$\mathrm{NAR} = \frac{\mathrm{W_2 - W_1}}{\mathrm{t_2 - t_1}} \cdot \frac{\log_e \mathrm{LA_2} - \log_e \mathrm{LA_1}}{LA_2 - LA_1} \text{.........} \textit{Equation } 13$$

4.3.3.4 Leaf Area Ratio (LAR)

Leaf area ratio is a morphological index of the leafiness of the plant and is an estimate of the ratio of the potentially photosynthesising and potentially respiring components of plant. It is calculated as the ratio of leaf area per plant and dry weight per plant and the unit of measurement is m^2g^{-1} or mm^2 mg^{-1}

LAR was calculated by formula proposed by Hunt (1992)

$$LAR = (\frac{LA_1}{W_1} + \frac{LA_2}{W_2})/2 \text{ ....} \textit{Equation } 14$$

4.3.3.5 Leaf Area Duration (LAD)

Leaf area duration of a crop an integral of leaf area index in relation to time period and expressed in number of days. It is a summation of all LAD computed during successive sampling period starting from germination to first sampling to last sampling to harvest, assuming LAI zero at germination and harvest time. LAD for particular period is computed as follows:

$$LAD = (\frac{LAI_1 + LAI_2}{t_2 - t_1})/2 \text{..........} \textit{Equation } 15$$

where LAI_1 and LAI_2 are leaf area index measured during t_1 and t_2 period i.e days after germination

4.3.4 Yield and yield components

Maize and soybean were harvested on 24 August and 18 September in 2001 and 2 and 22 September in 2002, respectively. At maturity, a net plot area of 3 x 3 m in each plot was demarcated on the central row leaving a border row from each side. To obtain required net plot size, two, three and four central rows were selected from 150, 100 and 75-cm row spacing plots respectively. Two border maize plants were discarded from each side. Four plants of maize were selected randomly from the net plot area and cut at ground surface to estimate yield components and dry matter production. The rest of the plants were cut at ground level. Cobs were separated and dehusked. The total number of plants harvested, number of cobs and field weight of cobs were recorded. Grain moisture content was taken by moisture meter immediately in the field. Fresh weight of straw was recorded. Agronomic grain yield per plot was adjusted to 14% moisture and 80% grain recovery assumed.

Height of four sampled plants was measured. Cobs were separated and dehusked. Grains were separated from cobs and weight of grain and their number were measured and counted for each plot. 1000 grains were separated from each plot and their weight recorded. These sample grains were oven dried at 70^0C to determine dry weight and finally dry weight of grains per plot was computed. Fresh weight of a sample of biomass was taken and cut into small pieces and to take a sub-sample taken for oven drying. After taking records of dry weight of grains and straw, these samples were used to analyse plant nutrients in soil laboratory. The N, P and K content in the plant samples were determined by weight digestion and colorimetric methods.

For harvest of soybean, the same net plot size of 3 x 3 m was selected as in maize from the centre of each plot. To do this, 50-cm area was discarded as border from the side where destructive sample was not taken. The number of soybean rows was double the maize rows. Plots were demarcated with thin rope to avoid confusion during harvest. A total of eight plants were randomly selected from net plot area for measuring yield components.

The rest of the plants were counted and harvested by cutting with a sickle near the ground surface. Pods were separated from stems and dried in the sun for 3 to 4 days. Fresh weight of biomass was recorded. After sun drying of pods, grains were separated from pericarps and weight of pericarps was measured, then oven dried and added to the dry weight of total shoot biomass. Heights of these sampled plants were measured. The pods were separated from sample plants and counted separately. Ten pods were sampled randomly and seeds per pod were recorded. Pods of sampled plants were sun dried for 3 to 4 days to separate grains from pericarps. After separating grains from pericarp, the weight of pericarps was taken and dried in an oven. Grains were added to grains of the harvested plot and total grain yield per plot was recorded. The moisture of grains was measured with a moisture meter. Agronomic grain yield per plot was adjusted to 12% moisture. 500 grains were counted from each plot and yield weight recorded to determine 100 seed wt. These grains were oven dried to determine dry matter of grains. Stem and remaining leaves of sampled plants were cut into small pieces and put in a paper bag to determine dry weight. After taking records of dry weight of straw and pericarps, these samples were mixed together with respective samples for each plot and were used for plant nutrient analysis. Sampled grains were also analysed for plant nutrients.

4.3.4.1 Intercropping Advantage

Many authors have proposed different methods of assessing the advantage of intercropping when two or more crops are grown simultaneously on the same land at the same time. Land Equivalent Ratio, proposed by Willey (1979), is widely accepted and is used to measure the efficiency of use of land. It is defined as the relative land area under sole crops that is required to produce the yield achieved in intercropping. LER is calculated as follow

$$LER = L_a + L_b = \frac{Y_a}{S_a} + \frac{Y_b}{S_b} ....Equation\ 16$$

where La and Lb are the partial LERs for the individual crops and Ya and Yb are the respective yield of species A and B in intercropping and Sa and Sb are their respective yield as sole crops.

4.3.4.2 Monetary advantage

LER gives an assessment of the biological efficiency of intercropping system, but it ignores the importance of the value of crops studied. Farmers are more interested in economic evaluation. To overcome this criticism, the calculation of monetary advantage was proposed by Willey (1979). It provides an economic term for increased value per unit area of land. It was calculated as follows:

$$MA = \text{Value of combined intercrop yield X} \frac{LER - 1}{LER} ....Equation\ 17$$

4.3.5 Meteorological data

Weekly meteorological data during the growing season for 2001 is shown in figure 3.3. Total rainfall during the cropping season was 1151.6 mm with the highest precipitation during the month of July. Maximum and minimum temperatures varied from 17^0C to 31.5^0C and 14^0C to 22.5^0C, respectively.

Weekly meteorological data recorded during the 2002 growing season is shown in Figure 3.4. Total rainfall during cropping season was 1010.6 mm with highest precipitation during the month of July. Both crops received only 863 mm rainfall from sowing to harvesting period, and distribution of rains was not uniform. Significant quantities of rain fell on just two days, 2 July (116 mm) and 25 September (125 mm). Maximum and minimum temperature varied from 17^0C to 31.0^0C and 14^0C to 22.5^0C, respectively.

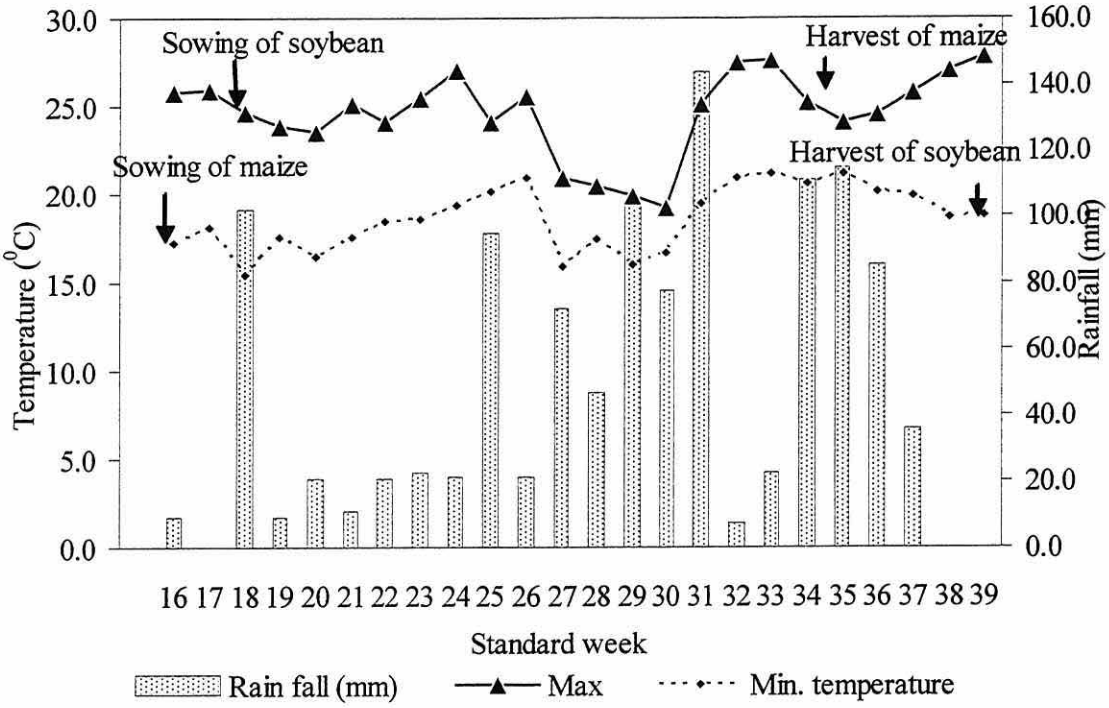


Figure 4.3. Weekly mean temperature and rainfall during cropping period from 16 April to 30 September, 2001 at Deorali

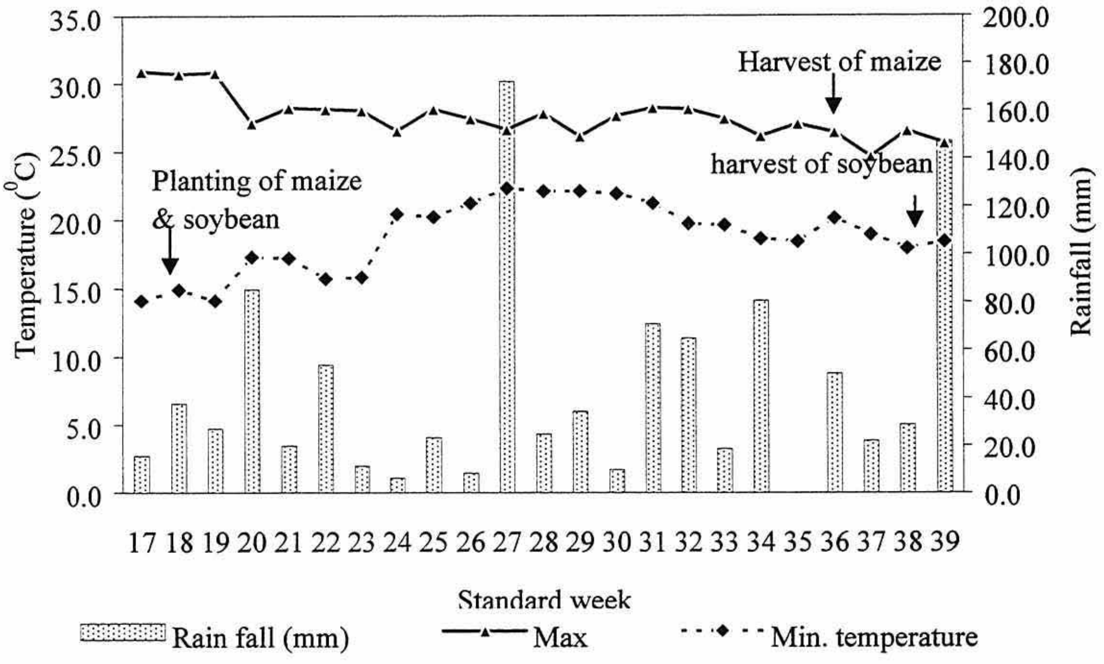


Figure 4.4. Weekly mean temperature and rainfall during cropping period from 23 April to 30 September, 2002 at Deorali

4.4 Results: Maize

4.4.1 Chemical properties of soil

The results of soil analysis taken before and after harvest of crop during 2001 and 2002 are presented in Appendix 4.1 and 4.2, respectively. In both years, pH, organic matter content (%), total nitrogen (%), available phosphorus and exchangeable potassium content of plots receiving different treatments were found to be not significantly different when soil samples were tested before and after crop harvest. pH value for both periods ranged from 5.8 to 5.9 and 5.7 to 5.9 respectively. Similarly, organic matter in the soil ranged from 1.23 % to 2.12 % and from 1.07 % to 1.91 % at beginning and after crop harvest, respectively. Total nitrogen varied from 0.07 % to 0.12 % and 0.06 % to 0.29 % during both periods. The available phosphorus ranged from 32.7 to 45.3 mg/g and 27.2 to 44.7 mg/g of soil during both periods. Similarly, exchangeable K varied from 0.27 to 0.44 me/100 g and 0.28 to 0.46 me/100 g of soil at beginning and after crop harvest, respectively.

In 2002, the range of soil pH was slight higher at beginning (5.7 to 5.9) than after crop harvest (5.4 to 5.6) indicating change in soil reaction from medium to strongly acidic (Brady, 1992). O.M content in the soil at beginning and after crop harvest was 1.65 % and 1.61 % with range of 1.52 % to 1.80 % and 1.55 % to 1.92 %, respectively. Total nitrogen for both periods varied from 0.09 % to 0.14 % and 0.12 % to 0.40 % respectively. The available phosphorus ranged from 26 to 36 and from 18 to 24 mg/g at beginning and after crop harvest, respectively. Similarly, exchangeable potassium for both periods varied from 0.36 to 0.49 and 0.30 to 0.43 me/100 g, respectively. It indicated that soils were medium in available P and potassium but low in organic matter content in both years (Landon, 1992).

4.4.2 Growth measurements of maize

Full tables of means, with significant effects are presented as appendices. In the results section, graphs are used only to illustrate particular significant treatment effects.

4.4.2.1 Plant height

In both seasons, plant height increased up to tasseling. However, by final harvest height had decreased due to drying and breakage of tassels after anthesis. There were no effects of any treatments on maize height (Appendix 4.3 and 4.4) apart from maize density at final harvest in 2001. This was probably due to variation in degree of tassel disintegration, as all values were noticeably smaller than their maxima at 85 DAS. There were no discernible differences in height between seasons.

4.4.2.2 Leaf area index (LAI)

Results of LAI are presented in tabular form in Appendix 4.5 and 4.6. Where there were significant effects over time or within particular harvest dates, they are presented as figures in the account which follows. The general trend was for LAI to increase as the season progressed. In 2001, it reached maximum at 71 DAS (Figure 4.5). Data are not presented for final harvest, as by then all leaves had senesced. In both seasons, LAI was ranked from lowest at 26.5 x 10^3 ha^{-1} population density, to greatest at 53 x 10^3 plants ha^{-1} (Figure 4.5 and 4.7). These effects were significant at all sampling occasions (Appendices 4.5, 4.6).

In both seasons, presence of the soybean intercrop significantly reduced maize LAI on all sampling occasions, except for 35 DAS in 2002 (Figures 4.6, 4.9). In 2002, not only did presence of soybean intercrop reduce mean maize LAI, but at 35 DAS and 78

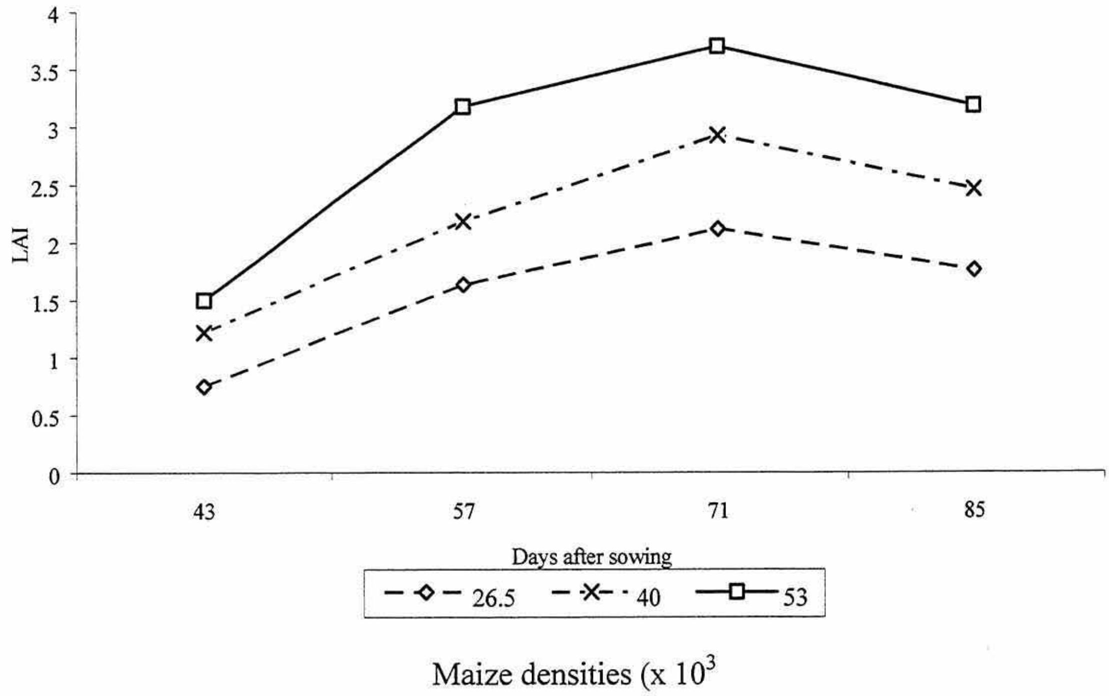


Figure 4.5. Effect of maize densities in intercrops on leaf area index (LAI) of maize measured over time in 2001 (Appendix 4.5)

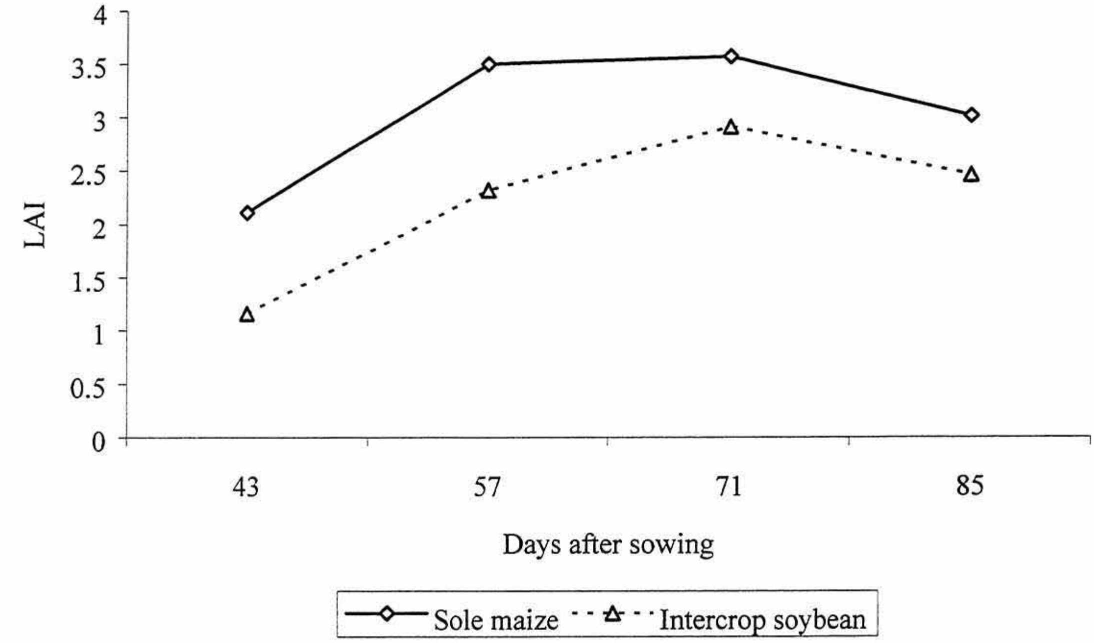
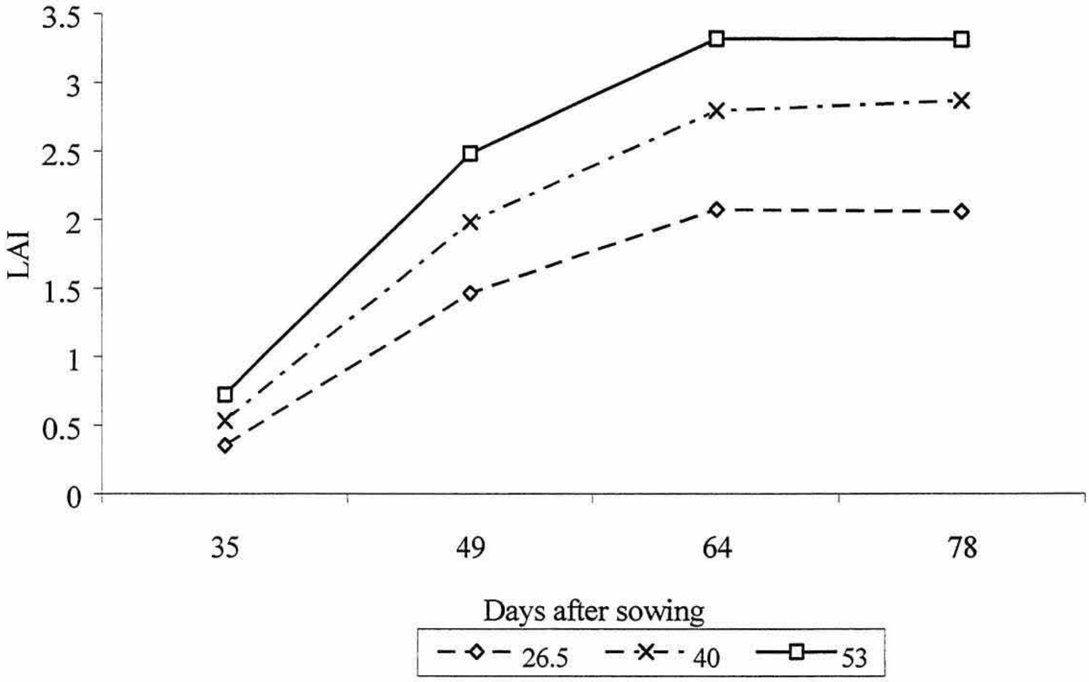


Figure 4.6. Means of LAI for sole and intercropped maize over time in 2001 (Appendix 4.5)



Maize densities (x 10^3)

Fig 4.7. Effect of maize densities in intercrops on LAI of maize measured over time during 2002 (Appendix 4.6)

DAS, effects of soybean population density were also evident (Appendix 4.6, Figure 4.8). Higher densities of soybean suppressed maize LAI more than the lowest densities. In 2002, at 78 DAS, there was also a significant interaction effect (Figure 4.10), with LAI of maize at 53 x 10^3 plant ha^{-1} being particularly suppressed at 100 x 10^3 plant ha^{-1} soybean population (Appendix 4.7).

4.4.2.3 Dry Matter

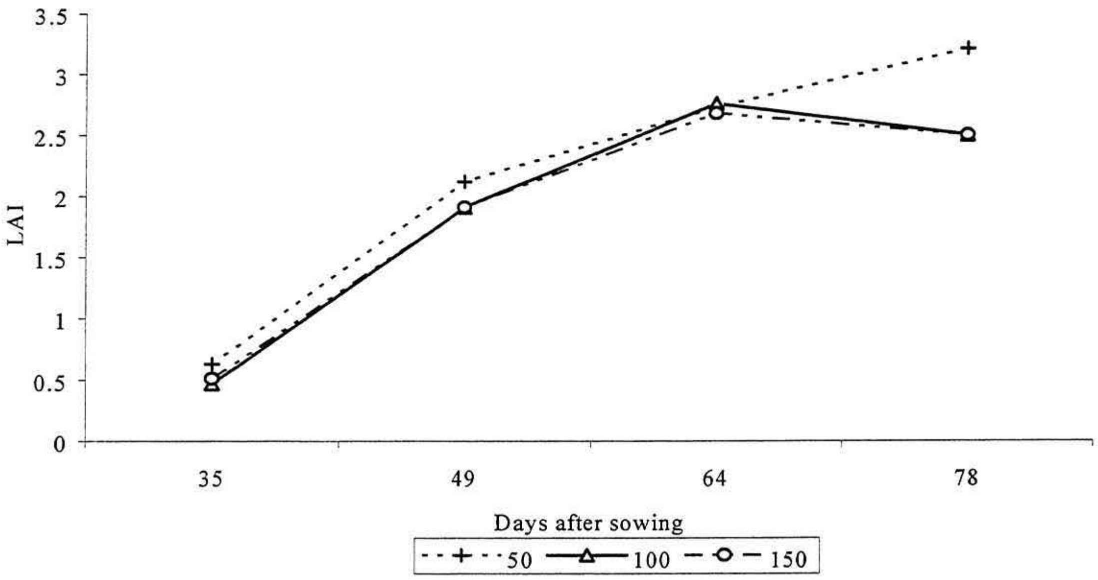
Trends in shoot dry matter of maize throughout the season are presented in Appendix 4.8 and Figure 4.11 for 2001 and Appendix 4.9 and Figure 4.13 for 2002. In both seasons, maize population density had a significant effect at all sampling dates, ranked from lowest to highest population density. In 2001, at the first three sampling occasions, sole maize had significantly higher dry matter than intercropped maize, although this difference was not apparent on the final two sampling dates (Figure 4.12). In 2002, there were also significant differences between sole and intercropped maize, but those effects were not consistent over time (Figure 4.15). Higher soybean density also significantly reduced maize dry matter in 2002 on two sampling occasions (Figure 4.14)

4.4.2.4 Crop Growth rate (CGR)

Data for crop growth rate are presented in Appendix 4.10 for 2001 and Appendix 4.11 for 2002. In both seasons, maize density had a significant effect on CGR of maize during the early growth period only, ranked lowest at 26.5 x 10^3 plants ha $^{-1}$ to highest at 53 x 10^3 plants ha^{-1} population density. These differences gradually narrowed and became insignificant as crop growth progressed towards maturity. In 2002, in contrast to sole maize, presence of soybean reduced CGR of maize during early growth period (35-49 DAS) only (Figure 4.16).

4.4.2.5 Net Assimilation Rate (NAR)

In 2001, there was no effect of any treatments on NAR of maize (Appendix 3.12). In 2002, maximum NAR was obtained with maize density 26.5 x10^3 plants ha^{-1} and declined as maize density increased from 26.5 to 53 x 10^3 plants per ha^{-1} during 49 to 64 DAS (Appendix 4.13). Figure 4.17 indicates that presence of soybean significantly increased net assimilation rate of maize compared to the sole crop during 49 to 64 DAS (late vegetative stage) but there was no obvious trend observed over the whole growing period.



Soybean densities (x 10^3)

Fig 4.8. Effect of soybean densities on LAI of maize measured over time during 2002 (Appendix 4.6)

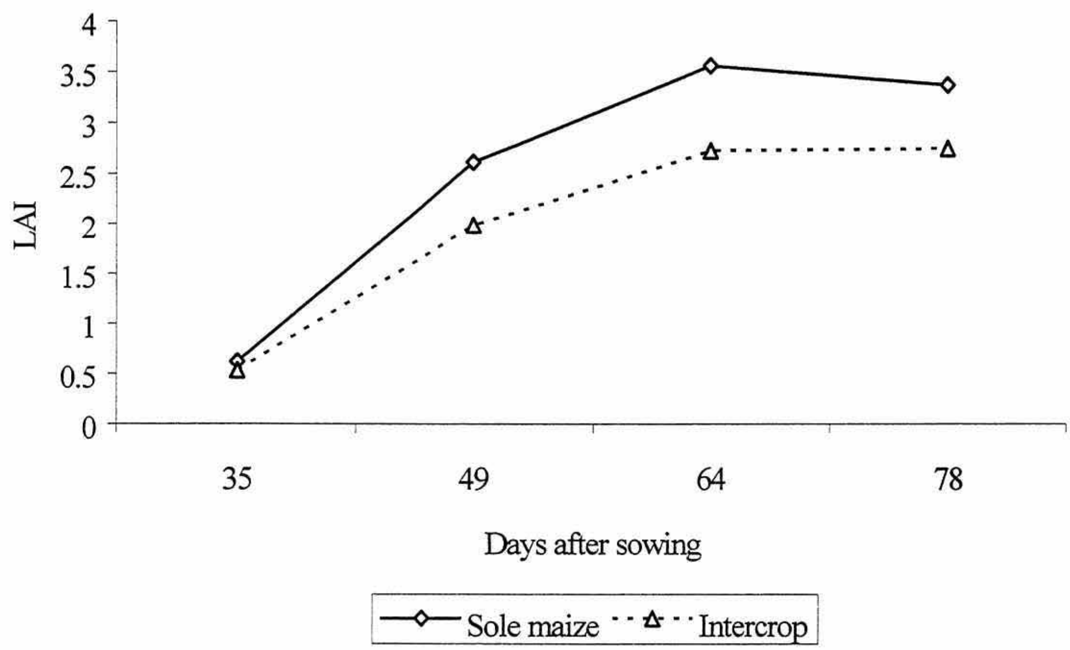


Figure 4.9. Means of LAI for sole and intercropped maize over time in 2002 (Appendix 4.6)

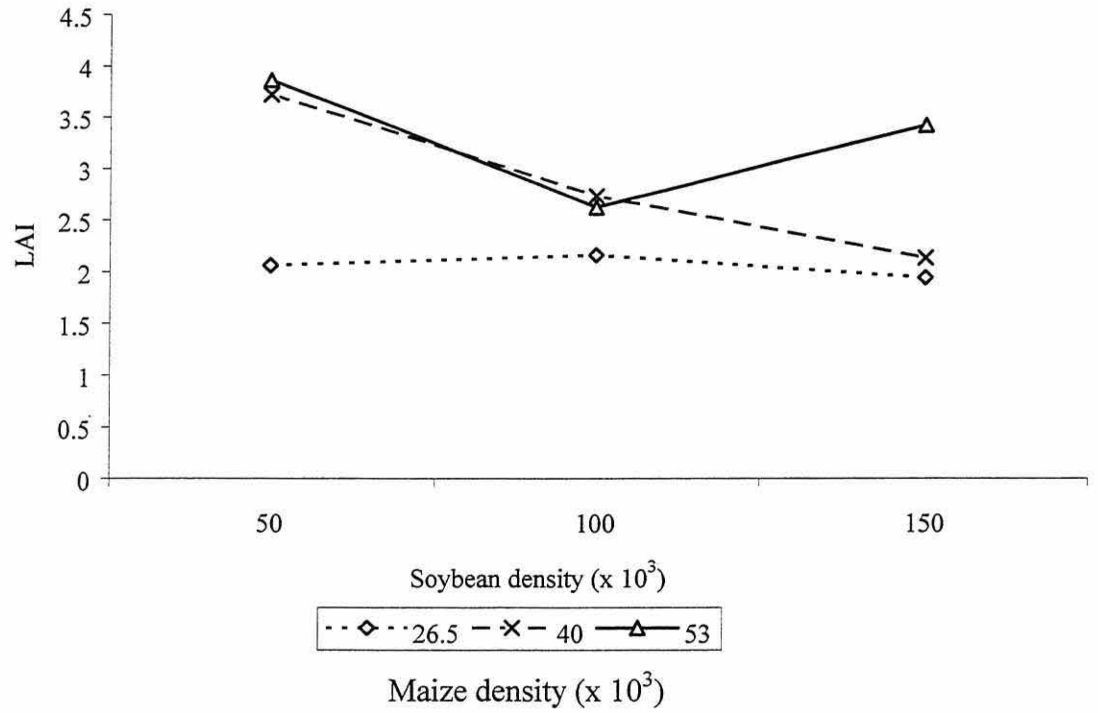


Figure 4.10. Effect of maize and soybean densities on LAI of maize measured at 78 DAS in 2002 (Appendix 4.7)

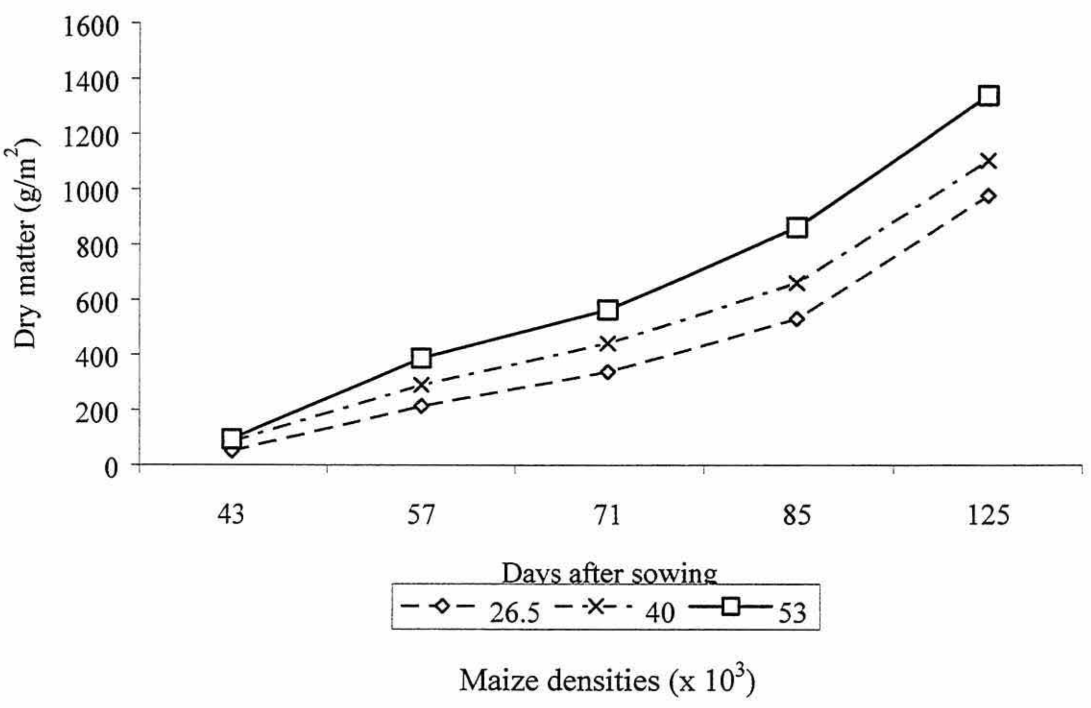


Figure 4.11. Effect of maize densities on dry matter (g/m^2) of maize measured over time in 2001 (Appendix 4.8)

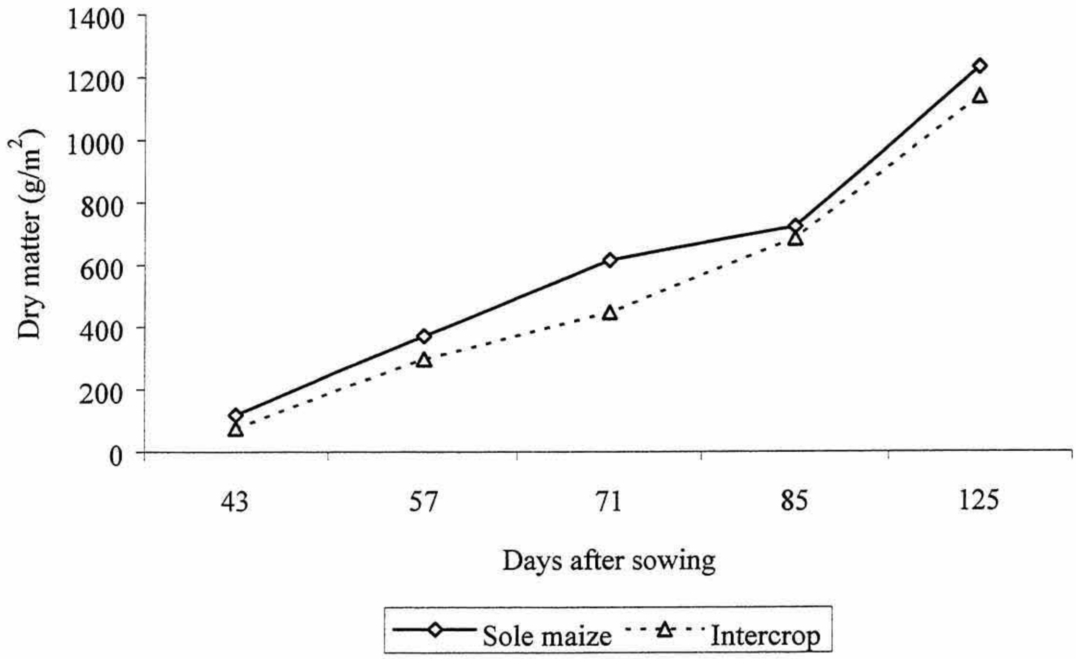


Figure 4.12. Effect of sole and intercrop on maize dry matter (g/m^2) measured over time in 2001(Appendix 4.8)

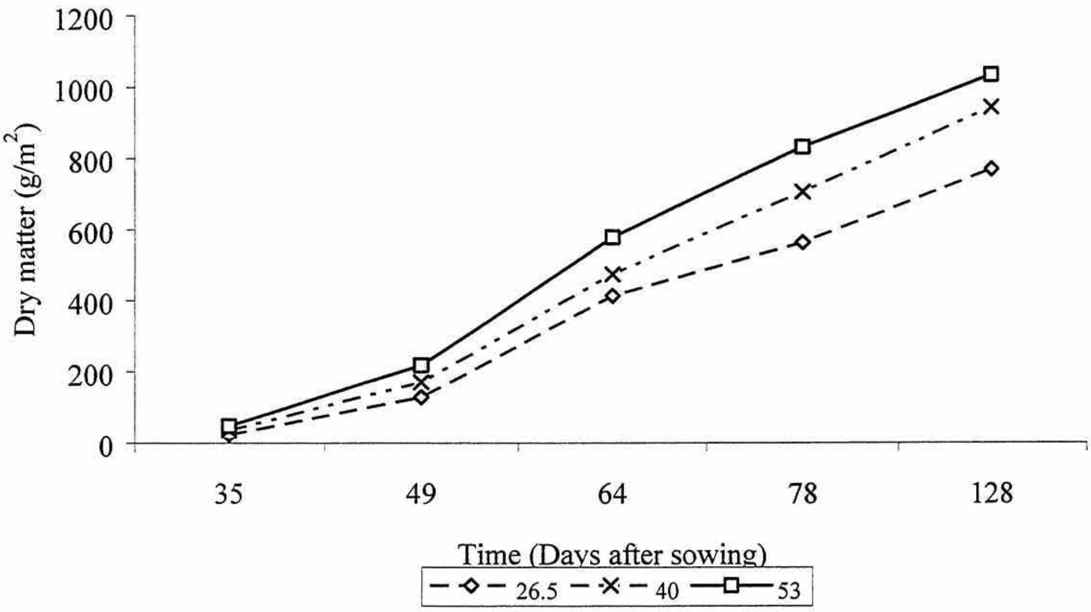


Figure 4.13. Effect of maize densities on dry matter (g/m^2) of maize measured over time during 2002 (Appendix 4.9)

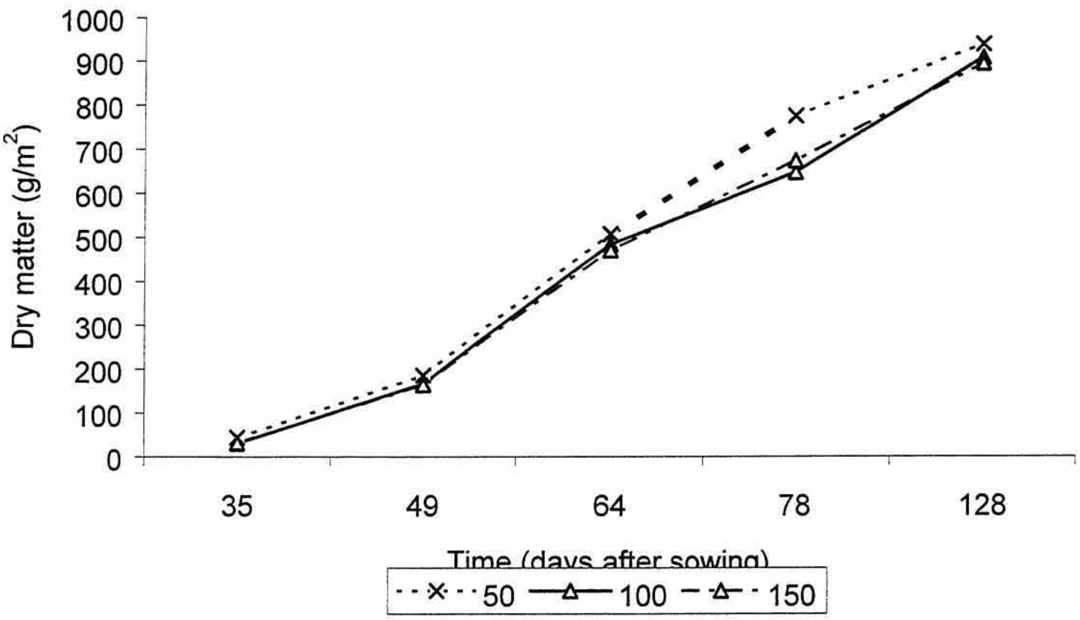


Figure 4.14. Effect of soybean densities on dry matter (g/m^2) of maize measured over time during 2002 (Appendix 4.9)

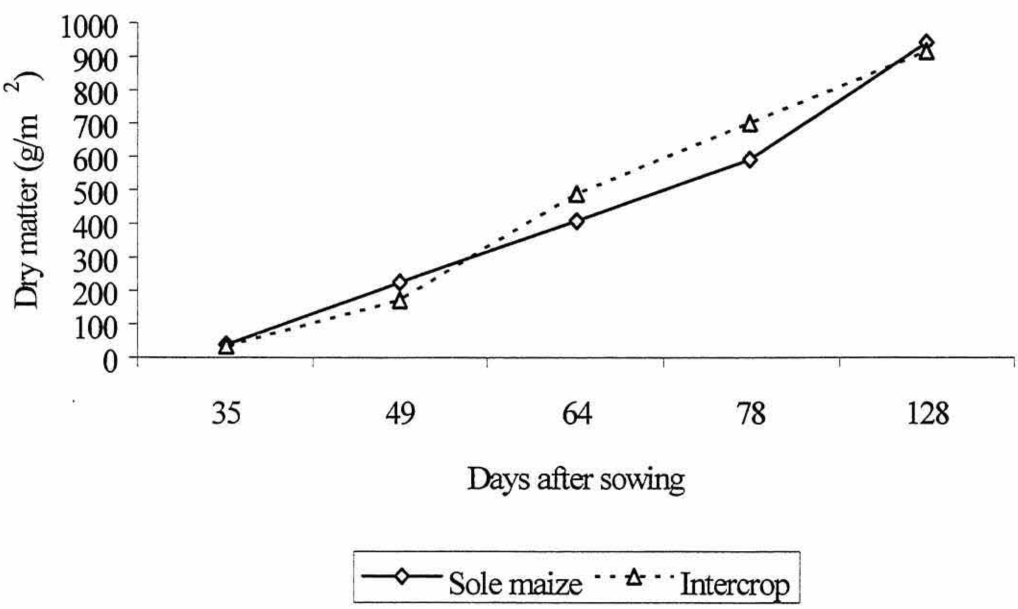


Figure 4.15. Effect of sole and intercrop maize on dry matter (g/m^2) measured over time during 2002 (Appendix 4.9)

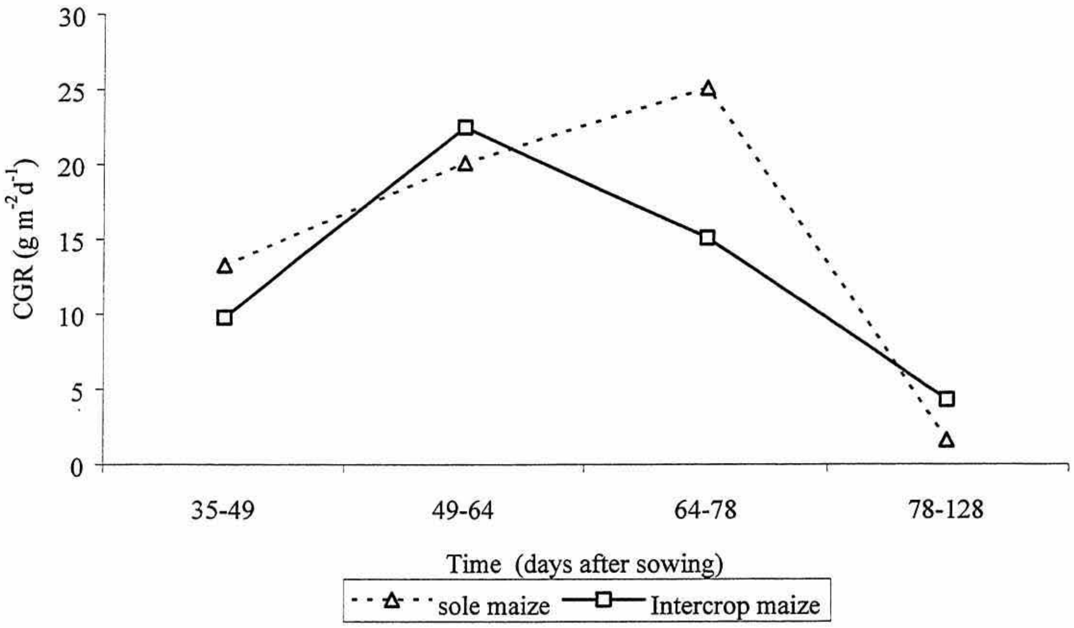


Figure 4.16. Mean of CGR (g $m^{-2}d^{-1}$) for sole and intercropped maize during different growth periods in 2002 (Appendix 4.11)

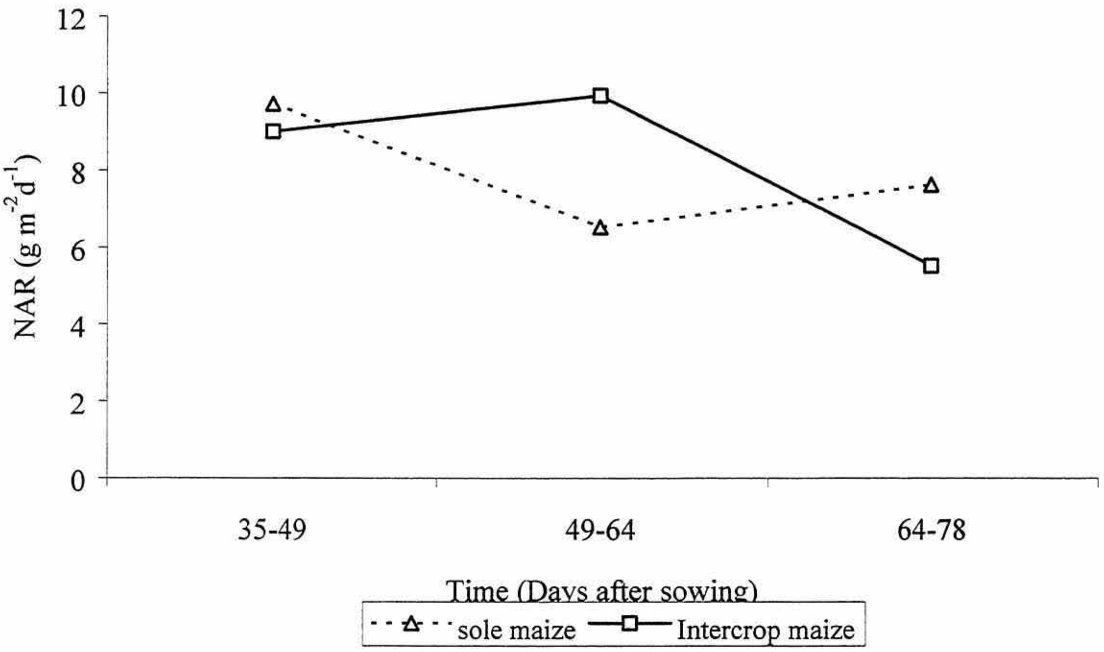


Figure 4.17. Mean of NAR (g $m^{-2}d^{-1}$) for sole and intercropped maize measured during different periods in 2002 (Appendix 4.13)

4.4.2.6 Leaf Area Ratio (LAR)

Results of LAR of maize are presented in Appendix 4.14 and 4.15 for 2001 and 2002, respectively. In both seasons, LAR in all treatments was higher at early growth stages and declined as the season progressed. In 2002, maize density of 26.5 x 10^3 plant ha^{-1} significantly reduced LAR of maize compared to 40 and 53 x 10^3 plants ha $^{-1}$ population density, but only during 64 to 78 DAS.

In both seasons, there was a significant effect of soybean grown under maize on LAR of maize but the magnitude of effect varied between seasons. Figure 3.18 indicated that inclusion of soybean reduced LAR during the 43 to 57 DAS period in 2001 whereas soybean gave consistently lower LAR throughout the whole growing period in 2002 (Figure 4.19) but the difference was not apparent during early growth period.

4.4.2.7 Leaf area duration (LAD)

In both seasons, maize density had a significant effect on LAD and was ranked greatest at standard maize density to lowest at 26.5 x 10^3 plants ha^{-1} (Table 4.5). In the first season, soybean density had no effect on LAD but it had a significant effect on LAD in the second season. Soybean density of 50 x 10^3 plants ha^{-1} significantly increased LAD of maize compared to 100 and 150 x 10^3 plants ha^{-1} but the difference between these latter two densities was not significant. There was a significant interaction effect (Figure 4.20), with LAD of maize at 53 x 10^3 plant ha^{-1} being reduced at soybean density of 100 x 10^3 plant ha^{-1} (Appendix 4.16). In both seasons, presence of soybean reduced LAD of maize significantly compared to sole maize.

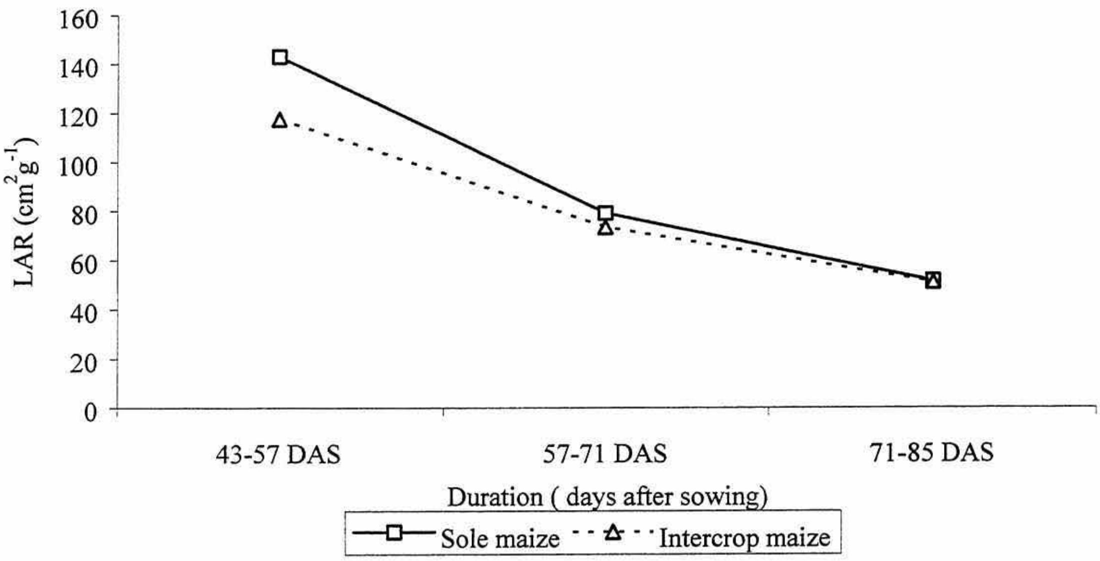


Figure 4.18. Means of leaf area ratio (LAR) for sole and intercropped maize during different growth periods in 2001 (Appendix 4.14)

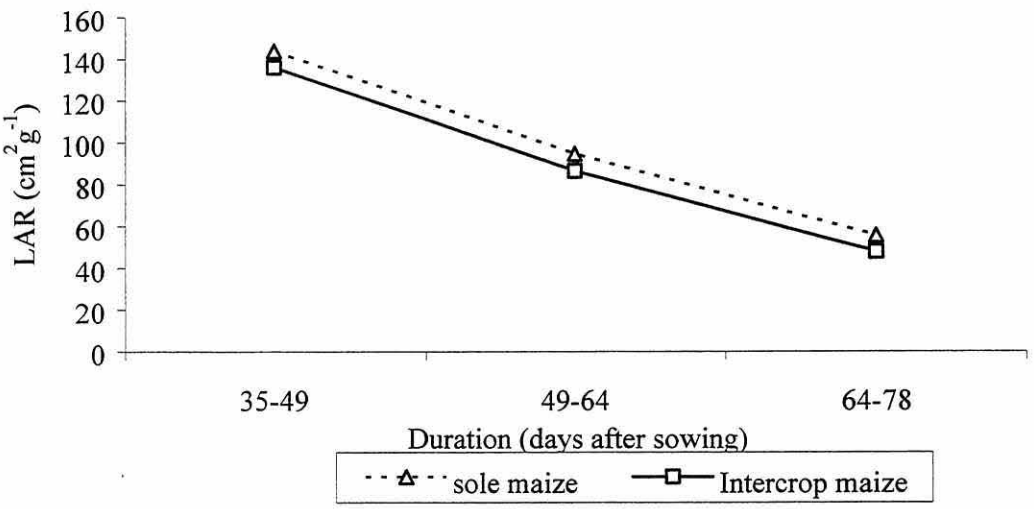


Figure 4.19. Means of LAR for sole and intercropped maize measured during different periods in 2002 (Appendix 4.15).

Table 4.5. Effect of maize and soybean density on leaf area duration (LAD) of maize during 2001 and 2002 seasons.

Densities (x 10^3)	LAD (days)	
Maize	2001	2002
26.5	118	122
40	167	169
53	217	202
soybean		
100 (50)	164	184
150 (100)	172	155
200 (150)	166	155
Sole maize	231	207
Intercrop	167	165
lsd (0.05)		
Maize density	13.3**	16.3**
Soybean density	NS	16.3**
Maize x soybean	NS	28.2*
Intercrop vs sole crop	17.2	21.0**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%. Figures in parentheses indicate densities in 2002.

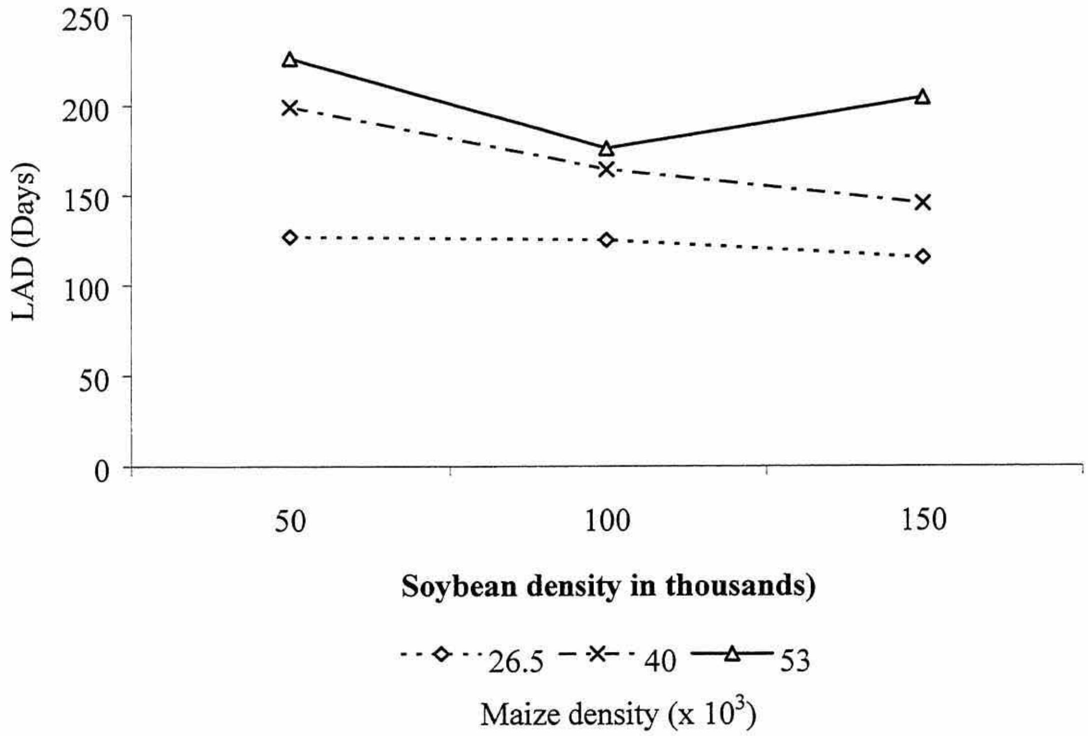


Figure 4.20. Effect of maize and soybean densities on LAD of maize during 2002 (Appendix 4.16)

4.4.3. Yield and yield components of maize

4.4.3.1 Grain yield (g/m^2)

Results of yield and yield components of maize for 2001 and 2002 are presented in tabular form in Tables 4.6 and 4.7, respectively. Grain yields (14 % moisture content) of maize at all densities during 2002 were lower than the previous year. In both seasons, maize density had a significant effect on grain yield of maize and was ranked highest at 53 x 10^3 plants ha^{-1} to least at 26.5 x 10^3 plant ha^{-1}. Grain yield of maize was reduced by 14.5 % and 30 % in 2001 and 8 % and 20 % in 2002 as maize density was reduced from 53 x 10^3 plants ha^{-1} to 40 and 26.5 x 10^3 plants ha^{-1} with reduction of 25 and 50% plant population. However, soybean density had no effect on grain yield of maize in either season.

Presence of soybean reduced grain yield of maize by 9 and 5.8% in 2001 and 2002, respectively compared to sole maize which indicated that maize yield was affected little by intercropped soybean. When yield of sole maize was compared with intercropped maize at the same density of 53 x 10^3 plant ha^{-1}, the difference was negligible

4.4.3.2 Number of plants/m^2

Among yield components of maize, the number of plants/m^2 has a significant role in the production of grain yield as it contributes in total number of cobs per unit area. In both seasons, there was a significant reduction in number of plants/m^2 in intercropped than sole maize. The reduction in number of plants/m^2 was 24 % and 25 % during 2001 and 2002, respectively. This was attributed due to average of all maize densities. In both seasons, effect of soybean density was not significant.

4.4.3.3 Number of cobs/plant

There was no effect of maize density on number of cobs/plant during 2002 but it had a significant effect during 2001. The number of cobs/plant was greatest at maize density of 26.5 x 10^3 plants/ha to lowest at standard maize density but the difference between 40 and 53 x 10^3 plants/ha was not significant.

Table 4.6. Effect of maize and soybean densities on yield (14% m.c.) and yield components of maize grown as intercrop during 2001 summer season

Density (x 10^3)	Grain yield (g/m^2)	Plants/ m^2	Cobs/plant	No. of grains/cob	1000 seed wt (g)
Maize					
26.5	400	2.67	1.02	494	327.4
40	464	3.95	0.89	429	341.1
53	526	5.28	0.86	383	329.7
Soybean					
100	474	4.00	0.95	457	343.1
150	458	4.00	0.89	430	331.6
200	459	3.92	0.92	418	323.5
Sole maize	513	5.22	0.91	425	311.9
Intercrop (mean)	464	3.97	0.92	435	332.7
lsd					
Maize density	27.6**	0.08**	0.09**	60**	NS
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	0.11**	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Table 4.7. Effect of maize and soybean densities on yield (14 % m.c.) and yield components of maize grown as intercrop during 2002 summer season.

Density (x 10^3)	Grain yield (g/m^2)	Plants/ m^2	Cobs/plant	No. of grains/cob	1000 seed wt (g)
Maize					
26.5	361	2.68	0.84	419	337.0
40	414	3.96	0.84	365	316.8
53	450	4.31	0.80	391	282.5
Soybean					
50	432	3.98	0.83	395	319.5
100	395	4.00	0.82	390	311.1
150	397	3.97	0.82	389	305.8
Sole maize	433	5.30	0.85	352	278.8
Intercrop (mean)	408	3.98	0.83	392	312.1
lsd					
Maize density	36.6**	0.04**	NS	34.4*	20.1**
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	0.05**	NS	NS	26.0*

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

4.4.3.4 Number of grains per cob

In both seasons, there was significant effect of maize density on the number of grains /cob (Table 4.6 and 4.7) and was greatest at 26.5 x 10^3 plants ha^{-1} to lowest at standard maize density of 53 x 10^3 plants ha^{-1}. However, the difference in number of grains/cob between 40 and 53 x 10^3 plants ha^{-1} was not significant in either season.

4.4.3.5 1000 grain weight

In 2001, there was no effect of any treatments on thousand grain weight (Table 4.6). However, maize density had a significant effect on 1000 grain weight of maize in 2002, ranked lowest at 53 x 10^3 plants ha^{-1} to heaviest at 26.5 x 10^3 plants ha^{-1} population density. Presence of soybean significantly increased grain weight of intercropped maize compared to sole maize

4.4.4 Dry matter production

Data on dry matter of straw and grains and harvest index, showing significant treatment effects are given in Table 4.8 for 2001 and Table 4.9 for 2002. Results of each component are presented separately as follows:

4.4.4.1 Dry matter of straw

The general trend of straw dry matter was that all treatments were higher in 2001 than 2002 season. In both seasons, standard maize density produced highest dry matter of straw and least at 26.5 x 10^3 plants ha^{-1} but the difference between 40 and 26.5 x 10^3 plants ha^{-1} was not significant in 2001. Dry matter of straw was reduced by 15 % and 22 % in 2001 and 13 % and 30 % in 2002 as maize density was reduced by 25 and 50% from the standard density.

4.4.4.2 Dry matter of grains

Like straw, dry matter of grains in all treatments were higher in 2001 compared to 2002. In both seasons, there was significant effect of maize density on dry matter of grains, ranked highest at 53 x 10^3 plants ha^{-1} to lowest at 26.5 x 10^3 plants ha^{-1} population density but the difference between 40 and 53 x 10^3 plants ha^{-1} was not significant in 2001. In comparison to standard maize density, dry matter of grains were reduced by 8 % and 23 % in 2001 and 8 % and 21 % in 2002 when maize density reduced by 25 and 50 %, respectively.

Table 4.8 Effect of maize and soybean densities on dry matter of grain, straw and harvest index of maize grown as intercrop during 2001 season

Density (x 10^3)	DM straw (g/m2)	DM grains (g/m^2)	Total dry matter (g/m^2)	Harvest index
Maize				
26.5	561	353	914	0.38
40	612	420	1032	0.41
53	722	458	1180	0.39
Soybean				
100	670	406	1076	0.38
150	630	405	1035	0.39
200	596	419	1016	0.41
Sole maize	641	465	1106	0.42
Intercrop	632	410	1042	0.40
lsd				
Maize density	103.9*	54.9**	141.8**	NS
Soybean density	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Table 4.9. Effect of maize and soybean densities on dry matter of grain, straw and harvest index of maize grown as intercrop during 2002 summer season

Density (x 10^3)	DM straw (g/m^2)	DM grain (g/m^2)	Total dry matter (g/m^2)	Harvest index
Maize				
26.5	414	338	752	0.45
40	518	386	903	0.43
53	596	427	1023	0.42
Soybean				
50	500	404	903	0.45
100	527	373	900	0.42
150	501	375	876	0.43
Sole maize	505	413	918	0.45
Intercrop	510	384	893	0.43
lsd				
Maize density	59.5**	35.4**	79.9**	NS
Soybean density	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

4.4.4.3 Total dry matter

In both seasons, similar to straw and grains, normally spaced maize produced the significantly highest total dry matter and the least at lowest maize density, although the difference between 40 and 26.5 x 10^3 plants ha^{-1} was not significant. In general, total dry matter production was lower with all maize densities in 2002 compared to previous year.

4.4.4.5 Harvest index

In both seasons, there was no effect of any treatments on harvest index.

4.4 5 Growth measurement of soybean

4.4.5.1 Plant height

Data on plant height of soybean throughout growing season are presented in Appendix 4.17 and Figures 4.21 and 4.22 for 2001 and Appendix 4.18 and Figures 4.23 and 4.24 for 2002. In both seasons, plant height of all treatments increased continuously up to pod formation stage (89 DAS) and reached an asymptote, and then there was a slight decline at harvest. However, heights of soybean were greater in 2002 than 2001. In 2001, maize density had a significant effect on height of soybean at first two sampling occasions, ranked highest at 53 x 10^3 plants ha^{-1} to lowest at 26.5 x 10^3 plants ha^{-1} but the effect was not significant at the last three sampling occasions (Figure 4.21). In 2002, lower soybean density resulted in a significantly lower soybean height throughout the season (Figure 4.23) and was ranked from lowest at 50 x 10^3 plants ha^{-1} to greatest at 150 x 10^3 plants ha^{-1} but the effect was not significant at the first sampling occasion.

In 2001, at the first two sampling occasions, sole soybean was shorter than intercropped soybean but this difference was reduced and reversed at last sampling occasion i.e. harvest (Figure 4.22). In 2002, the soybean intercrop produced taller plants throughout the season compared to sole soybean but this difference was significant only at the last sampling occasion (Figure 4.24).

4.4.5.2 Leaf Area Index (LAI)

Trends in LAI of soybean throughout growing period for 2001 and 2002 are presented in Appendix 4.19 and Figures 4.25 and 4.26 and Appendix 4.20 and Figures 4.27, 4.28 and 4.29, respectively. In 2001, LAI of soybean in all treatments increased up to 75 DAS as the season progressed and declined at 89 DAS, whereas it increased up to 87 DAS in 2002. Although, the effect of maize density was not significant in 2001, in 2002, the standard maize density suppressed LAI of soybean at the second and last sampling occasions and ranked lowest at 53 x 10^3 plants ha^{-1} to highest at 26.5 x 10^3 plants ha^{-1} during 2002 (Figure 4.27).

In both seasons, higher soybean density resulted in significantly greater soybean LAI compared to the lower density throughout growing season, but the difference was not significant at third sampling occasion in 2001 (Figures 4.25, 4.28). In both seasons, LAI of intercropped soybean was suppressed under maize compared to sole soybean

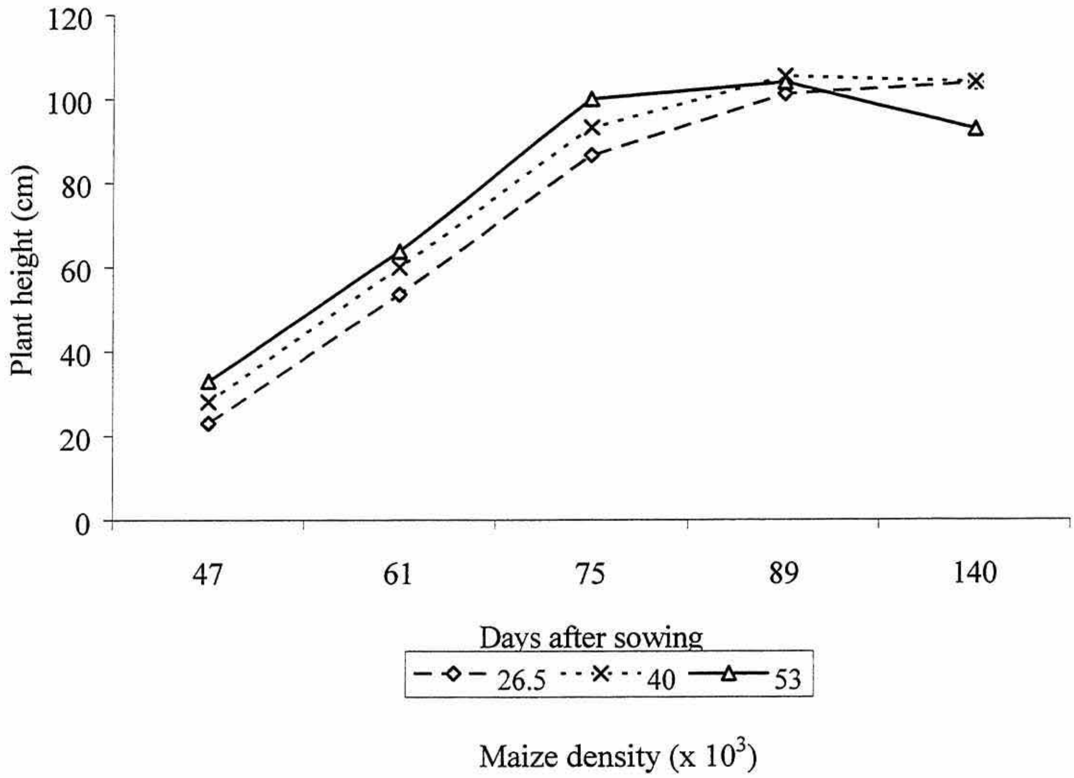


Figure 4.21. Effect of maize densities on plant height of intercropped soybean measured over time in 2001 (Appendix 4.17)

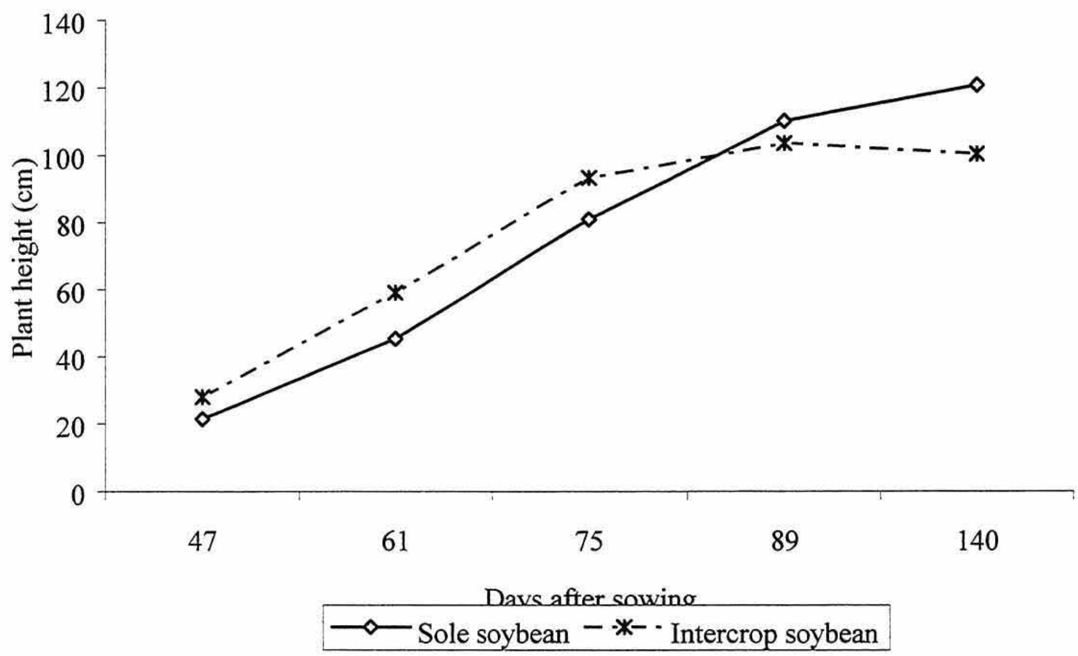


Figure 4.22. Effect of sole and intercropped soybean on plant height measured over time during 2001 season (Appendix 4.17)

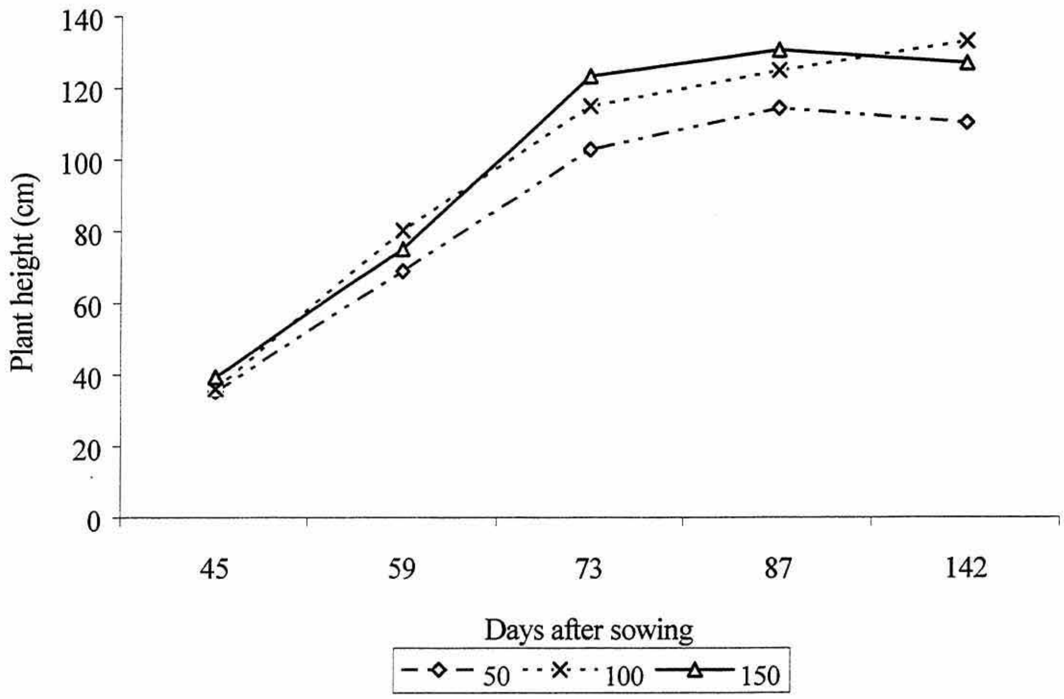


Figure 4.23. Effect of maize densities on plant height of intercropped soybean measured over time in 2002 (Appendix 4.18)

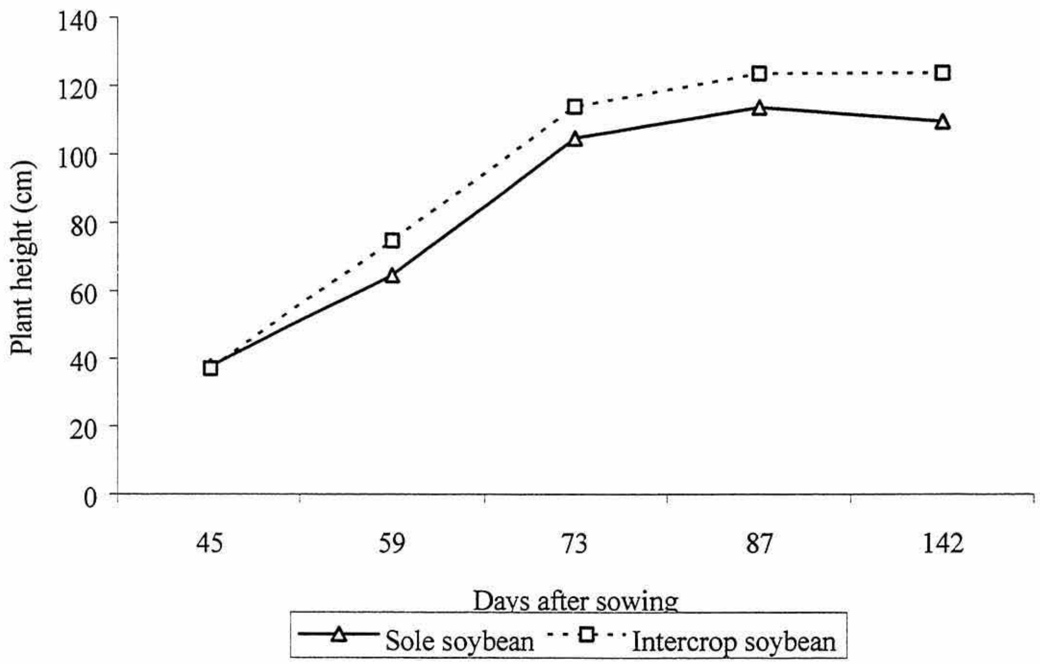


Figure 4.24. Effect of sole and intercropped soybean on plant height measured over time in 2002 (Appendix 4.17)

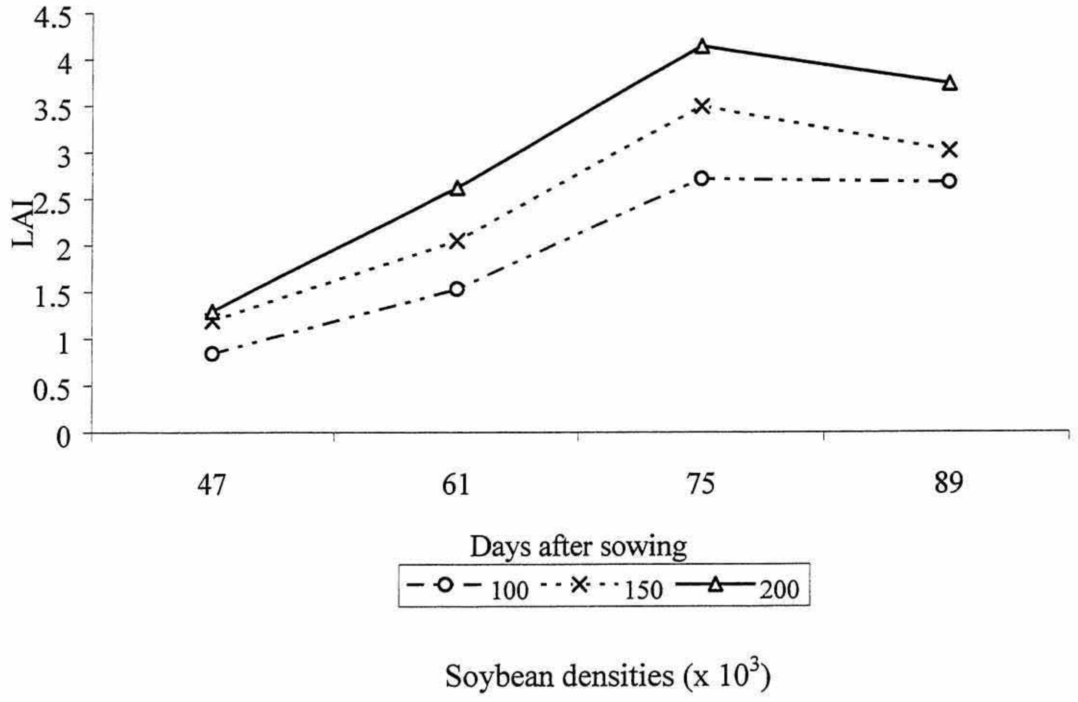


Figure 4.25. Effect of soybean densities in intercropping on LAI measured over time during 2001 (Appendix 4.19)

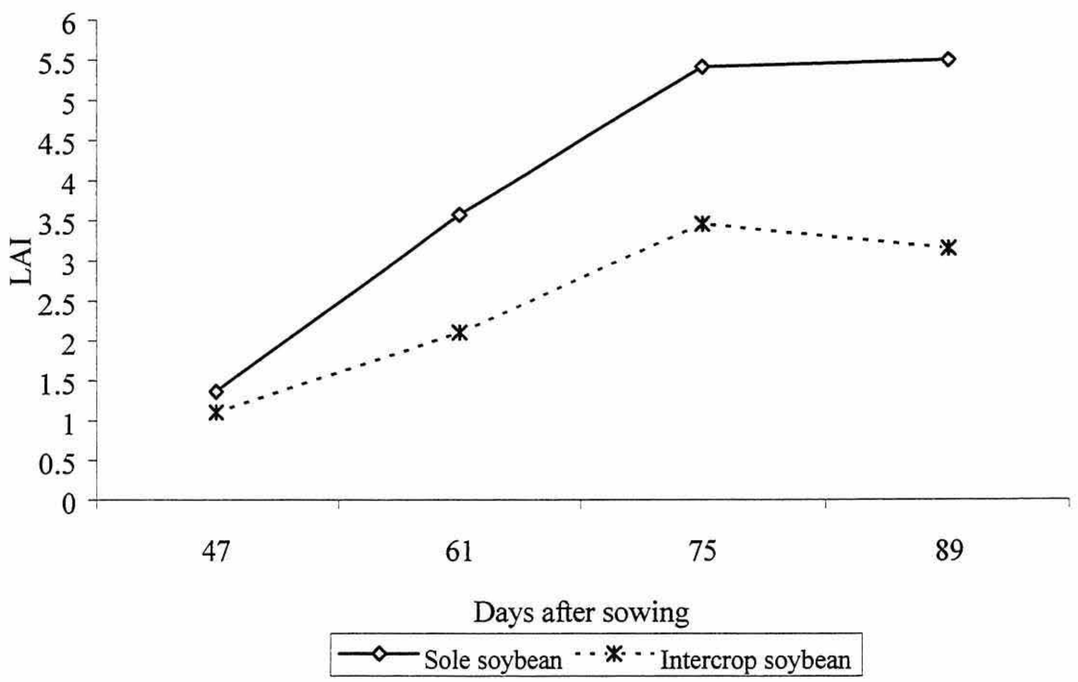


Figure 4.26. Effect of sole and intercrop soybean on LAI measured over time during 2001 season (Appendix 4.19)

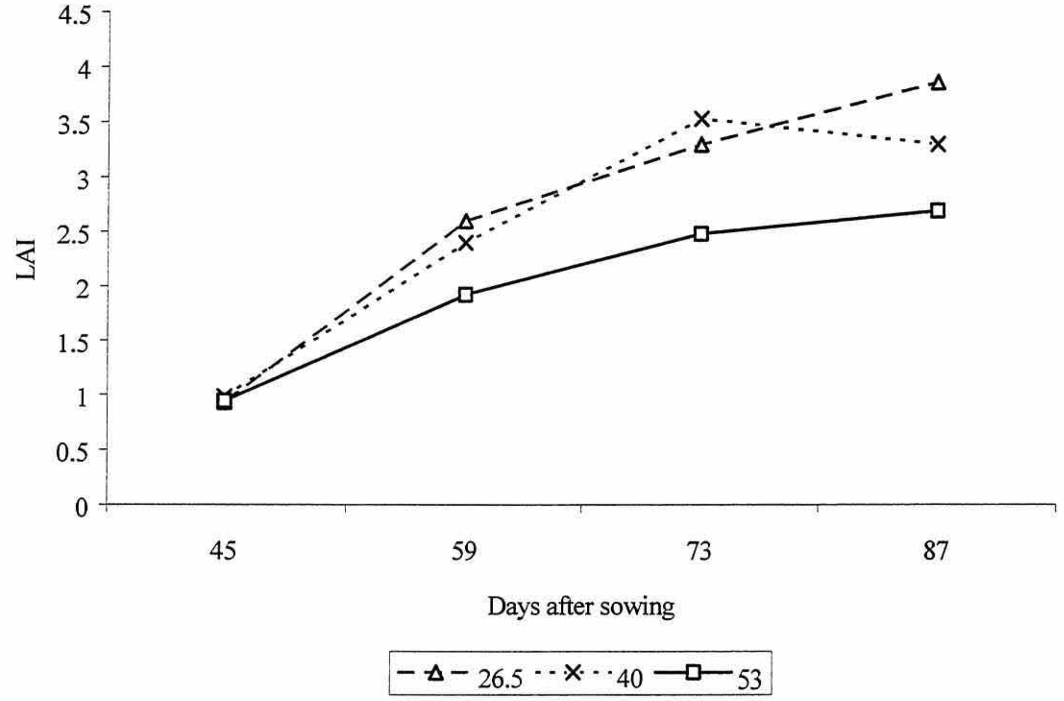


Figure 4.27. Effect of maize densities on leaf area index (LAI) of intercropped soybean measured over time in 2002 (Appendix 4.20)

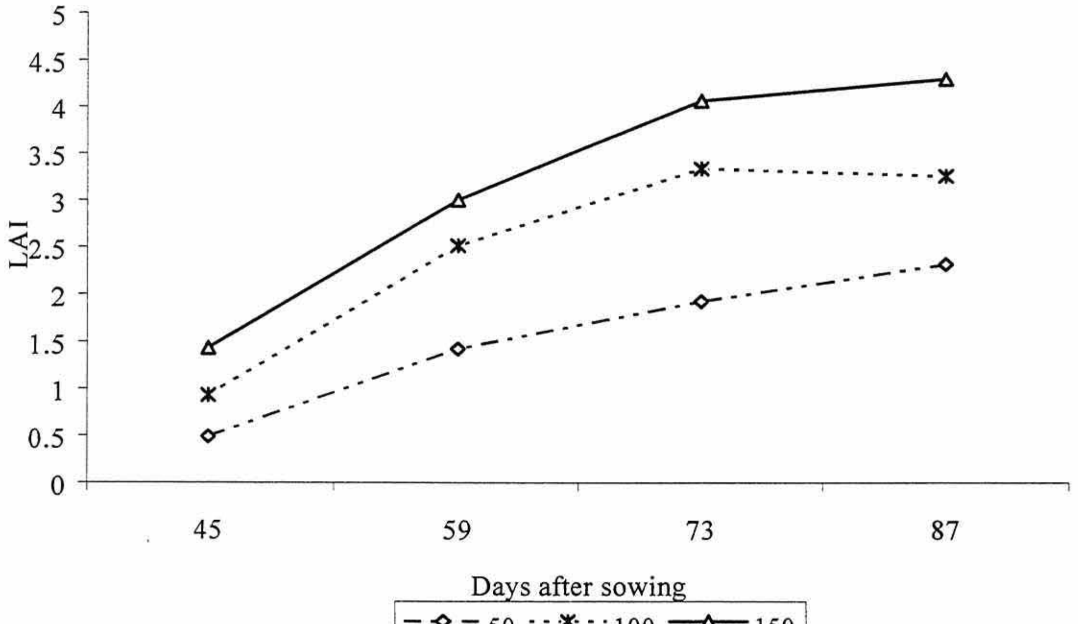


Figure 4.28. Effect of soybean densities in intercropping on leaf area index (LAI) measured over time in 2002 (Appendix 4.20)

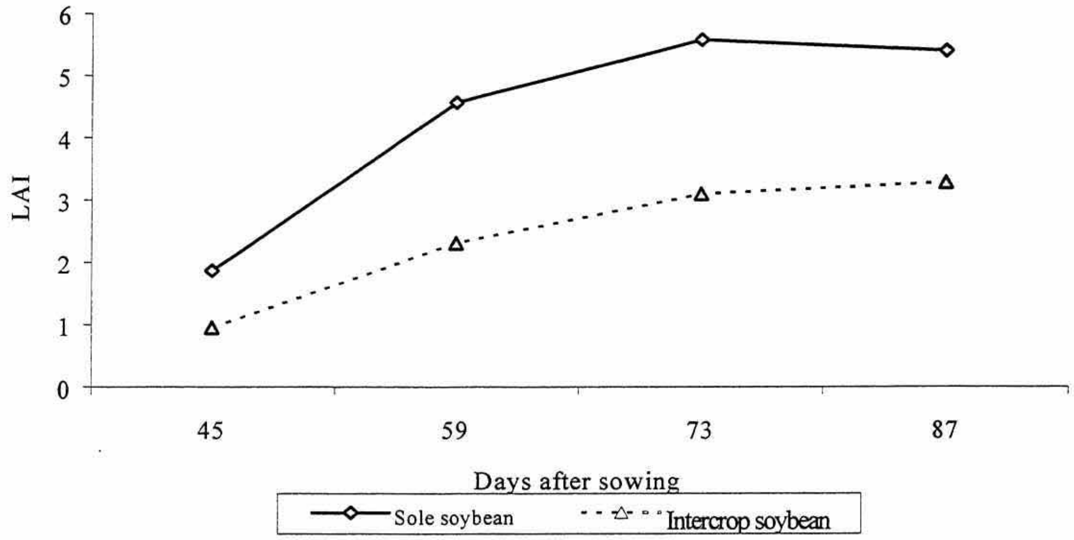


Figure 4.29. Effect of sole and intercropped soybean on LAI measured over time in 2002 (Appendix 4.20)

throughout growing season (Figure 4.26, 4.29) but the effect was not significant at the first sampling occasion in 2001.

4.4.5.3 Shoot dry matter (g/m^2)

Results of shoot dry matter of soybean for 2001 and 2002 are presented in Appendix 4.21 and 4.22, respectively. Shoot dry matter increased up to pod formation stage in 2001 and up to harvest in 2002, as the season progressed. The decline in dry matter at harvest was due to senescence of dried leaves at maturity which were not included in sampling. In general, dry matter of soybean in all treatments was higher in 2002 than 2001. In 2002, dry matter of all treatments was lower during third sampling than second sampling occasion. This was possibly due to heavy rainfall (116mm) on 2 July 2002 which caused lodging of soybean plants resulting in loss of most of the lower leaves. In 2001, the recommended maize density affected dry matter of soybean most and 53 x 10^3 plants ha^{-1} was ranked lowest, and greatest at 26.5 x 10^3 plants ha^{-1} maize density, but these differences were significant at the third and last sampling occasions only (Figure 4.30). In 2002, similarly, maximum dry matter of soybean was obtained with maize density of 26.5 x 10^3 plants ha^{-1} throughout the growing season and decreased as maize density was increased from 26.5 to 53 x 10^3 plant ha^{-1}, except at first sampling occasion (Figure 4.33).

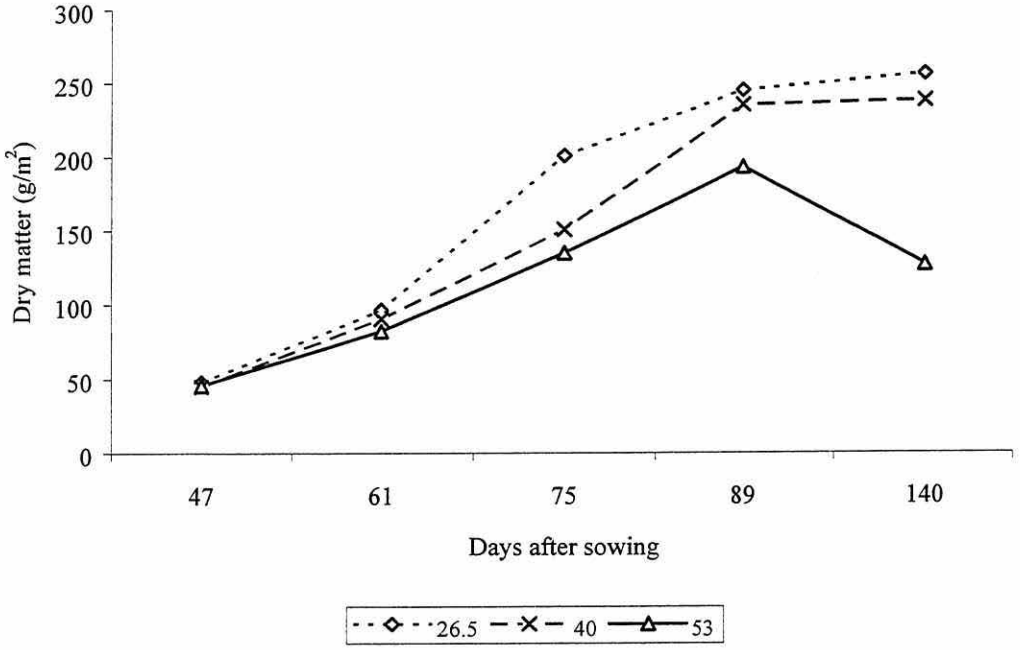


Figure 4.30. Effect of maize densities on shoot dry matter of soybean measured over time in 2001 (Appendix 4.21)

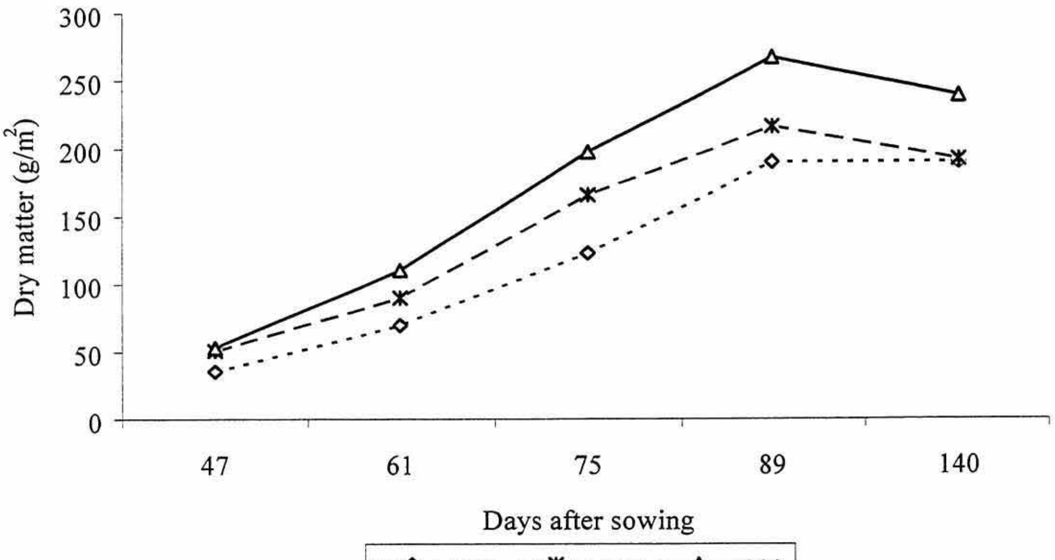


Figure 4.31. Effect of soybean densities on shoot dry matter of soybean measured over time in 2001 (Appendix 4.21)

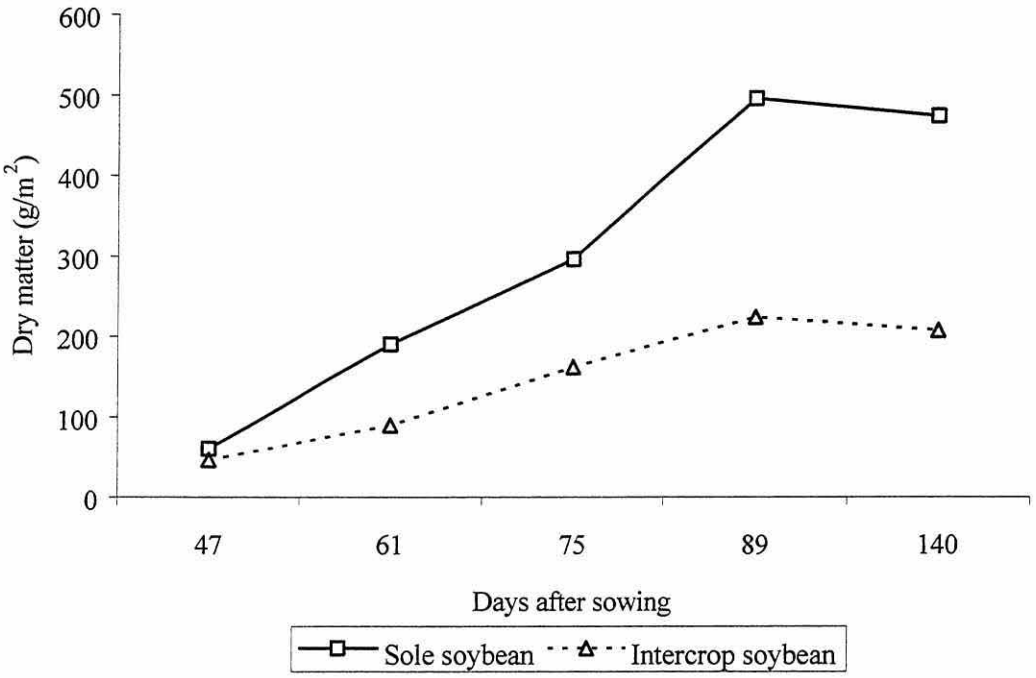


Figure 4.32. Effect of sole and intercropped soybean on shoot dry matter measured over time in 2001 (Appendix 4.21)

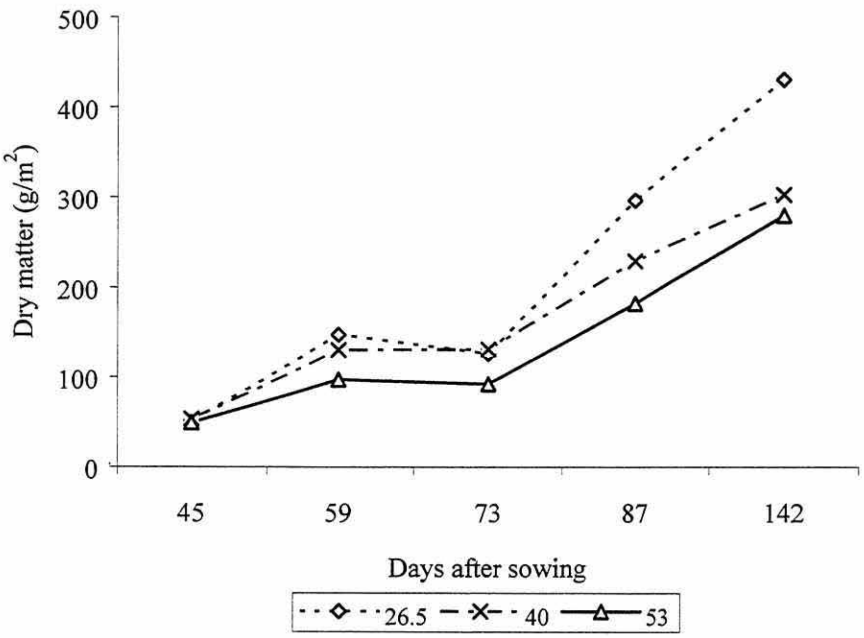


Figure 4.33. Effect of maize densities on shoot dry matter of soybean measured over time in 2002 (Appendix 4.22)

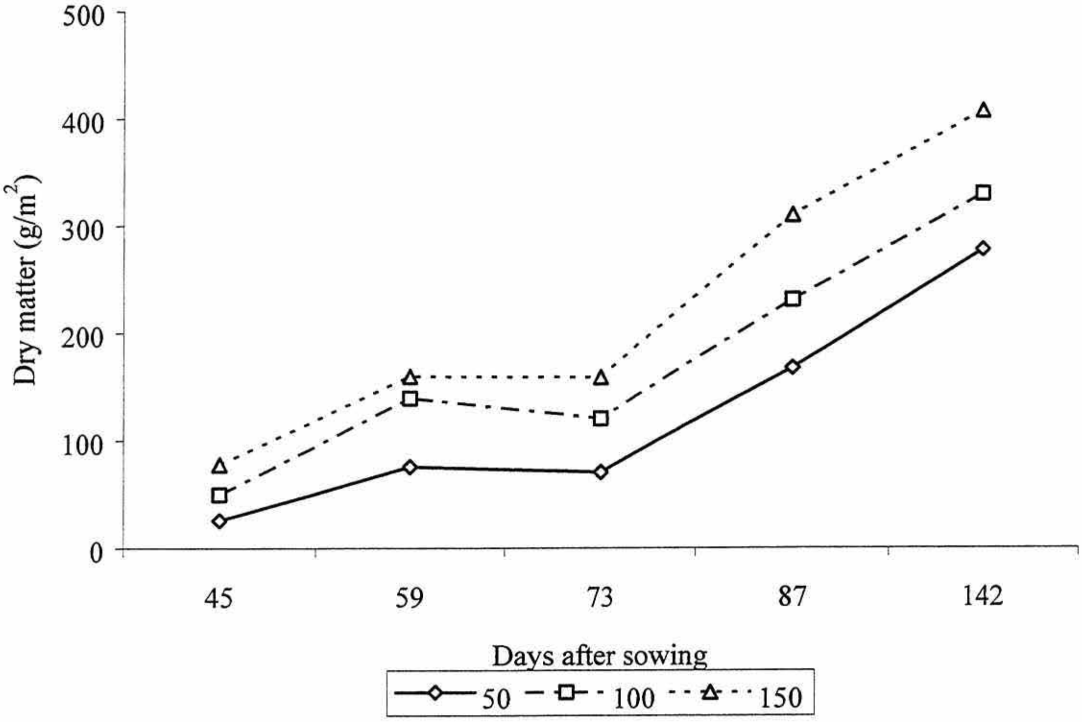


Figure 4.34. Effect of soybean densities on shoot dry matter of soybean measured over time in 2002 (Appendix 4.22)

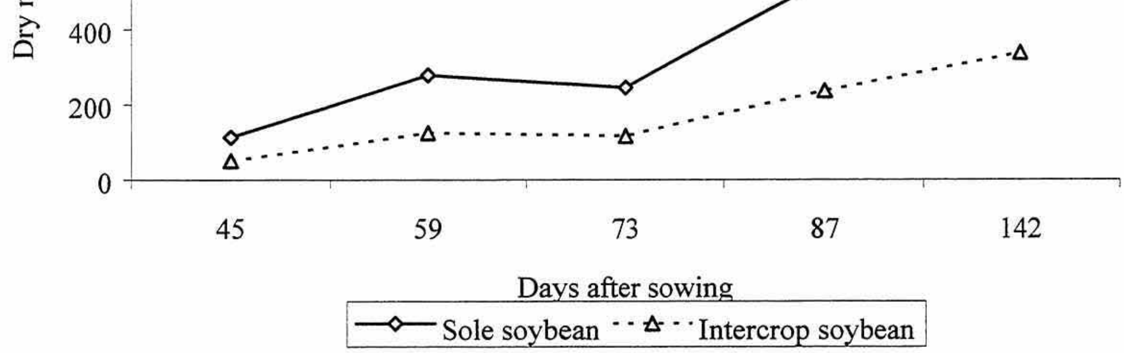


Figure 4.35. Effect of sole and intercropped soybean on dry matter production of soybean measured over time in 2002 (Appendix 4.22)

In both seasons, as opposed to the trend observed with increasing maize density, higher soybean density increased dry matter of soybean throughout growing period except at the last two sampling occasion in 2001 (Figures 4.31, 4.34). The trend for dry matter declined as soybean density decreased from 200 to 100 and from 150 to 50 x 10^3 plants ha^{-1}, during 2001 and 2002, respectively. In both seasons, intercropped soybean also produced consistently lower dry matter than sole soybean throughout the seasons, and at each sampling occasion (Figures 4.32, 4.35)

4.4.5.4 Crop Growth Rate (CGR)

Results of crop growth rate of soybean are presented in Appendix 4.23 and Appendix 4.24. In 2001, there was a significant effect of maize density on crop growth rate of soybean during the early growth period only (47-61 DAS) and was ranked from lowest at 53 x 10^3 plants ha^{-1} to maximum at 26.6 x 10^3 plant ha^{-1} population density. Similarly, maize density had a significant effect on CGR during 45-49 DAS and 73-89 DAS period in 2002 only. Maximum CGR was obtained with a maize density of 26.5 x 10^3 plant ha^{-1} and declined as maize density increased from 26.5 to 53 x 10^3 plants ha^{-1} (Figure 4.37). In 2001, there was no effect of soybean density on CGR whereas soybean density of 50 x 10^3 plant ha^{-1} had a significantly lower crop growth rate than 100 and 150 x 10^3 plants ha^{-1}, during the early growth period in 2002 only.

In both seasons, intercropped soybean had significantly lower CGR than sole soybean throughout the growing season but the difference was not significant during the second and last growth period in 2001 (Figure 4.36) and second growth period during 2002 (Figure 4.38). The negative values of CGR during second sampling period was due to lower dry matter at the third sampling occasion, as explained in section 4.3.3.3.

4.4.5.5 Net Assimilation Rate (NAR)

In 2001, there was no effect of either maize or soybean density on NAR (Appendix 4.25) but intercropped soybean had significantly lower NAR than sole soybean, although this difference was significant only during the 47-61 DAS period (Figure 4.36). In 2002, maize density had a significant effect on NAR during the first growth period (45- 59 DAS), was ranked lowest at 53 x 10^3 plants ha^{-1} to greatest at 26.5 x 10^3 plants ha^{-1} population density (Appendix 4.26). Soybean density of 150 x 10^3 plants ha^{-1}

reduced NAR of soybean more than two other densities during the 45-59 DAS period only.

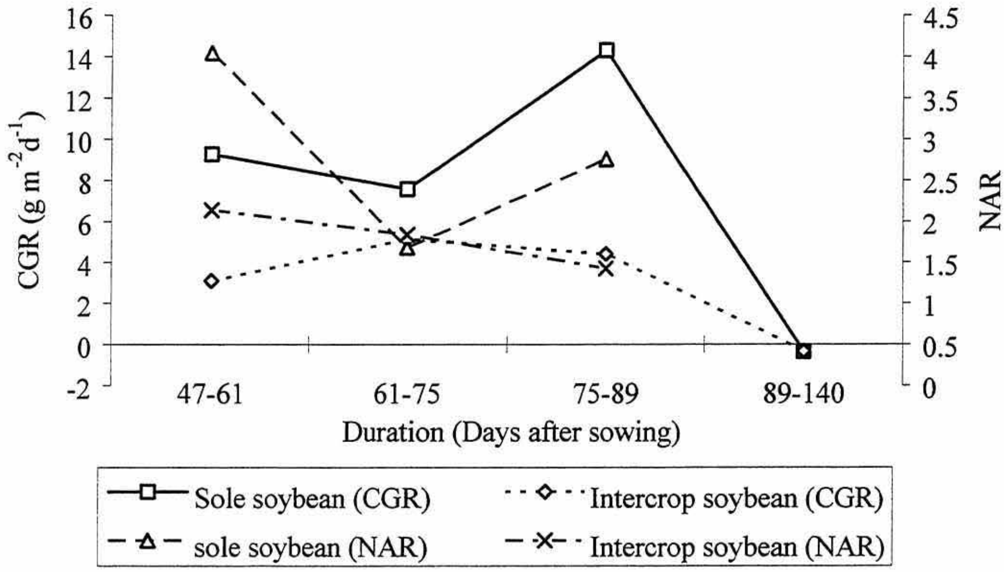


Figure 4.36. Effect of sole and intercropped soybean on CGR and NAR over time in 2001 season (Appendix 4.23 and 4.25).

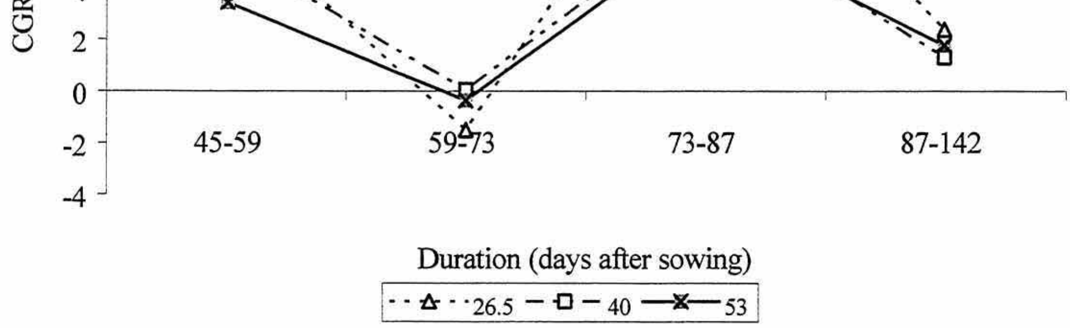


Figure 4. 37. Effect of maize densities in intercrop on crop growth rate (CGR) of soybean measured during the 2002 season (Appendix 4. 24).

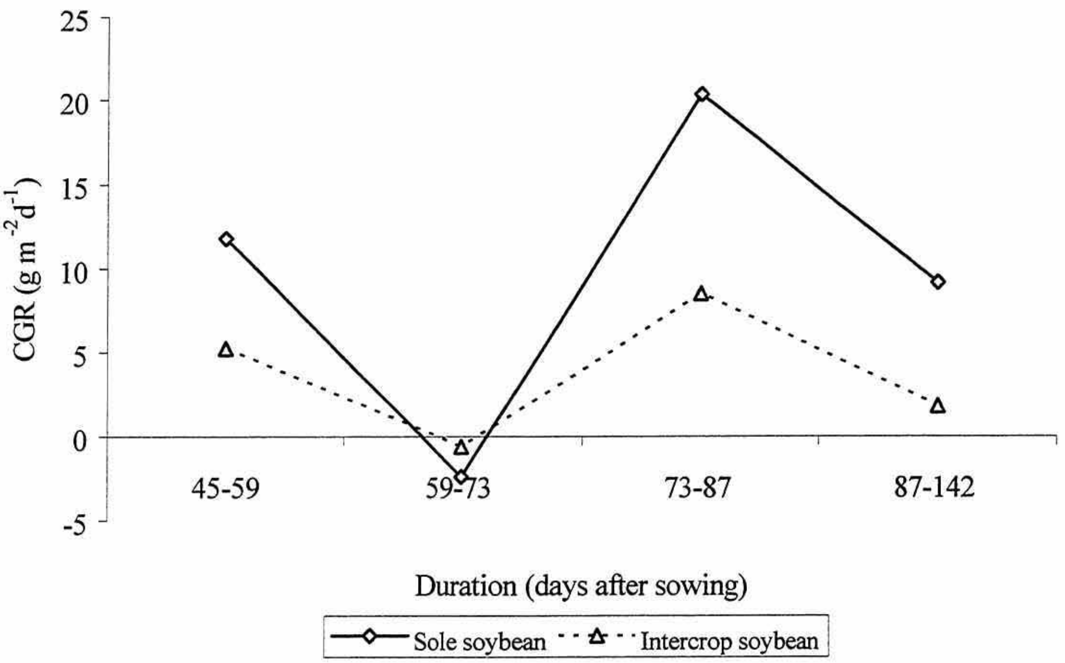


Figure 4.38. Effect of sole and intercropped system on crop growth rate (CGR) measured during the 2002 season (Appendix 4.24).

4.4.5.6 Leaf area ratio (LAR)

LAR of soybean for 2001 and 2002 are presented in tabular form in Appendix 4.27 and Appendix 4.28, respectively. In both seasons, maize density had a significant effect on leaf area ratio, ranked from lowest at 26.5 x 10^3 plants ha^{-1} to maximum at 53 x 10^3 plants ha^{-1} population density, but these effects were not significant between the last two sampling occasions in 2001 and the second and third growth sampling periods in 2002 (Figure 4.39). In both seasons, intercropped soybean under maize had higher LAR than sole soybean throughout growing season, although this difference was significant during first and last growth periods only (Figures 4.40, 4.41)

4.4.5.7 Leaf area duration (LAD)

Data on leaf area duration of soybean are presented in Table 4.10. In the first season, there was no effect of maize density on LAD of soybean but it had a significant effect during second season. LAD of soybean ranked was highest at a maize density of 26.5 x 10^3 plants ha^{-1} to lowest at standard maize density but the difference between 26.5 and 40 x 10^3 plants ha^{-1} was not significant. LAD of soybean was significantly affected by

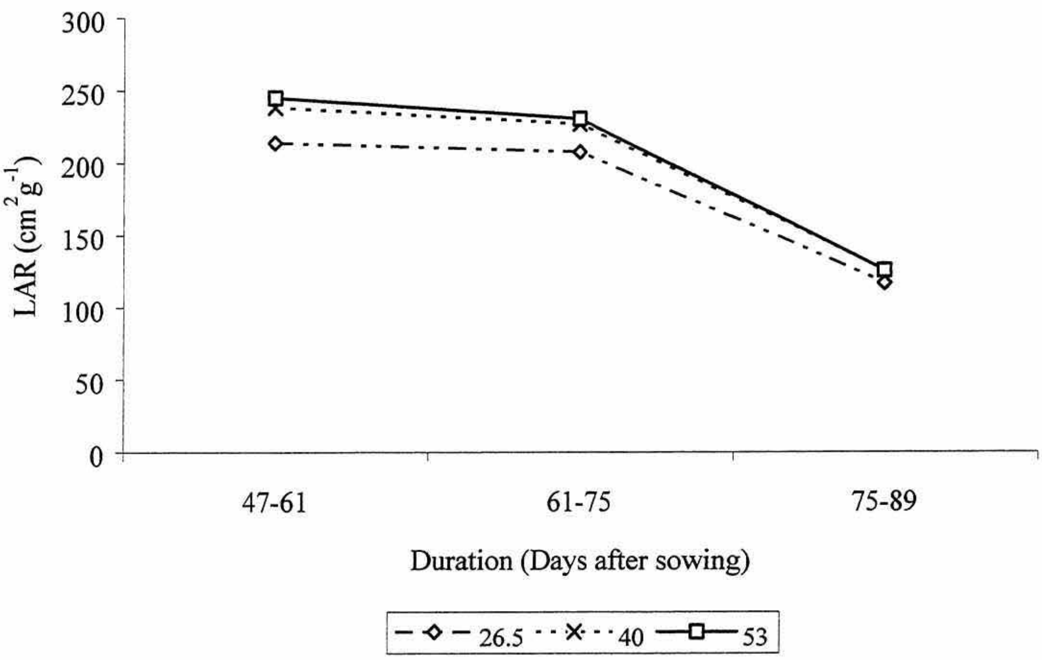


Figure 4.39. Effect of maize densities in intercrop on leaf area ratio (LAR) of soybean measured during the 2001 season (Appendix 4.27)

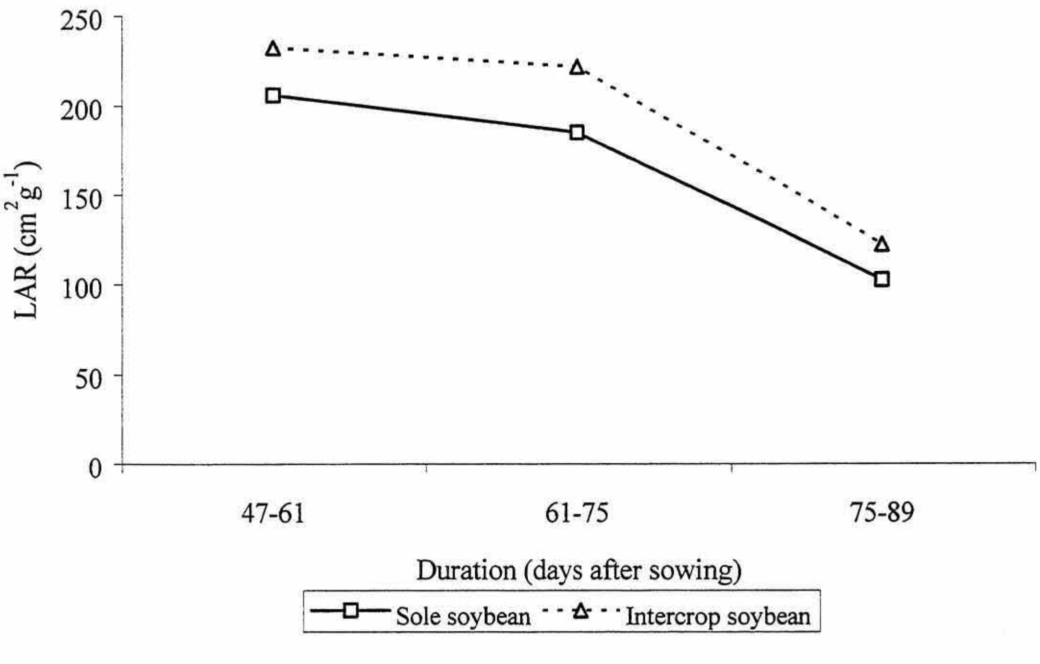


Figure 4.40. Effect of sole and intercropped soybean on leaf area ratio (LAR) measured during different periods in 2001 (Appendix 4.27)

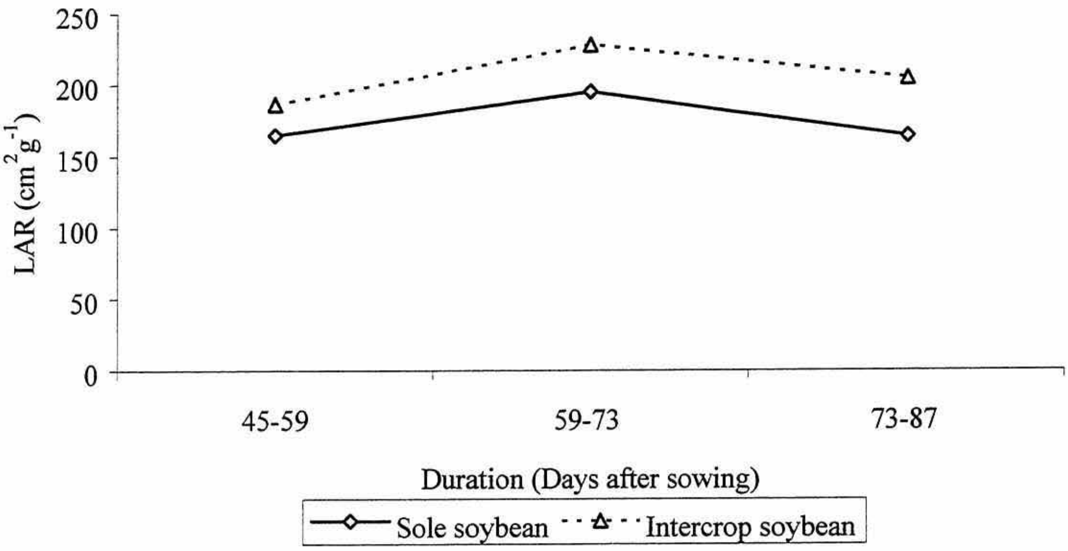


Figure 4.41. Effect of sole and intercropped soybean on leaf area ratio (LAR) measured during the 2002 season (Appendix 4.28)

soybean density and ranked highest at 150 x 10^3 plants ha^{-1} to lowest at 50 x 10^3 plants ha^{-1} but the difference between 50 and 100 x 10^3 plants ha^{-1} was not significant during 2001. In both seasons, intercropped soybean reduced LAD significantly compared to sole soybean.

4.4.5.8 Number of nodules per plant

Data on nodules/plant taken at flowering time for both years are presented in Table 4.11. In 2001, soybean planted under maize density of 53 x10^3 plants ha^{-1} produced a lower number of nodules/plant than 40 and 26.5 x 10^3 plants ha^{-1}. In 2002, association with maize suppressed the number of nodules per plant compared to sole soybean.

Table 4.10. Effect of maize and soybean density on leaf area duration (LAD) of soybean (days) during 2001 and 2002 seasons.

Densities (x 10^3)	LAD (days)	
	2001	2002
Maize		
26.5	222	239
40	211	222
53	190	178
Soybean		
100 (50)	167	139
150 (100)	206	217
200 (150)	249	283
Sole soybean	338	376
Intercrop	207	213
lsd (0.05)		
Maize density	NS	24.5**
Soybean density	31.5**	24.5**
Maize x soybean	NS	NS
Intercrop vs sole crop	40.7**	31.6**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%. Figures in parentheses indicate densities in 2002.

Table 4. 11 Effect of maize and soybean densities on the number of nodules per plant of soybean at flowering stage under maize/soybean intercropping during 2001 and 2002 summer season.

Density (x 10^3)	Number of nodules per plant	
	2001	2002
Maize		
26.5	31	91
40	39	94
53	27	97
Soybean		
100 (50)	37	117
150 (100)	33	85
200 (150)	26	95
Sole soybean	32	166
Intercrop	32	94
lsd		
Maize density	9.8*	NS
Soybean density	NS	NS
Maize x soybean	NS	NS
Int x sole crop	NS	36**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%. Figure in parentheses are modified density of soybean during 2002

4.4.6 Yield and yield component of soybean

The interaction effect of maize and soybean density on yield, yield components and dry matter of soybean was not significant in either year. Therefore, means of main effects, with significant effects are presented in Table 4.12 and 4.13 for 2001 and 2002, respectively. The results of each variable are presented in separate sections.

4.4.6.1 Grain yield

In general, grain yields of soybean in all treatments were higher in 2002 compared to previous year in contrast to maize grain yields, which were lower in 2001. In both seasons, there was a significant effect of maize density on grain yield of soybean. Recommended density of maize suppressed grain yield of soybean most and 26.5 x 10^3 plants ha^{-1} least. The increase in grain yield was 52 % and 96 % in 2001 and 23 % and 43% in 2002 when it was intercropped under reduced maize densities of 40 and 26.5 x 10^3 plants ha^{-1}.

In both seasons, intercropped soybean produced lower grain yield than sole soybean. The decrease in grain yield was 59 and 53 % during 2001 and 2002, respectively. In 2002, soybean density of 50 x 10^3 plant ha^{-1} produced significantly lower grain yield than other two densities but the difference between 100 and 150 x 10^3 plants ha^{-1} was not significant.

4.4.6.2 Number of pods per plant

The number of pods/plant was generally higher in 2002 than the previous season. In both seasons, maize density had a significant effect on the number of pods/plant, ranked from lowest at 53 x 10^3 plants ha^{-1} to greatest at 26.5 x 10^3 plants ha^{-1} population density. The percentage increment in pods/plant of soybean was 55 % and 105 % in 2001 and 29 % and 110 % in 2002 when soybean was planted under a reduced maize density of 40 and 26.5 x 10^3 plants ha^{-1}.

In both seasons, there was a significant difference in production of pods/plant between intercropped and sole soybean. The decrease in pods/plant was 48 % and 34 % during 2001 and 2002, respectively. In 2002, soybean density of 50 x 10^3 plants ha^{-1} produced higher pods/plant than 100 and 150 x 10^3 plants ha^{-1} but the difference between these two densities was not significant.

Table 4.12. Effect of maize and soybean densities on yield, yield components and dry matter of soybean grown as intercrop during 2001 summer season.

Density (x 10^3)	Grain yield (g/m^2)[1]	Pod/ plant	Seed/ pod	100 seed wt.	DM straw (g/m^2)	DM grains g/m^2	Total DM (g/m^2)	Harvest index
Maize								
26.5	98.5	37	2.1	20.5	170	88.8	259	0.34
40	76.4	28	2.1	20.5	144	68.7	213	0.31
53	50.2	18	2.0	19.8	94	45.9	140	0.32
Soybean								
100	74.4	30	2.2	19.9	124	67.6	191	0.36
150	74.4	26	2.1	20.5	138	67.1	205	0.33
200	76.3	27	2.0	20.4	145	68.7	214	0.30
Sole soybean	183.9	54	2.3	18.5	338	167.6	506	0.33
Intercrop (mean)	75.0	28	2.1	20.2	143	67.8	204	0.33
lsd								
Maize density	14.8**	5.4*	NS	NS	40.9**	13.5**	55.3**	NS
Soybean density	NS	NS	NS	NS	NS	NS	NS	0.04*
Int x sole crop	19.2**	7.0*	NS	1.5*	31.6**	17.5**	42.9*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Table 4.13. Effect of maize and soybean densities on yield, yield components and dry matter of soybean grown as intercrop during 2002 summer season

Density (x 10^3)	Grain yield g/m^2	Pod/ plant	Seed/ pod	100 seed wt.	DM straw g/m^2	DM grain g/m^2	Total DM g/m^2	Harvest index
Maize								
26.5	125.1	61.9	2.1	22.8	174	116	290	0.40
40	107.7	38.2	2.0	24.2	141	100	241	0.43
53	87.7	29.5	2.1	24.4	108	81	189	0.44
Soybean								
50	96.8	57.4	2.1	23.7	110	90	200	0.46
100	113.1	40.4	2.1	23.9	153	105	258	0.41
150	110.6	31.8	2.0	23.8	160	102	262	0.39
Sole soybean	225.4	65.5	2.1	21.2	390	209	599	0.35
Intercrop (mean)	106.8	43.2	2.1	23.8	141	99	240	0.42
lsd								
Maize density	11.8**	9.0**	NS	0.70**	27.4**	10.9**	32.7**	NS
Soybean density	11.8*	9.0*	NS	NS	27.4**	10.9*	32.7**	0.05*
Int x sole crop	15.2**	11.6**	NS	0.90**	35.4**	14.1**	42.2**	0.06*

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

[1] Grain yield corrected to 12 % m.c.

4.4.6.3 Seeds per pod

In both seasons, there was no effect of any treatments on the number of seed per pod. In general, seed per pod varied from 1 to 3 per pod and mean value ranged from 2.0 to 2.3 in all treatments.

4.4.6.4 100 seed weight

When comparing seed weight between seasons, all treatments produced heavier grains in 2002 than the previous season. In 2001, there was no effect of either maize or soybean density on seed weight of soybean, but maize density had a significant effect during 2002. A lighter grain weight of soybean was produced when planted under low maize density of 26.5 x 10^3 plants ha^{-1} than under 40 and 53 x 10^3 plants ha^{-1} but the difference between these two densities was not significant. In both seasons, sole soybean produced lighter grains than intercropped soybean.

4.4.7 Dry matter production

4.4.7.1 Dry matter of straw

In both seasons, maize density had significant effects on straw dry matter and produced the highest at 26.5 x 10^3 plants ha^{-1} to lowest at 53 x 10^3 plants per ha^{-1} population density, but the difference between 40 and 26.5 x 10^3 plants ha^{-1} was not significant in 2001. The percentage increase in straw dry matter of soybean was 77 % and 81 % in 2001 and 30 % and 61 % in 2002, respectively when it was planted under reduced maize densities of 40 and 26.5 plants ha^{-1}. In 2002, soybean density of 50 x 10^3 plants ha^{-1} produced significantly least dry matter of straw, but the difference between 100 and 150 x 10^3 plants ha^{-1} was not significant. In both seasons, there was a significant difference in straw dry matter between intercropped and sole soybean. The magnitude of reduction was 58 % and 64 % in 2001 and 2002, respectively when soybean was planted under maize.

4.4.7.2 Dry matter of grains yield.

Like straw, dry matter of grains was significantly affected by maize densities in both seasons. Dry matter of grains was ranked highest when planted under maize density of 26.5 x 10^3 plants ha^{-1} to lowest at 53 x 10^3 plants per ha^{-1}. The dry matter of grains was reduced by 23 % and 48% in 2001 and 14 % and 30 % in 2002 when planted under reduced maize densities of 40 and 53 x 10^3 plants ha^{-1}.

In both seasons, dry yield of soybean grains was suppressed by the presence of maize when compared to sole soybean. The magnitude of reduction in dry matter of grains was 59 % and 53% in 2001 and 2002, respectively. In 2002, soybean density of 100 x 10^3 plants ha^{-1} produced greatest dry matter than 50 x 10^3 plants ha^{-1} but this did not differ significantly from 150 x 10^3 plants ha^{-1}.

4.4.7.3 Total dry matter

Overall, total dry matter of soybean in all intercrops was lower than sole soybean. Like straw and grains, maize density had a significant effect on total dry matter in both seasons. Maximum total dry matter was produced when soybean was planted under maize density of 26.5 x 10^3 plants ha^{-1} and declined to lowest at 53 x 10^3 plants ha^{-1}. The magnitude of reduction in total dry matter production was 18 % and 46% when planted under maize density of 40 and 53 x 10^3 plants ha^{-1}.

In 2002, soybean density had a significant effect on dry matter of grains. Soybean density of 50 x 10^3 plants ha^{-1} produced lower dry matter of grains than 100 and 150 x 10^3 plants ha^{-1} but the difference between these two densities was not significant. In both seasons, the presence of maize reduced total dry matter of soybean by 58 % and 60 % in 2001 and 2002, respectively.

4.4.7.4 Harvest Index

In both seasons, soybean density had a significant effect on harvest index, ranked highest at the lower density to lowest at the highest soybean density, but the effect was not significant between 100 and 150 x 10^3 plants ha^{-1}. In 2002, intercropped soybean had a significantly higher harvest index than sole soybean. In spite of low harvest index, sole soybean produced higher grain yield, compensated for by increased number of pods per plant.

4.4.8 Measurement of Intercropping Efficiency

Means of Partial LER, LER, total value and monetary advantage of all treatments are presented in Table 4.14 and 4.15 for 2001 and 2002, respectively.

4.4.8.1 Partial Land Equivalent Ratio of Maize and Soybean

In both seasons, the higher value of partial LER of maize indicated that the maize crop was more competitive in utilizing growth resources than soybean. In both seasons, maize density had a significant effect on partial LER of maize, ranked highest at 53 x 10^3 plants ha^{-1} to lowest at 26.5 x 10^3 plants ha^{-1}.

Also, in both seasons, maize density had a significant effect on partial LER of soybean. The maximum partial LER of soybean was recorded at the lowest maize density of 26.5 x 10^3 plants ha^{-1} and it was least at 53 x 10^3 maize plants ha^{-1}. In 2002, soybean density of 50 x 10^3 plants ha^{-1} had a significantly lower partial LER than the other two densities, although differences between these two densities were not significant (Table 4.15). There was a significant interaction of partial LER of soybean during 2002 (Table 4.16), caused by a significant increase in partial LER with soybean density of 100 x 10^3 plants ha^{-1} at maize density of 53 x 10^3 plants ha^{-1}

4.4.8.2 Land Equivalent Ratio

Grain yield

In both seasons, the biological advantage as measured in term of LER was greater than unity in all intercropping treatments, indicating higher land use efficiency of intercrops over monoculture. The mean LER of all treatment combinations of maize and soybean densities for 2001 and 2002 are presented in Appendix 3.29. Overall, LER of treatments were greater in 2002 than the previous season. In 2001, the highest LER of 1.36 was obtained with maize density of 26.5 x 10^3 plants per ha, indicated that land use efficiency increased by 36% when soybean was intercropped with maize. Similarly, soybean density of 100 x 10^3 plants ha^{-1} gave the highest LER of 1.35, which indicated that 35% more area would be required to produce same yield from sole crops.

In 2002, LER ranged from 1.41 to 1.45, but there was no significant effect; indicating that any combination of soybean with maize increased land use efficiency by at least 41 % compared to monoculture.

Table 4.14. Effect of maize and soybean densities on partial LER of maize and soybean (grain), LER (grain and biomass), total value and monetary advantage of maize/soybean system during 2001.

Density (x 10^3)	Partial LER maize	Partial LER soybean	LER grain	LER biomass	Total Value (Rs/m^2)	Monetary Advantage
Maize						
26.5	0.79	0.56	1.36	1.25	5.80	1.46
40	0.91	0.42	1.33	1.34	5.72	1.39
53	1.02	0.28	1.30	1.35	5.53	1.27
Soybean						
100	0.93	0.42	1.35	1.32	5.71	1.45
150	0.90	0.42	1.32	1.31	5.63	1.31
200	0.90	0.42	1.32	1.31	5.68	1.35
Sole maize					4.10	
Sole soybean					4.85	
Intercrop					5.69	
lsd						
Maize density	0.11**	0.08**	NS	NS	NS	NS
Soybean density	NS	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS	NS
INt x sole					0.67**	

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%, total value calculated @ of Rs 8 and 26.36/kg for maize and soybean, respectively

Table 4.15. Effect of maize and soybean densities on partial LER of maize and soybean, LER (grain and biomass), total value and monetary advantage in maize/soybean system during 2002.

Density (x 10^3)	Partial LER maize	Partial LER soybean	LER grain	LER biomass	Total value (Rs/m^2)	Monetary Advantage
Maize						
26.5	0.84	0.56	1.41	1.32	6.18	1.78
40	0.97	0.48	1.45	1.40	6.15	1.90
53	1.05	0.40	1.45	1.44	5.91	1.80
Soybean						
50	1.01	0.44	1.45	1.33	6.01	1.84
100	0.92	0.51	1.43	1.42	6.14	1.83
150	0.93	0.50	1.43	1.41	6.09	1.81
Sole maize					3.47	
Sole soybean					5.94	
Intercrop					6.08	
lsd						
Maize density	0.08**	0.04**	NS	0.09*	NS	NS
Soybean density	NS	0.04**	NS	NS	NS	NS
Maize x soybean	NS	0.06*	NS	NS	NS	NS
Int x sole					0.46*	

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%, total value calculated @ of Rs 8 and 26.36/kg for maize and soybean, respectively

Table: 4.16. Effect of maize and soybean densities on partial LER of soybean during 2002 season, interaction effects.

Density ($x 10^3$)	Soybean density ($x 10^3$)			
Maize	50	100	150	Mean
26.5	0.55	0.59	0.55	0.56
40	0.43	0.49	0.54	0.48
53	0.32	0.45	0.41	0.40
Mean	0.44	0.51	0.50	0.48
lsd (0.05) for maize x soybean	0.06*			

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Biomass yield

Land equivalent ratio computed on the basis of above ground biomass production indicated that all treatment combinations of maize and soybean had a greater than unity value of LER. It indicated higher land use efficiency in biomass production than the monocrop. In 2002, maize density had a significant effect on LER and was ranked from highest at 53 x 10^3 plants ha^{-1} to lowest at 26.5 x 10^3 plants ha^{-1} but the difference between 40 and 53 x 10^3 plants ha^{-1} was not significant.

4.3.8.3 Total value of maize and soybean

In general, total value in term of Rs/m^2 was higher in 2002 than 2001. During 2002, maize grain yield was reduced but at the same time grain yield of soybean increased. Intercropping treatments (averaged over all intercrops) gave highest returns of Rs 5.69 and 6.08/m^2 during 2001 and 2002, respectively, whereas sole maize gave the lowest return of Rs 4.10 and 4.47/m^2 during 2001 and 2002, respectively. Sole soybean gave higher returns than sole maize but lower than intercropped treatments. Therefore valuations do not take into account input costs such as labour, seed, fertilizer, etc.

4.4.8.3 Monetary Advantage

As for LER, maize density of 26.5 x10^3 plants ha^{-1} and soybean density of 100 x 10^3 plants ha^{-1} in an intercrop gave highest monetary advantage of 1.46 and 1.45, respectively in 2001. In 2002, highest M. A. of 1.90 and 1.84 were obtained with a maize density of 40 x 10^3 and soybean density of 50 x 10^3 plants ha^{-1}, respectively.

4.4.9 Photosynthetic active radiation (PAR) measurement

The mean PAR values measured by Ceptometer at different strata within the intercropped canopy are presented in Table 4.17. The highest PAR was recorded above maize (ranging from 695 to 1964 over the season) and soybean canopy (733 to 1914(μmol $m^{-2}s^{-1}$) while intermediate levels of PAR were recorded above the intercropped soybean canopy which ranged from 171 to 540. The readings of PAR changed abruptly during partially cloudy days when the sun was covered by moving clouds. The lowest PAR was recorded at the base of soybean canopy at the last three sampling dates. The mean percentage of PAR intercepted by maize and soybean canopy, with significant effects, are presented in Appendix 4.30, 4.31, 4.32 and results are illustrated with figures.

Table 4.17 Mean PAR (μmol $m^{-2}s^{-1}$) above maize and soybean and below soybean canopy, measured during 2001 season.

Location	56 DAS	70 DAS	84 DAS	98 DAS	112 DAS
Above maize (n = 40)	1416 (645)	1964 (320)	695 (219)	997 (341)	992 (400)
Above int. soybean (n = 40)	464 (309)	540 (213)	171 (91)	298 (169)	377 (193)
Below int. soybean (n = 36)	209 (180)	156 (107)	20 (9)	43 (53)	35 (29)
Above sole soybean (n = 4)	1220 (875)	1914 (421)	733 (283)	1117 (620)	1201(256)
Below sole maize (n = 4)	226 (71)	420 (66)	123 (69)	194 (67)	302 (63)
Below sole soybean (n = 4)	724 (933)	268 (222)	6.5 (4.9)	8 (5.8)	30 (23.2)

Note: Figures in parenthesis are standard deviations

4.4.9 1 PAR interception by maize

Results of the proportion of PAR intercepted by maize canopy are presented in Appendix 4.30. Maize density had a significant effect on proportion of PAR interception throughout the growing period and was ranked from greatest at 53 x 10^3 plants ha^{-1} to least at 26.5 x 10^3 plants ha^{-1} population density. These effects were not significant at 70 and 112 DAS (Fig 4.42). At 112 DAS, a significant difference in PAR intercepted by the maize canopy between maize densities of 40 and 26.5 x 10^3 plants ha^{-1} was observed. Data showed that presence of soybean reduced percentage of PAR intercepted by intercropped maize compared to the sole crop at 84 and 98 DAS (Figure 4.43).

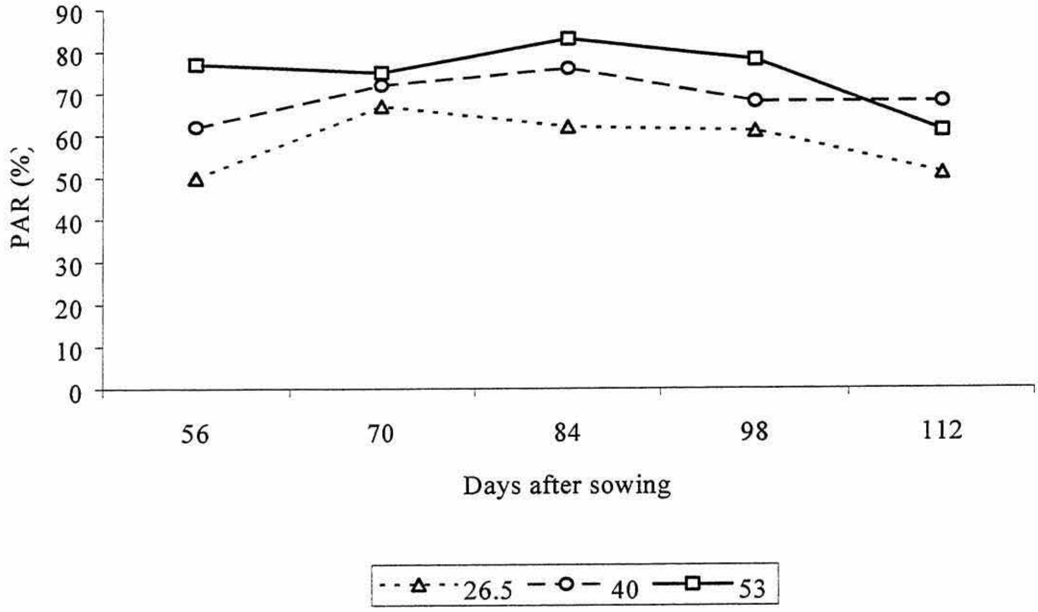


Figure 4.42. Effect of maize densities on % PAR intercepted by maize canopy measured at different dates in 2001 (Appendix 4.30)

As explained above, due to equipment failure in 2002, interception of PAR was recorded on only one occasion. The trend of proportion of PAR intercepted by maize was found to be similar to first season when measured at 112 DAS (Table 4.18). The standard maize density intercepted the highest proportion of PAR and the least was at a maize density of 26.5 x 10^3 plants ha^{-1}. This result was similar to the previous season.

4.4.9 2 PAR interception by intercropped soybean

Data on PAR intercepted by intercropped soybean are presented in Appendix 4.31 and Figures 4.44 and 4.45. There was a significant effect of maize density on interception of PAR by soybean at 84 DAS only (Appendix 4.31). Soybean density had a significant effect on the percentage of PAR intercepted by soybean and was ranked from lowest at 100 x 10^3 plants ha^{-1} to greatest at 200 x 10^3 plants ha^{-1}, but the effects were significant at 70 and 98 DAS only. There was a significant difference between sole and intercropped soybean on the percentage of PAR intercepted at all dates except for the first and last sampling occasions.

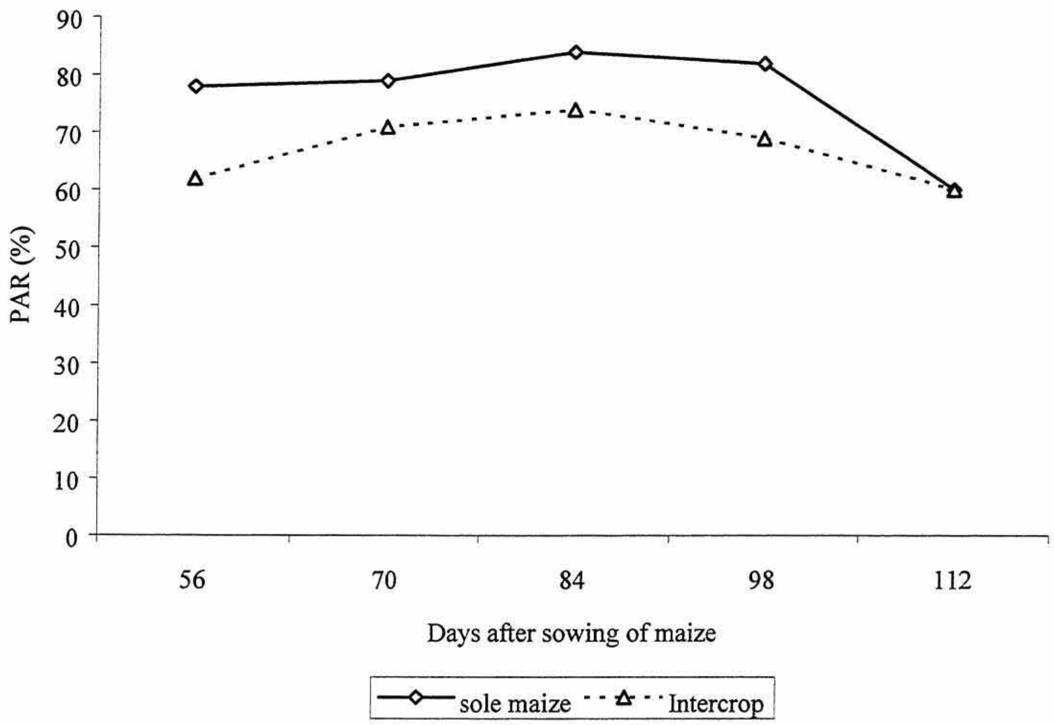


Figure 4.43. Effect of sole and intercropped maize on % PAR intercepted by maize measured at different dates during 2001 (Appendix 4.30)

Table 4.18 Effect of maize and soybean densities on % PAR intercepted by maize and soybean under maize/soybean intercropping at 112 DAS, 2002 season.

Density (x 10^3)	% PAR Interception	
	Maize canopy to top of soybean	Maize + Soybean canopy
Maize		
26.5	41	96
40	56	95
53	62	94
Soybean		
50	53	95
100	55	95
150	52	96
Sole maize	58	
Sole soybean		98
Intercrop	53	95
lsd		
Maize density	10.2	1.2
Soybean density	NS	NS
Maize x soybean	NS	NS
Int x sole crop	NS	1.6

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

In the second season, the proportion of PAR intercepted by soybean ranged from 94 % to 98 % (Table 4.18) which gave similar results to the first season (86 - 97 %). Maize density had a significant effect on PAR intercepted by soybean, ranked highest to lowest as maize density increased indicating an inverse relationship with maize density. Sole soybean intercepted more PAR than intercropped soybean at 112 DAS due to its greater LAI.

4.4.9.3 PAR Interception by whole canopy

At the first two recording dates, maize density had a significant effect on PAR intercepted by maize + soybean and was ranked from highest at 53 x 10^3 plants ha^{-1} to lowest at 26.5 x 10^3 plants ha^{-1} plant population. Effects were not significant for the last three dates (Appendix 4.32, Figure 4.46). The percentage of PAR intercepted by intercropped canopy was significantly greater than sole maize throughout growing season (Appendix 4.32, Figure 4.47). The sole soybean canopy intercepted the least PAR (55%) at the beginning (56 DAS), but increased linearly up to a plateau at 84 DAS (99%) and thereafter was constant up to 112 DAS (appendix 4.32, Figure 4.47). The sole maize canopy intercepted a maximum of 85% PAR at 84 DAS and then declined gradually as leaves senesced.

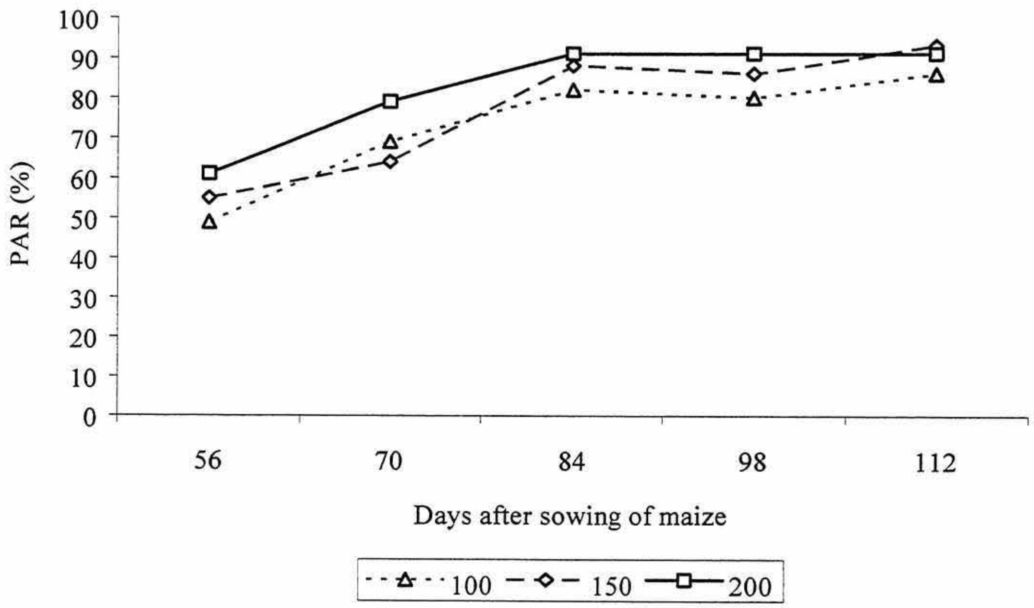


Figure 4.44. Effect of soybean densities on % PAR intercepted by soybean measured at different dates in 2001 (Appendix 4.31)

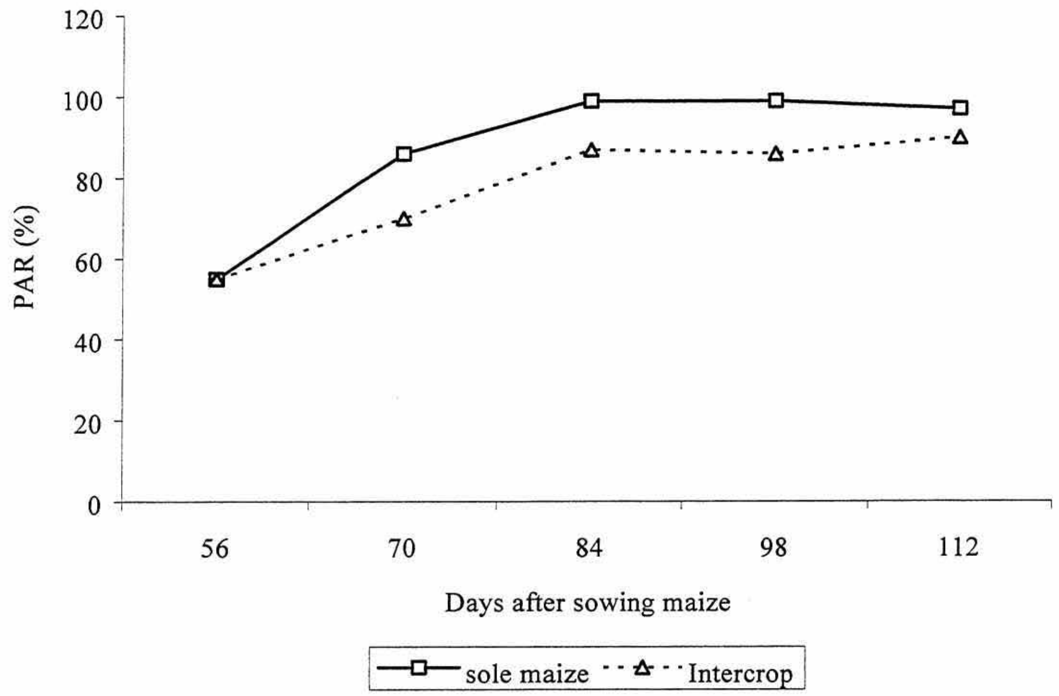


Figure 4.45. Effect of sole and intercropped soybean on % PAR intercepted by soybean measured at different date in 2001 (Appendix 4.31)

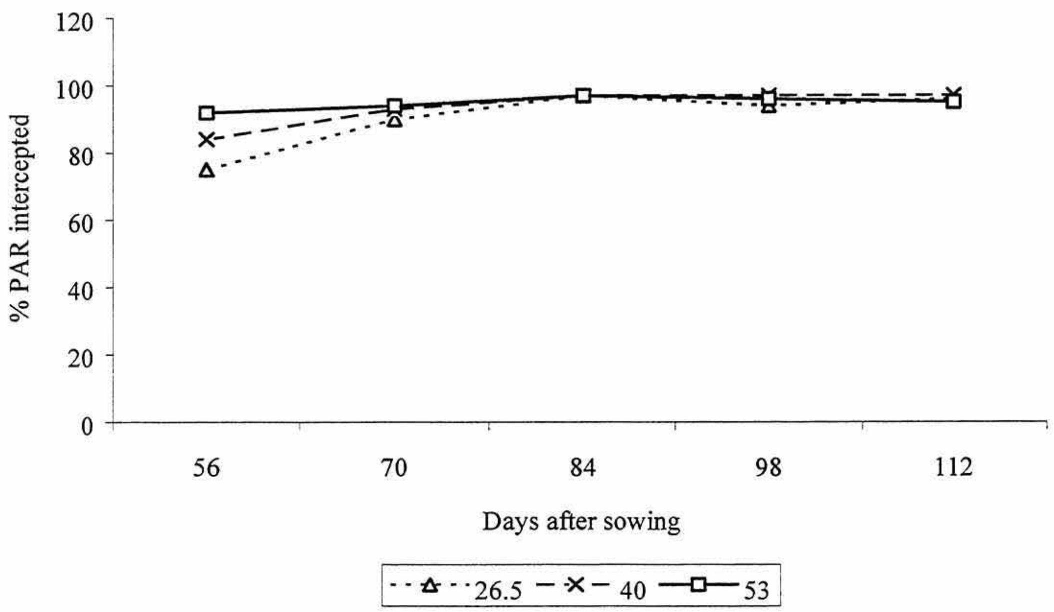


Figure 4.46. Effect of maize densities on % PAR intercepted by intercrop canopy measured at different dates in 2001 (Appendix 4.32)

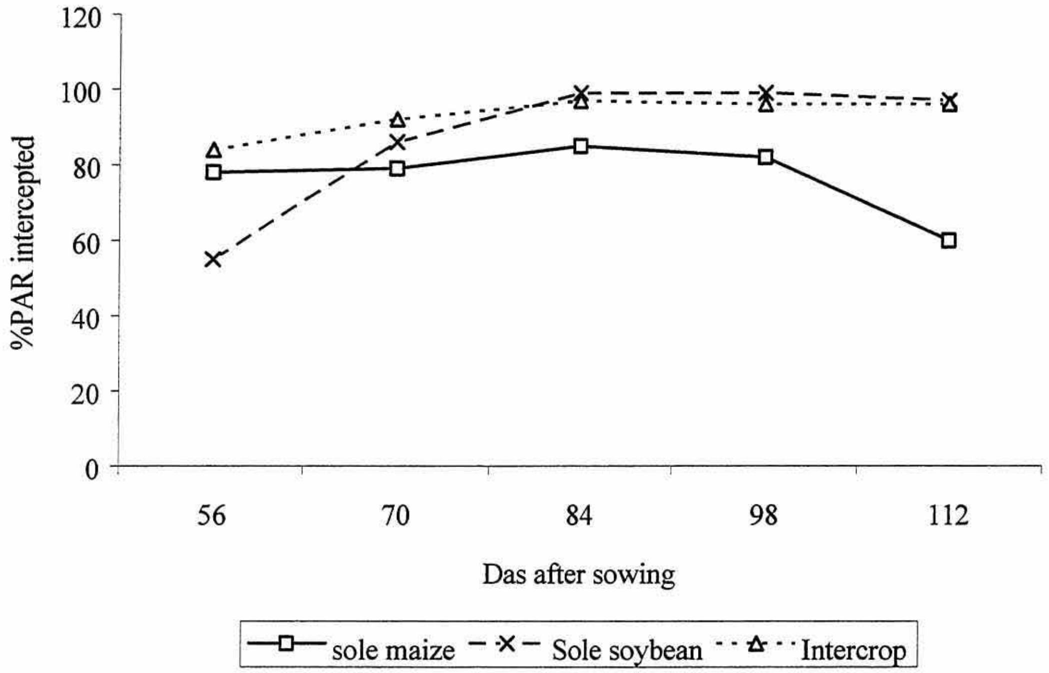


Figure 4.47. Mean of % PAR intercepted by sole maize and soybean and intercrop canopy measured at different dates in 2001 (Appendix 4.32)

4.4.10 Nutrient content and uptake

4.4.10.1 Nutrient content in straw and grains of maize

In 2001, there was no effect of any of the treatments on nutrient content in straw and grains of maize (Table 4. 19), but % N content in maize grains was significantly affected by maize density in 2002 (Table 4.20). It was ranked from highest at the lowest maize density and least at the highest density. In 2002, soybean density had also a significant effect on % N content in maize straw. Low soybean density (50 x 10^3) resulted in a higher % N content in straw of maize (1.23%) than 100 x 10^3 plants ha^{-1} (1.09%), but the difference between 50 and 150 x 10^3 plants ha^{-1} (1.18%) was not significant. In 2002, the presence of soybean reduced % K content in straw of maize compared to sole maize.

4.4.10.2 Nutrient content in straw and grains of soybean

Means of nutrient content in straw and grains of soybean are presented in Table 4.21 and Table 4.22 for 2001 and 2002, respectively. In 2002, the % N content in soybean straw was affected by maize density. A significantly lower % N content in straw was recorded when it was planted under maize at 26.5 x 10^3 plant ha^{-1} than 40 and 53 x 10^3 plants ha^{-1}, although differences between these latter two densities were not significant. In both seasons, maize density had a significant effect on % P content in straw. Soybean planted under low maize density (26.5 x 10^3) had significantly lower % P content in the straw than the other two higher maize densities in 2002 but the reverse response was observed in 2001. In 2001, only % P content in straw was higher with intercropped soybean, whereas all three major nutrients N, P and K were higher in the straw of intercropped soybean than sole soybean during 2002. There was a significant interaction on % K content (Figure 3.48), due to a significant increase in % K content with soybean density 50 x 10^3, at maize density of 26.5 x 10^3 plant ha^{-1}.

In 2002, nutrient content in soybean grains was not affected by any treatments but there was a significant difference between intercropped and sole soybean in % N and K content in 2001. Intercropped soybean had higher % N and K content in grains than sole soybean.

Table 4.19. Effect of maize and soybean densities on % nutrient content in grain and straw of maize grown as intercrop during 2001 summer season

Density (x 10^3)	Straw			Grains		
	% N	% P	% K	% N	% P	% K
Maize						
26.5	0.71	0.20	1.08	1.63	0.38	0.30
40	0.66	0.21	1.08	1.53	0.38	0.31
53	0.63	0.19	0.96	1.49	0.36	0.28
Soybean						
50	0.64	0.18	1.09	1.54	0.36	0.29
100	0.71	0.21	0.10	1.52	0.37	0.30
150	0.64	0.21	1.04	1.58	0.39	0.31
Sole maize	0.58	0.19	1.08	1.51	0.36	0.28
Intercrop	0.67	0.20	1.04	1.55	0.37	0.30

Table 4.20. Effect of maize and soybean densities on % nutrient content in grain and straw of maize grown as intercrop during 2002 summer season

Density (x 10^3)	Straw			Grains		
	% N	% P	% K	% N	% P	% K
Maize						
26.5	1.19	0.16	1.27	1.90	0.36	0.50
40	1.18	0.20	1.18	1.76	0.34	0.49
53	1.14	0.20	1.27	1.64	0.35	0.49
Soybean						
50	1.23	0.17	1.27	1.83	0.36	0.50
100	1.09	0.18	1.24	1.70	0.36	0.50
150	1.18	0.20	1.21	1.78	0.34	0.49
Sole maize	1.06	0.19	1.47	1.68	0.34	0.49
Intercrop	1.17	0.18	1.24	1.77	0.35	0.50
lsd (0.05)						
Maize density	NS	NS	NS	0.17*	NS	NS
Soybean density	0.098*	NS	NS	NS	NS	NS
Int x sole crop	NS	NS	0.14*	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

4.4.10.3 Nutrient uptake of maize

Data on nutrients uptake of maize and soybean are presented in tabular form in Table 4.23 for 2001 and Table 4.24 for 2002. In 2001, nitrogen, phosphorus and potassium uptake of maize was not affected by any treatments but maize density had a significant effect on N, P, and K uptake during 2002. The maximum uptake of N, P and K was recorded at 53 x 10^3 plants ha^{-1} and was reduced to lowest at 26.5 x 10^3 plants ha^{-1}

Table 4.21. Effect of maize and soybean densities on % nutrient content in grain and straw of soybean grown as intercrop during 2001 summer season

Density (x 10^3)	Straw			Grains		
	% N	% P	% K	% N	% P	% K
Maize						
26.5	2.24	0.27	1.77	6.54	0.74	1.57
40	2.10	0.24	1.68	6.49	0.74	1.55
53	1.95	0.23	1.74	6.42	0.74	1.52
Soybean						
100	2.01	0.23	1.73	6.73	0.74	1.56
150	2.14	0.25	1.71	6.22	0.73	1.51
200	2.06	0.25	1.75	6.51	0.76	1.56
Sole soybean	1.82	0.20	1.90	5.49	0.69	1.40
Intercrop	2.10	0.25	1.73	6.49	0.74	1.54
lsd (0.05)						
Maize density	NS	0.02**	NS	NS	NS	NS
Int x sole crop	N	0.03*	NS	0.68**	NS	0.10**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

Table 4.22. Effect of maize and soybean densities on % nutrient content in grains and straw of soybean grown as intercrop during 2002 summer season

Density (x 10^3)	Straw			Grains		
	% N	% P	% K	% N	% P	% K
Maize						
26.5	1.53	0.21	2.02	6.56	0.80	2.37
40	1.86	0.24	1.90	6.20	0.84	2.34
53	1.75	0.25	1.96	6.26	0.82	2.33
Soybean						
50	1.76	0.24	1.93	6.49	0.78	2.39
100	1.63	0.25	2.05	6.37	0.83	2.35
150	1.75	0.22	1.90	6.15	0.85	2.30
Sole soybean	1.34	0.17	1.77	6.72	0.86	2.32
Intercrop	1.71	0.24	1.96	6.34	0.82	2.35
lsd (0.05)						
Maize density	0.27*	0.038*	NS	NS	NS	NS
Maize x soybean	NS	NS	0.25*	NS	NS	NS
Int x sole crop	0.34*	0.05**	0.19*	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

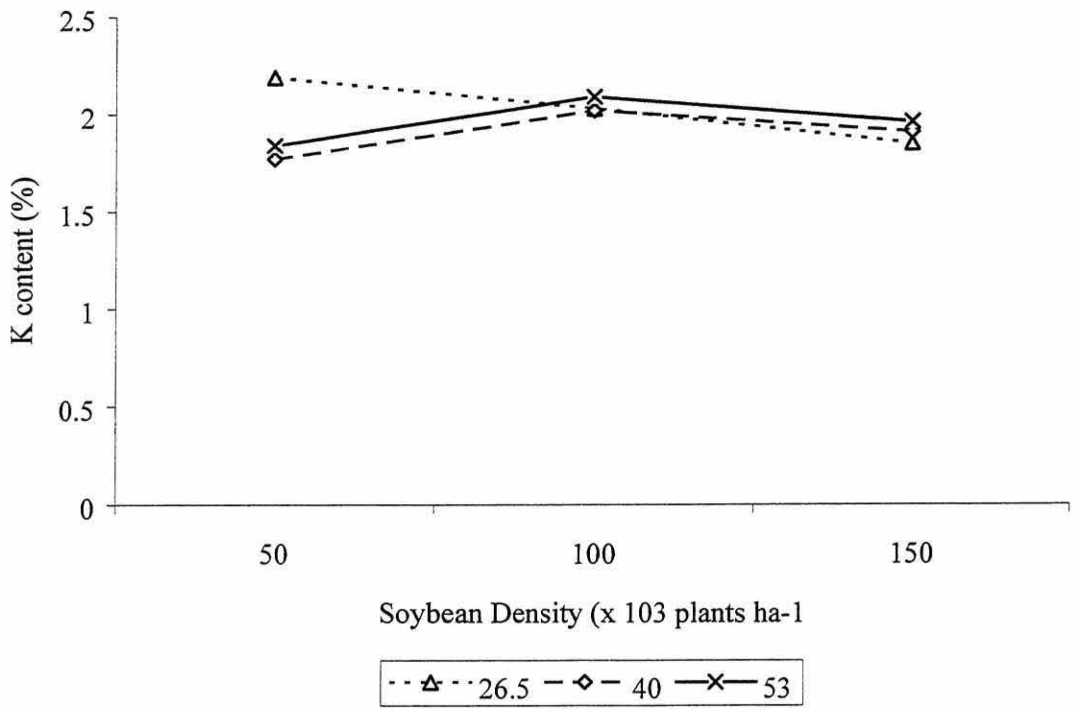


Figure 4.48. Effect of maize and soybean density on % K content in straw of soybean in 2002

maize density. There was no significant difference in any nutrient uptake between sole and intercropped maize.

4.3.10.4 Nutrient uptake of soybean

In both seasons, maize density had a significant effect on % N, P and K uptake of soybean and was ranked lowest at maize density of 53 x 10^3 to highest at 26.5 x 10^3 plants ha^{-1}. N, P and K uptake of soybean under recommended maize density was less than 40 and 26.5 x 10^3 plants ha^{-1}, but differences between these densities were significant only for N and K uptake in 2001 and P uptake in 2002.

In 2001, N uptake of soybean was not affected by soybean density, whereas it had a significant effect on N, P and K uptake of soybean during 2002. N, P and K uptake of soybean was significantly lower in the lowest soybean density (50 x 10^3 plants ha^{-1}) compared to the other two densities, although the difference between these densities was not significant. In both seasons, N, P and K uptake of soybean was reduced when planted under maize compared to sole soybean.

Table 4.23. Effect of maize and soybean densities on total nutrient uptake (g/m^2) by maize and soybean grown as intercrop during 2001 summer season.

Density (x 10^3)	Maize (g/m^2)			Soybean (g/m^2)		
	N	P	K	N	P	K
Maize						
26.5	9.78	2.46	7.21	9.09	1.05	4.04
40	10.38	2.89	7.67	7.79	0.90	3.62
53	11.33	3.02	8.27	5.12	0.60	2.26
Soybean						
100	10.45	2.64	8.31	6.95	0.81	3.03
150	10.50	2.84	7.36	7.09	0.85	2.24
200	10.54	2.89	7.47	7.96	0.88	3.34
Sole maize	10.57	2.79	8.38			
Sole soybean				15.23	1.83	8.27
Intercrop	10.50	2.79	7.71	7.34	0.85	3.31
lsd (0.05)						
Maize density	NS	NS	NS	1.46**	0.15**	0.76**
Int x sole crop	NS	NS	NS	1.88**	0.20**	0.98**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

Table 4.24. Effect of maize and soybean densities on total nutrient uptake (g/m^2) by maize and soybean grown as intercrop during 2002 summer season

Density (x 10^3)	Maize (g/m^2)			Soybean (g/m^2)		
	N	P	K	N	P	K
Maize						
26.5	11.39	1.87	7.00	10.32	1.29	6.26
40	12.97	2.36	8.03	8.85	1.20	5.06
53	13.76	2.69	9.65	6.99	0.95	4.08
Soybean						
50	13.44	2.29	8.30	7.79	0.96	4.36
100	12.08	2.30	8.47	9.24	1.26	5.63
150	12.61	2.33	7.90	9.12	1.23	5.4
Sole maize	12.39	2.44	9.44			
Sole soybean				19.33	2.48	11.70
Intercrop	12.71	2.31	8.23	8.2	1.15	5.13
Lsd (0.05)						
Maize density	1.69*	0.39**	1.08**	1.17**	0.16**	0.61**
Soybean density	NS	NS	NS	1.17**	0.16**	0.61**
Int x sole crop	NS	NS	NS	1.52**	0.20**	0.79**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%.

4.5 Discussion

4.5.1. Effect of maize density on maize

4.5.1.1 Plant growth

Competition between plants and their neighbours generally occurs in agricultural crops grown in communities and its intensity is a function of duration of interaction and competitiveness of plants. In a plant community, two individual plants interact such that one exerts a negative pressure on the other (Vandermeer, 1989). At wider spacing in intercropping, normally neither intra-specific nor inter-specific competition occurs; whilst at high density both types of competition occur to create a complex interaction (De Wit, 1960; Trenbath, 1974). The result of the experiments reported here showed that maize density had significant effects on maize LAI and shoot dry weight throughout the growing season in both seasons (Figures 4.5, 4.7, 4.11, 4.13). Maximum LAI and dry weight were obtained with the standard maize density (53 x 10^3) and these decreased with decrease in density. The leaf area index is a determinant of dry matter production in most agricultural crops, because leaves intercept and use photosynthetically active solar radiation (Patel *et al.*, 2000), which determines growth and yield of the component crop in intercropping provided other resources like nutrients and water are not limiting (Watiki *et al.*, 1993). LAI increases with increasing density, achieving its maximum at optimum density and declines with further increase in density due to intense intra-specific competition for growth resources above as well as below ground. In the present study, standard maize density intercepted a higher proportion of PAR than lower densities (Figure 4.42, Appendix 4.30) due to of greater LAI at higher plant population. Patel *et al.* (2000) reported that total dry matter production was strongly correlated ($r = 0.9^{**}$) with cumulative intercepted PAR.

Dry matter production in crop plants is directly related to the utilization of solar radiation (Daughtry *et al.*, 1983). In the present study, Figure 4.49 indicates that light interception increased curvilinearly with increasing LAI of maize at all densities, but the increment was greater with standard maize density because of its greater LAI, the maize canopy intercepting a maximum of 83% of PAR at LAI of 3.89. This result is similar to the finding of Wakiti *et al* (1993), where a maize canopy intercepted only 50% of solar radiation under low maize density because of its low LAI. Therefore, a lower maize density provides more penetration of light to the soybean canopy which increases LAI

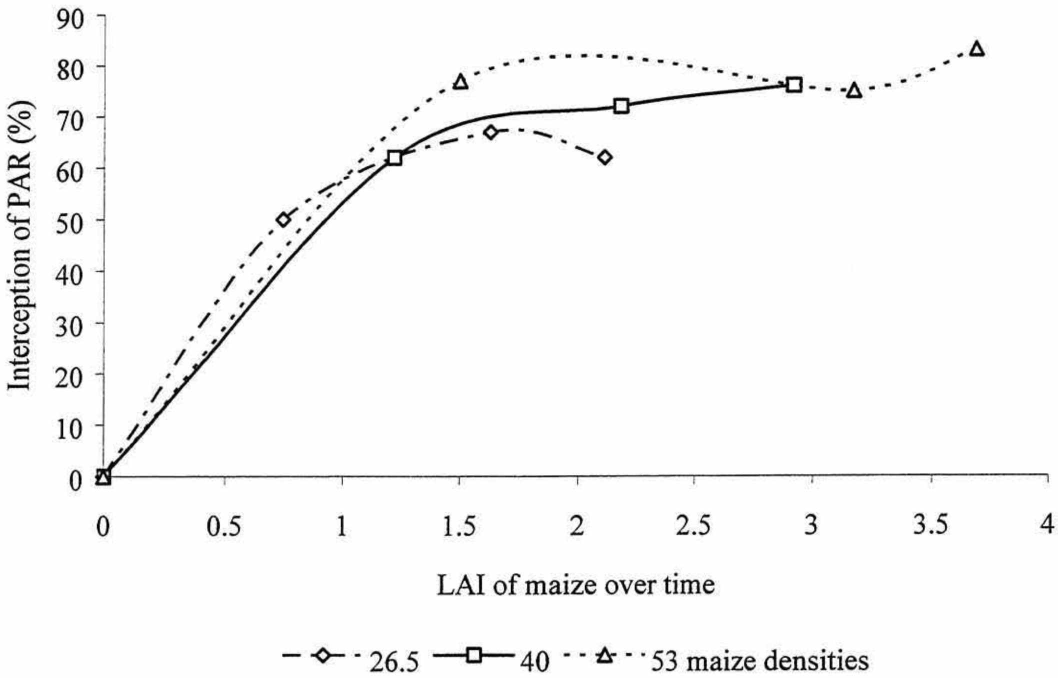


Figure 4.49. Effect of maize density and LAI on interception of PAR during 2001 season (Appendix 4.5, 4.30).

of soybean. In the present study, the interception of light by the intercropped soybean canopy increased with increasing LAI of soybean under all maize densities (Figure 4.50). The soybean canopy under the lowest maize density intercepted more light (92% PAR) at a LAI of 4.2 while least light interception (81%) was observed under standard maize density because of a lower LAI (2.89) of soybean. This finding is similar to Wells (1991) who reported that light interception by soybean was curvilinearly related to LAI until canopy closure (Wells, 1991). The maize crop alone is unable to utilize all the available solar radiation during its growing period (Figure 4.47). Similarly, sole soybean can not intercept all incoming radiation at an early growth stage due to incomplete canopy cover. In the present study, 95% interception of light occured in the combined canopy of maize and soybean at a combined LAI of 3 and levelled off thereafter (Figure 3.51). Similar observations were made by Aslam (1988), that a wheat crop grown at lower density intercepted a lower percentage of radiant energy and interception increased with increasing density in both the pure crop as well as in mixture with pea. Aziz (1984) showed a close relationship between leaf area and plant dry weight. This may explain the reason for a higher LAI and dry weight with higher maize density. This result is in agreement with Tetio-Kagho and Gardener, (1988) and

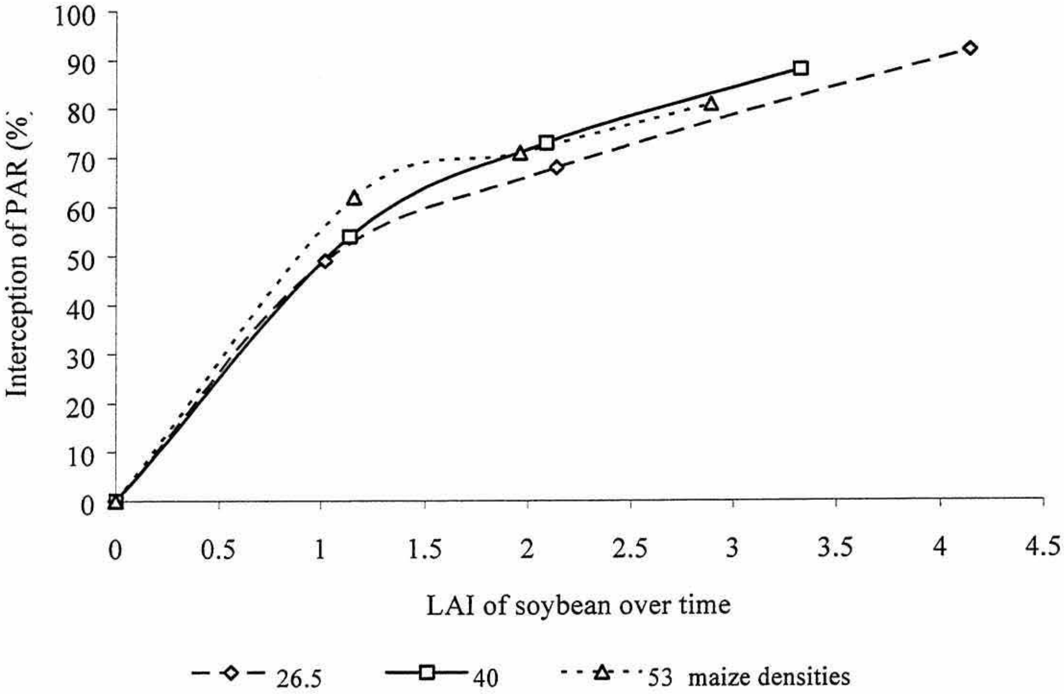


Figure 4.50. Effect of maize density and soybean LAI on interception of PAR by understorey soybean crop during 2001 (Appendix 3.19, 4.31)

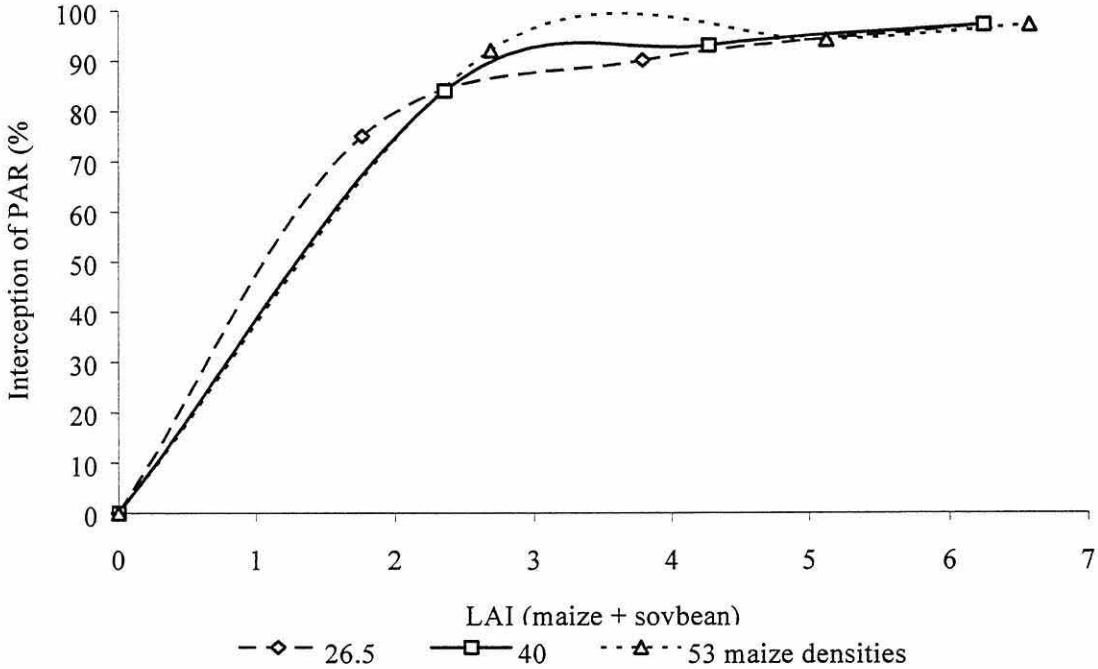


Figure 4.51. Effect of maize density and combined maize + soybean LAI on interception of PAR during 2001 (Appendix 4.5, 4.18, 4.32)

Chowdhury (1993), who reported that LAI and vegetative dry matter increased with increasing maize density from 1.9 to 6.3 plants/m^2. Quinglu *et al.* (1988) also recorded the highest plant dry weight and leaf area of maize at highest maize density. Harper *et al.* (1980) also reported that maize LAI increased linearly with plant density ($r = 0.92$). Conversely, Fourtan-Pour (1999) reported that maize leaf area index decreased with increasing maize density at 72×10^3 ha^{-1}, but this might be higher than the optimum density.

The finding that the density of maize was the most important controlling factor in these experiments was reinforced by the finding that CGR was highest in the densest maize and lowest in the least dense crop (Appendix 4.10, 4.11). Dry weight per plant is independent of density at early growth stages. As plants become bigger and the crop reaches canopy closure, competition for available resources starts, resulted in intra-specific competition and inter-specific if it is a mixed crop. Plants grown at low density (wider spacing) are less affected by intra-specific competition than at higher density. At the beginning, higher dry matter/m^2 was obtained with standard maize density compared to lower maize density simply because of the higher number of plants/m^2, as all densities had similar dry weight per plant. The greater LAI with standard maize density intercepted more solar radiation resulting in a higher crop growth rate. However, the increase in dry weight per plant was lower at higher densities due to greater intra-specific competition, compared to low densities, as crop growth progressed. This may have reduced the treatment effects in CGR due to maize density at later growth stages. Higher NAR was recorded at low maize densities during the later vegetative stage. NAR is the increase in dry matter per unit assimilatory leaf area (Hike, 1978), and declines as crop growth progresses because leaf area development gives rise to self shading of lower leaves. Lower leaves are older and less active photosynthetically which also contributes to the decline in NAR. At low maize density, there is less self shading of lower leaves due to a lower LAI compared to high maize density so photosynthetic rates are greater resulting in higher NAR at low maize density. Ahmad *et al.* (2000) found that CGR and NAR were higher in low maize density at later stages of growth. The difference in effect on CGR compared to the current work might be due to difference in growth period.

The trend for LAR was higher at the beginning in both seasons and declined as crop growth progressed. LAR is an index of "leafiness" in plant communities and in a estimate of the ratio of the potentially photosynthesing and potentially respiring components of plant. At the beginning, all leaves are photosynthetically active and there is relatively little non-productive respiring mass such as stem. As plant growth progressed, so stem weight increased. This may cause in decline in LAR at later growth stage. The results (Appendix 4.15) indicated that low maize density had a significant lower LAR than the other two densities during grain filling period, due to greater increase in dry weight per plant.

4.5.1.2 Yield and its components

Grain yield is the end result of all the interactions taking place within and between plants during the growth period. Subedi (1990) mentioned that crop yield is a function of yield per unit and number of plants per unit area. Any deviation from optimum population decreases grain yield. Among yield components of maize, plants/m^2, cobs/plant and grains/cob make major contribution to total grain production. The results (Tables 4.6, 4.7) showed that maize density had a significant effect on grain yield, plants/m^2, cobs/plant and grains/cob in both seasons except for cobs/plant in 2002. The highest grain yield was obtained at standard maize density (53 x 10^3) and declined as density decreased, while the reverse was the case for cobs/plant and number of grains/cob. Westgate *et al.* (1997) also reported that kernels per ear decreased with increasing plant population of maize. However, the greater number of cobs/plant and grains /cob at lower maize densities could not fully compensate for yield loss due to reduction in plant population, although yield loss was much less than the reduction of plant population by 25 and 50%. These results are supported by many authors, including Fisher (1977a); Putnam *et al.* (1985); Tariah and Wahua (1985), Robinson (1997) and Craufurd (2000). They reported that maize grain yield increased with increasing density. Similarly Mutungamiri (2001) found a 28 and 39 % yield increase when maize density increased from 24 to 37 x 10^3 plants ha^{-1} in respective seasons. This result confirms the finding of Fisher (1977a) who reported that maize yield per plant was only 30% lower at high density (60 x 20 cm) than yield per plant at low density (135 x 45 cm) in spite of a more than three fold increase in plant density.

Weight per grain is considered as a stable characteristic (Donald, 1958) which varies little in normal circumstances. However, in cases of significant changes to availability of resources for growth during grain filling, responses may be observed with this characteristic. In 2002, maize planted at wider spacing (26.5 x 10^3 plants ha^{-1}) produced heavier grains than in maize planted at standard spacing. In 2002, grain weight was positively correlated with cobs/plant and negatively correlated with plants/m^2 at harvest (Table 4.25) whereas the number of grains/cob was positively correlated with cobs/plant and negatively related with plant/m^2 in 2001. Rainfall was less in 2002 and maize yields were lower. Higher plant density increased barrenness and decreased kernel set per ear more drastically due to higher competition in poorer growing conditions, where inter-specific competition for resources such as soil moisture would have been greater. Overall production of maize grain was lower in the second season than the previous season. The total rainfall during the cropping period in the first and second seasons were 1151.6 mm and 1010.6 mm, respectively. The distribution of rainfall was also irregular during second season compared to first season (Figures 4.3 and 4.5). The maize crop is more susceptible to moisture stress at grain filling stage. The lower rainfall during late vegetative and grain filling stage of maize caused moisture stress which adversely affected on the number of cobs/m^2, and number of grains/cob and 1000 grain weight resulting in a lower grain yield of maize in second season. This finding is similar to that of Roy (1976), that grain weight of wheat declined with increasing density. Correlation coefficients between grain yield and yield components indicates that grain yield was positively correlated with number of plants/m^2 at harvest in both years and weakly negatively related with 1000 grain weight in 2002 only. This result is in agreement with Echarte *et al.* (2000) who reported that grain yield response to plant density was positively and strongly correlated and negatively and weakly related to weight per kernel. It clearly indicates that plants/m^2 at harvest was the major factor determining grain yield of maize.

Standard maize density produced the highest dry weight of straw and grains (Table 4.8, 4.9) and declined to lowest as maize density decreased. This was attributed due to a higher LAI in the standard maize density, than low density as explained earlier, because the dense crop intercepted more solar radiation, consequently more carbohydrate accumulation in leaves. Additionally, the longer leaf area duration (LAD) at standard maize density (Table 4.5) resulted in a greater opportunity for assimilation resulting in

Table 4.25 Correlation between grain yield and yield components (plant/m², cobs/plant, 1000 grain weight and grains/cob) of maize during 2001 and 2002 seasons.

Yield and yield components	Correlation (2001)				Correlation (2002)			
	Cobs/ plant	Plants/ m^2	Grain weight	Grains/ cob	Cobs/ plant	Plants/ m^2	Grain weight	Grains/ cob
Grain yield	0.43ns	0.75**	0.54ns	-0.23ns	0.15ns	0.77**	-0.52*	0.08ns
Cob/plant		-0.83**	0.01ns	0.74**		-0.32ns	0.57*	0.20ns
Plant/m^2			0.05ns	-0.59*			-0.89**	-0.30ns
Grain wt.				0.00ns				0.22ns

* ** indicates significance at p≤ 0.05 and p≤ 0.01, respectively, ns indicates that the correlation was not significant

higher biomass production compared to the low maize density. In both seasons, correlation between LAD and total biomass production (Table 4.26) of maize indicated that LAD of maize was strongly correlated with total biomass production, where sole crop was either included or excluded. The harvest index of maize was not affected, suggesting that maize reacted to competition by reducing the weight of grains to balance the loss of vegetative biomass, rather than altering its partitioning of resources. Similar observations were made by Carruthers *et al.* (2000) in maize and soybean intercropping.

Table 4.26 Correlation (r) between total biomass and leaf area duration of maize either including or excluding sole crop during 2001 and 2002 season.

	Total biomass (maize)			
	2001		2002	
	Including sole crop	Excluding sole crop	Including sole crop	Excluding sole crop
LAD	0.62**	0.62**	0.48**	0.66**

* ** indicates significance at p≤ 0.05, respectively, ns indicates that the correlation was not significant. Correlation analysis was done by both ways including or excluding sole crop

4.5.1.3 Nutrient content and uptake by maize

Maize planted at low density contained higher N content in maize grains than when planted at standard density in 2002 only (Table 4.19). Maize roots planted at wider spacing may explore a greater volume of soil and absorbs more nitrogen due to less intra-specific competition, resulting in a higher % N content in the grains.

Maize density also had a significant effect on uptake of N, P and K by maize in 2002 only (Table 4.23). The biomass of maize planted at standard density removed the greatest amount of N, P and K from the field than when planted at low density. This removal of biomass (grain and straw) at harvest causes depletion of plant nutrients in the field, more at higher maize density than lower. The difference in nutrient uptake due to season might have been due to variation in rainfall patterns. Higher and regular rainfall during the first season prevented stress resulting in higher production of both straw and grains than the second season.

4.5.2. Effect of soybean density on maize

4.5.2.1 Plant growth

When two crop species are grown together, the presence of one species may interfere with the other depending upon age, size and distance (Harper, 1977). In mixture, as the density of secondary crop increases, we expect an increasing negative effect upon the principal crop due to competition from the secondary crop. The result in this study (Figures 3.8, 3.14) showed that only in the second season did soybean density have a significant effect on LAI and shoot dry weight of maize, at 35 and 78 DAS. A significantly higher LAI and dry weight of maize were obtained when soybean was planted at 50 x 10^3 plant ha^{-1} rather than at 100 and 150 x 10^3 plants ha^{-1}. Maize is considerably taller than soybean and shades it, while soybean, being shorter, does not influence light interception of maize but may compete for plant nutrients and water from soil. At higher densities, soybean plants intercropped with maize may compete for nutrients and water and so suppress LAI and consequent dry matter production of maize. It clearly indicates that there is a close relationship between LAI and shoot dry matter production.

In the first season, soybean density had no effect on LAI and dry weight of intercropped maize but it had significant effect in the second season. This might have been due to inclusion of a low soybean density of 50 x 10^3 instead of 200 x 10^3 plant ha^{-1}. The difference between 100 and 150 x 10^3 plants ha^{-1} was not significant during the second season. It indicates that soybean density above 100 x 10^3 plants ha^{-1} exerts a negative effect on LAI and dry weight of maize.

4.5.2.2 Yield and its components

The present finding (Table 4.5. 4.6, 4.7, 4.8) showed that maize yield and components were not affected by soybean density. Maize, being dominant and having fast early growth, escapes competition from its companion crop. Soybean, being a weak competitor, did not affect light interception of maize but had to utilize unused solar radiation left by maize. This observation is in conformity with those reported by Heibsch *et al.* (1995) in maize/soybean, Chowdhury (1993) in maize/mungbean and Ifenkwe *et al.* (1989) in maize/potato intercropping.

4.5.2.3 Nutrient content and uptake by maize

Presence of soybean at low density (50 x 10^3 plants ha^{-1}) under maize increased percent N content in maize straw compared to higher soybean density (Table 4.19). This may be due to weak inter-specific competition at low soybean density and maize plants are able to extract more nitrogen from greater volume of soil resulting higher N content in maize straw.

4.5.3. Effect of intercropping on maize

4.5.3.1 Plant growth

The results of present study (Figures 4.6, 4.9) indicated that sole maize produced higher LAI than intercropped maize in both seasons except at the first sampling occasion in the first season. The main reason for lower LAI with intercropped maize is a difference in plant population, because it is an average of all densities. When LAI of sole maize was compared with intercropped maize at the same density, the difference was not significant. The results (Figures 4.12, 4.15) showed that presence of soybean decreased plant dry weight of intercropped maize compared to the sole crop at the first three sampling occasions in the first season and the second and fourth sampling occasions in the second season. One possible reason for decrease in dry weight with intercropped maize is variation of plant population as explained for LAI. At an early growth stage, dry weight per plant is similar in all treatments due to less intra-specific competition and variation in dry weight per unit area depends upon plant population only. As plant growth progressed, dry weight per plant of sole maize, planted at higher density was reduced due to more intra-specific competition compared to intercropped maize planted at a wider spacing. Therefore, the difference in dry weight per unit area between sole and intercropped gradually disappeared at later growth stages. This result is in agreement with Weil and McFadden (1991) who reported that cropping systems differed significantly for maize dry weight production because of maize population difference. Allen and Obura (1983) and Jana and Saren (1998) also reported that sole maize produced higher total dry matter than intercropped maize. Similarly, in sorghum/pigeonpea intercropping, Subramanian and Rao (1988) reported that total dry matter of sorghum was reduced by the presence of pigeonpea.

Crop growth rate of sole maize was greater than intercropped maize at an early growth stage. The growth of maize per plant is independent of density at early stage because of minimal intra-specific competition. Higher CGR of sole maize is attributed to greater LAI of sole maize whereas intercropped maize is an average of all intercropping treatments with different densities. As growth progressed, the increment in dry weight per plant was greater in intercropped maize due to reduced competition planted at wider spacing which may reduce difference in CGR between sole and intercropped maize at later growth stage. A similar observation was made by Mason *et al.* (1986) in cassava/peanut intercropping who reported that sole crop cassava had higher CGR (14.8 and 18.9 g $m^{-2}d^{-1}$) than when intercropped (11.9 and 12.3 g $m^{-2}d^{-1}$) between 80 and 150 and 150 and 212 DAP. The present study (Figure 3.18, 3.19) indicated that intercropping of soybean with maize suppressed leaf area ratio of maize in both seasons but at different stages of growth. The slow increment in leaf area in comparison to increment in dry weight per plant of intercropped maize may explain lower LAR in intercropped maize compared to sole crop.

4.5.3.2 Yield and its components

In the present study, intercropped maize produced only 9 % and 5.8 % less grain yield than sole maize during 2001 and 2002 seasons, respectively (Table 4.6, 4.7, 4.8, 4.9). The difference was not significant in either season, even though, there was a 50% reduction in plant population of intercropped maize from standard density to the lowest density. Similarly, dry weight of straw and grains were not affected by presence of soybean. In maize/soybean intercropping, maize is the dominant component (Haxley and Maingu, 1978) and being a C_4 plant, is usually more competitive at the expense of the legume (Maingi *et al.*, 2001). Thus, it indicates that maize yield was not affected by presence of soybean. This result confirms the finding of Yunusa (1989), Weil and McFadden (1991), and Carruthers *et al.* (2000) in maize/soybean, Ahmed *et al.* (2000) in maize/mungbean, Tariah and Wahua (1985) in maize/cowpea, Fisher (1977a) in maize/bean and Jana and Saren (1998) in maize groundnut intercropping. Searle *et al.* (1981) also explained that in cereal-legume intercropping, generally yield levels of cereal are reported to be similar to sole crop indicating no effect of competition from legume. Similarly, Singh *et al.* (1995) also reported that yield loss in maize due to intercropping was only12.4% while yield of blackgram was reduced by 31%.

The results on yield components indicated that intercropped maize produced lower number of plants/m^2 but heavier grains than the sole crop. Sole maize planted at a higher density produced lighter grains indicating higher intra-specific competition. Maize in mixture with soybean produced heavier seed at lower or intermediate densities. This finding is similar to finding of Aslam (1988) that wheat cultivars in mixture with pea produced heavier seed. Intercropped maize compensate for grain yield to some extent by increasing in number of grains/cob and grain weight.

4.5.3.3 Nutrient content and uptake by maize

Presence of soybean reduced potassium content in maize straw during 2002 only (Table 4.19). Total plant population in intercropped plots are higher due to combined population of maize and soybean. In intercropped maize, both crops compete for K resulting in lower absorption of K due to high inter-specific competition than sole maize. Potassium is a luxurious element in the soil and is taken up by sole maize in large quantities, although it is not essential for grains and reserves in straw resulting higher K content in straw of sole maize.

4.5.4. Effect of maize density on soybean

4.5.4.1 Plant growth

The result of present study (Figure 4.21) showed that maize density had a significant effect on plant height of soybean at first two sampling occasions in 2001. The height of intercropped soybean was significantly increased under standard maize density compared to low density. The maize has tall stature and quick growth, so becomes dominant and casts shade on the soybean (Maingi *et al.* 2000). Under shade, there is a tendency for plants to increase in height by elongation of internodes in an attempt to capture receive more light. Odeleye *et al.* (2001) also reported that soybean grown under 50% reduced light had a higher stem height per plant than grown under 75% light intensity. Standard maize density shaded soybean more due to its higher LAI than lower density. Under higher density of maize, soybean plants were narrower and more linear, with shoot developing in a plane perpendicular to the row, as competition was higher within than between rows (Foroutan-Pour *et al.*, 1999). This may explain the increased height of soybean planted under standard maize density. The genotype of soybean used in this experiment was a determinate type in which main stem elongation terminated at and sooner after flower initiation (Beaver and Johnson, 1981) whereas it continued for several weeks after flowering in indeterminate type and is governed by the genome. The difference in height due to maize density reduced as plant growth progressed at maturity and became insignificant at flowering and maturity.

LAI of soybean was significantly affected by maize density in the second season (Figure 4. 27). A lower LAI resulted when planted under standard maize density compared to low density, but the difference was only significant at the second and fourth sampling occasions in the second season. As explained above, the greater LAI of the maize canopy at standard density casts more shade on soybean and so reduces light penetration. Thus, the excessive shading caused by higher maize density reduced plant growth leading to a lower LAI of soybean. This finding is similar to Foroutan-Pour *et al.* (1999) who reported that light penetration and leaf area of soybean decreased with increasing maize density.

There was a significant reduction in dry weight of soybean when intercropped under standard maize density compared to low density (Figure 4.30, 4.33) but the effect was more pronounced in the second season. The dry weight of soybean in all treatments was higher in the second season. Soybean was planted 10 days after maize in the first year while it was planted at same time in second season, so in the first season, soybean suffered more from competition with maize. Regular rainfall during first year favoured maize growth but it also suppressed soybean. Excessive rainfall had an adverse effect on soybean resulting in lower dry weight in the first season. Similar observations were made by Carruthers *et al.* (2000) who reported that heavy precipitation had an adverse effect on a soybean crop planted in association with maize. Soybean planted under low maize density receives more light consequently increases dry matter production. Wakiti *et al* (1993) also supported this finding that maize canopy intercepted only 50% radiation during the 52 to 67 DAS period under low maize density because of its low LAI, thus allowing the remaining solar radiation to fall on the intercropped cowpea. Similarly, Haraguchi *et al.* (2000) reported that intercropped mungbean intercepted more solar radiation as planting density of maize decreased. This finding agrees with Tetio-Kagho (1988) in maize/soybean intercropping, who reported that LAI and dry matter accumulation in soybean was reduced under increased maize density. Rao and Mitra (1994) also found a 28% dry weight of groundnut increased when row spacing of pigeonpea was increased from 90 to 150 cm in groundnut/pigeonpea intercropping.

Intercropped soybean under low maize density had higher CGR and NAR than when planted under higher maize density (Figure 4.36). CGR is an estimate of photosynthesis per m^2 land whilst NAR is an estimate of photosynthesis per m^2 leaf area. Greater light interception is a major cause for higher NAR of soybean at low maize density. Higher maize density suppressed LAI of soybean by reducing light penetration to soybean canopy (Appendix 4.19, 4.20). At low maize density, greater LAI and light interception by soybean causes a greater increment in dry matter resulting in a higher CGR and NAR of soybean. This result is agreement with Wells (1993) who reported that soybean planted at a greater interplant spacing had large relative growth rate (RGR) and NAR during the early growth period. RGR is the dry weight increase per unit of dry weight present and per unit of time and is an estimate of investment a plant is making in new growth. However, it is more useful in ecological rather agronomic studies (Beadle, 1993). Similarly, Tetio-Kagho (1988) found that CGR of soybean reduced under increased maize density. The present study (Figure 4.39) indicated that a significantly lower LAR of soybean was obtained when planted under low maize density. Leaf area of soybean increases more under shade caused by higher maize density as a response to low levels of light. Thus, the rate of development of leaf area is higher than increment of dry weight of soybean resulting higher LAR under higher maize density than low maize density.

4.5.4. 2 Yield and its components

Maize density had significant effects on biomass, grain yield and number of pods/plant of soybean in both seasons (Table 4.12, 4.13). Grain yield of intercropped soybean was increased significantly by 96 % and 43 % during 2001 and 2002, respectively when maize density was reduced from 53 to 26.5 x 10^3 plants ha^{-1}. Similarly, biomass and number of pods per plant were also increased as maize density was reduced. Similar observations were made by Gardner and Craker (1981) in maize/bean intercropping, where the bean canopy received 50% of the incident light at low maize density compared to 20% at the highest maize density (55 x 10^3 plant/ha). In maize/ tall fescue intercropping, Harper (1980) reported that solar radiation transmission by a maize canopy with a LAI of 4.2 was below the optimum insolation level for intercropped tall fescue and reduced its yield by 30 %. Similarly Vandermeer (1989) reported that shading by tall cereals reduced soybean photosynthesis and consequently N_2 fixation. Reduced light intensity was more damaging to soybean performance at the pod filling stage and caused great yield reduction (Odeleye *et al.*, 2000). Mathew *et al.* (2000) explained that reduced light at early stage of soybean development would decrease availability of assimilate to developing reproductive structures, decrease flowering and increase flowering and pod abscission resulting in a decrease in number of pod/plant at harvest. Among yield components of soybean, the number of pods/plant is closely related to yield and the factor most affected by competition (Hume *et al.*, 1985). Similarly, in the current work, grain yield and number of pods/plant were strongly correlated (Table 4.27). Thus, biomass, grain yield and number of pods/plant are reduced with increasing density of maize. The results of the present experiment are in conformity with the observations of Putnam *et al.* (1985) and Heibsch *et al.* (1995) in maize/soybean intercropping who reported that the yield of intercropped soybean was suppressed at high maize density and affected negatively by increasing maize density. Similar observations were made by Saloman *et al.* (1995) and Fisher (1977) in bean/maize, Ahmed *et al.* (2000) in maize/mungbean, Craufurd (2000) in maize/cowpea and Wahua and Miller (1978a) in sorghum/soybean intercropping. Rao and Mittra (1994) also reported that pod yield of groundnut was increased by 27% when pigeon pea spacing was changed from 90 cm to 150 cm. Shinde *et al.* (1990) reported that the yield of groundnut declined with increasing population of pigeonpea and *vice versa*.

A significantly lower weight per grain of soybean was recorded when planted under low maize density in the second season. The 100 seed weight gives an indication of the ability of the plant to meet sink demand during grain filling (Putnam *et al.*, 1992). The number of pods/plant was lower under high maize density, indicating abortion of pods

Table 4.27 Correlations between grain yield and yield components (plants/m^2, pods/plant, 100 seed weight and seed/pod) of soybean during 2001 and 2002.

Yield and yield components	Correlation (2001)				Correlation (2002)			
	pod/ plant	seed /pod	seed weight	plant/ m^2	pod/ plant	Seed/ pod	seed weight	plant/ m^2
Grain yield	0.90**	0.34ns	0.46ns	-0.09ns	0.93**	0.03ns	-0.47ns	0.24ns
pod/plant		0.09ns	0.37ns	-0.20ns		0.17ns	-0.66*	-0.48ns
Seed/pod			0.45ns	-0.08ns			-0.18ns	0.39ns
Seed wt.				-0.20ns				-0.48ns

* ** indicates significance at $p \leq 0.05$ and $p \leq 0.01$, respectively, ns indicates that the correlation was not significant

due to inadequate resources to retain them. Subsequently, photosynthates manufactured in leaves were translocated to the limited number of sink (pods) resulting in heavier grains under higher maize density particularly as maize was harvested three weeks before soybean, thus removing inter-specific competition during grain filling. The correlation analysis showed that pods/plant and seed weight were negatively correlated during 2002.

4.5.3.3 Nutrient content and uptake by soybean

Soybean planted under low maize density had lower N and P content in straw than when planted under higher maize density in 2002 (Table 4.21, 4.22). However, the reverse result was obtained in the case of P content in first season. At low maize density, soybean was planted 50 cm apart from maize row while it was planted closer to the maize row in higher density. Soybean planted under higher maize density may have received fertilizer applied to the maize crop, because chemical fertilizer was not applied to the soybean crop. This may have resulted in higher N and P content in soybean straw when planted under high maize density. Higher rainfall during first season may have increased availability of P in straw when planted under wider spacing and low maize density. Secondly, soybean plants may experience weak competition from maize resulting higher absorption of P.

The present study indicated that soybean planted under low maize density had greatest total uptake of N, P and K into straw and grains at harvest compared to soybean planted under high maize density Table 4.23, 4.24). Higher biomass and grain production of soybean with low maize density may explain the reason for higher nutrient uptake by soybean plants.

4.5.5. Effect of soybean density on soybean

4.5.5.1 Plant growth

The results (Figure 4.23) showed that soybean density had a significant effect on height of soybean only in 2002 except at first sampling occasion. Plant height increased as soybean density increased. At the beginning, plant heights were similar at all densities due to absence of competition. As plant growth progressed, both types of competition (intra and inter-specific) increased when plant canopy achieved closure. Plants compete for light above ground and for nutrients and water below ground. At higher plant densities, intra-specific competition is greater than inter-specific. Plants of same species compete for light by increasing height due to elongation of internodes. Thus, it explains the reason for the increase in plant height at higher soybean density. This result is similar to finding of Aslam (1988) that plant height of bean increased with increasing density. Sometimes higher density reduces the survival and increases mortality in the individuals, called "self-thinning" (Harper, 1977: Anto Vice and Levit, 1980). Although data are not reported, mortality of some soybean plants did occur at the highest density of both crops.

LAI and shoot dry weight of soybean increased with increasing density in both seasons but difference in dry weight was not significant at the last two sampling occasions in the first season (Figures 4.25, 4.28, 4.31, 4.34). As explained, in section 4.4.1.1, leaf area is a determinant of dry matter production and it increases with increasing density and reaches the plateau at optimum population. Any deviation from the optimum population may have adverse effects. Increasing trend of LAI and dry weight with density indicates that densities included in this experiment are within the optimum range. In present the study, higher soybean density intercepted more PAR than lower density but the difference was significant only at the second sampling occasion (Appendix 4.31). Incoming radiation is intercepted by maize canopy and only the remaining PAR reached to the soybean canopy which may have caused the insignificant results. Change in plant population was a major reason for higher LAI and dry weight with higher soybean density. This result agrees with Aslam (1988) that biomass production of bean/m^2 increased with increasing density.

Results (Appendix 4.24, 4.26) showed that soybean density of 50 x 10^3 plant ha^{-1} had lower CGR than the higher densities while the reverse was true with NAR at an early growth period. At early stage, plant dry weight per plant is independent of density, because of low requirement for growth resources. Therefore, differences in CGR due to density were only due to variations in plant population. The greater CGR at higher soybean density was attributed due to greater LAI at higher density. However, at later growth stage, the increment in dry weight per plant increased more at lower density than higher density due to reduced intra-specific competition which may have reduced the difference in CGR due to density at a later growth stage.

Competition for light is the major factor inducing morphological changes in plants when plant density is increased. This was reflected in lower NARs at higher densities. In early growth stages, most of the leaf area may be effective, but as the open space between plants decreases, the effectiveness of the leaf area declines because of mutual shading of leaves. The more rapid canopy closure and greater LAI of higher soybean density induced competition for light at an early stage compared to in lower densities, lowering photosynthetic efficiency. High density resulted in smaller increments in dry weight of soybean than at lower density, which may have caused lower NAR at higher soybean densities. This result is in agreement with the findings of Herbert and Litchfield (1984), who reported that NARs were greater throughout the season for the low density compared to high density of soybean.

4.5.5.2 Yield and its components

Soybean density had no effect on yield and components of soybean in the first season (except for harvest index) while it had significant effects on biomass, grain yield, number of pods/plant and harvest index in second season (Table 4.12, 4.13). Lower soybean density resulted in a lower grain and biomass yield than the other two densities, while the reverse was true for pods/plant and harvest index. Overall, grain yield was higher in second season, as lower rainfall during the second season favoured the growth of soybean. Inclusion of a lower density of 50 x 10^3 plants ha^{-1} instead of 200 x 10^3 plant ha^{-1} may have also affected significance of results in the second season, because difference the between 100 and 150 x 10^3 plants ha^{-1} was not significant for biomass, grain yield and harvest index. It indicated that soybean yield does not increase above 100 x 10^3 plants ha^{-1}. Similar observations were made by Carpenter and Board (1997), who reported that soybean yield increased by only 9 % when plant population increased from 70 to 234 x 10^3 plants ha^{-1}. Among yield components, seeds per pod and seed weight were not affected and generally these are strongly genetically determined. At low density, the number of pods/plant increased due to low intra-specific competition. This finding was similar to that reported by Yunusa (1989), that the number of pods/plant of soybean was reduced with increase plant density in mixture. Similarly Aslam (1988) reported that highest number of pods of bean was obtained at the lowest density. However, increased number of pods/plant at low soybean density could not compensate for yield loss due to reduced plant population. The lower LAI and dry matter production at lower soybean density may also have caused for lower grain and biomass production in 2002. In addition, the lower LAD of soybean at low density (Table 4.10) provided a shorter opportunity for assimilation causing lower biomass production. The correlation between LAD and total biomass production of soybean (Table 4.28) indicated that LAD was significantly correlated with total biomass production when sole crop included in 2001 and either included or excluded in 2002. These results are in agreement with Fisher (1977) who reported that seed yield of bean decreased with increasing plant density. A higher harvest index at low soybean density indicated that plants at lower density experienced less stress and were more efficient in partitioning of resources to grains.

4.5.5.3 Nutrient content and uptake by soybean

Soybean density had no effect on nutrient content in either straw or grains in either season (Table 4.21, 4.22). It indicated that nutrient uptake was not affected by the stress caused by soybean density. It is a poorer competitor for nutrient absorption than maize. At higher densities, biomass and grains of soybean removed greater quantities of N, P and K from the soil than at lower densities but differences in P and K uptake by soybean were not significant in the first season (Table 4.23, 4.24). Higher uptake of these nutrients at higher density was due to greater crop dry weight per unit land area.

Table 4.28 Correlation (r) between total biomass and leaf area duration in soybean either including or excluding sole crop during 2001 and 2002 season.

	Total biomass (soybean)			
	2001		2002	
	Including sole crop	Excluding sole crop	Including sole crop	Excluding sole crop
LAD	0.55**	0.29ns	0.74**	0.59**

** indicates significance at p≤ 0.01, respectively, ns indicates that the correlation was not significant. Correlation analysis was done by both ways including or excluding sole crop.

4.5.6 Effect of intercropping on soybean

4.5.6.1 Plant growth

The results (Figure 4.22, 4.24) showed that plant height of soybean was greater when planted under maize than sole crop but the difference was not significant at the first two sampling occasions in the first season. However, the opposite result was obtained at harvest during the first season. This result is similar to the findings of Carruthers *et al.* (2000) who reported that plant height of intercropped soybean was 15 to 20 cm greater than monocropped soybean. Similarly Marchiol *et al.* (1992) reported that intercropping increased soybean plant height compared to pure stand. Bhatta *et al.* (2002) also reported that plant height of legumes increased with decreasing light intensities, reaching a maximum at 50 % light intensity. Excessive rainfall during the first season may have enhanced vegetative growth of sole soybean resulting in increased plant height at harvest, while the more vigorous growth of maize may have suppressed the growth of intercropped soybean.

LAI and plant dry weight of soybean were suppressed when grown under maize compared to sole crop throughout the growing season except at first sampling during the first season (Figure 4.26, 4.29, 4.32, 4.35). The proportion of PAR intercepted by the sole soybean crop was greater than by the intercropped soybean (Fig 4.52). The presence of maize canopy reduced light interception by soybean canopy and caused an adverse effect on the growth of the companion crop. Reddy and Chatterjee (1973) reported that soybean under tall canopy was receiving less than 50% of incoming radiation. Profiles of light intensity and leaf area indices in crop canopies indicated why sole soybean produced more dry matter than intercropped soybean, a shade caused by maize canopy suppressed LAI and thus dry weight of intercropped soybean. Similar observations were made by Behairy (1994) in maize/soybean, Chowdhury and Rosario

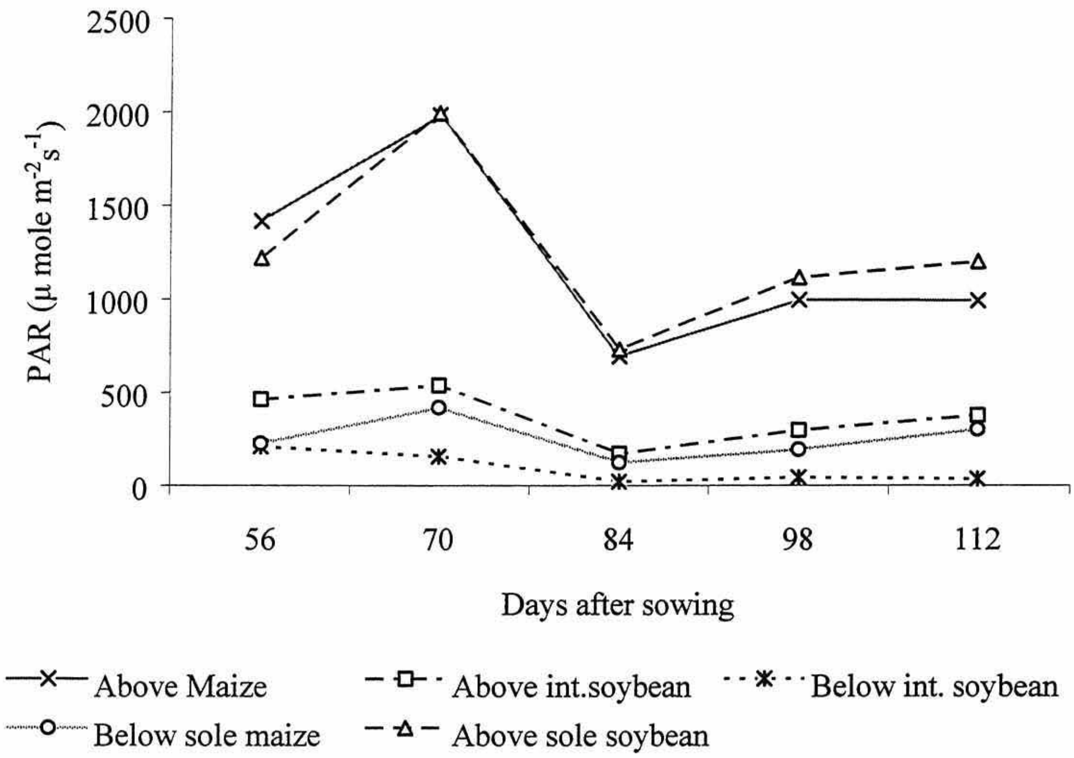


Figure 4.52. PAR (μmol $m^{-2}s^{-1}$) recorded above and below maize, intercropped and sole soybean canopies measured over time in 2001 (Table 4.17)

(1992) in maize/mungbean, Thakur and Sharma (1988) in maize/groundnut and Devkota and Rerkasem (2000) in maize/lablab and Rao and Mittra (1994) in pigeonpea/groundnut intercropping. Eriksen and Whiteney (1984) also reported that shading caused a 34 % reduction in dry matter production of soybean.

The results of the present experiment (Figure 4.36, 4.38) indicated that intercropped soybean had a significantly lower CGR and NAR than the sole crop throughout the growing season but differences were not significant during the second and last sampling intervals in the first season and second sampling interval in the second season. The increment in dry weight production of intercropped soybean was reduced due to stress caused by shading by maize. Reduction in light interception by soybean (Figure 4.52) was the main cause for reduced CGR and NAR of intercropped soybean. These results agreed with those of Chandel *et al.* (1993) who reported that intercropping decreased the NAR of soybean by 61.0 to 73.1 % at 45 DAS and 39.8 %- 51.3 % at 60 DAS. Egli (1988) reported that shading caused large reduction in crop growth rate of soybean at growth stage R1 to R5 (beginning of blooming to beginning of seed formation, Borton, (1997)).

A significantly higher LAR for intercropped soybean was recorded than sole crop in both seasons but the difference was not significant at the first and last sampling events in the first season (Figure 4. 40, 4.41). Leaves of intercropped soybean are larger and thinner due to shading caused by maize canopy (Redfearn *et al.*, 1999). Reduced light interception by intercropped soybean canopy reduced photosynthetic rate resulting in a lower increment in dry matter production than sole soybean. This result is in agreement with Bowes *et al.* (1972) who reported that shading of legumes caused elongated growth and increased leaf area per unit of plant weight (LAR).

4.5.6.2 Yield and its components

It was observed that due to intercropping, there was a reduction in biomass and grain yield as well as number of pods/plant of soybean compared to the sole crop (Table 4.12, 4.13) whereas, 100 seed weight and harvest index were increased with intercropping. The reduction of soybean yield in this experiment was likely to have been due to shading of soybean by faster growing maize. Shading not only reduced vegetative growth but also resulted in fewer flowers. Egli (1997) reported that shading created stress by reducing photosynthesis and assimilate supplies to the seed during seed filling. The translocation of essential assimilates is reduced considerably under low light (Lim and Hamdan, 1984: Rao and Mitra, 1990) and the increase in shading at maximum flowering thus affected the supply of photosynthates and caused abortion of flowers initials. The number of pods/plant is the component most influencing yield and was greatly affected by intercropping. Wahua and Millar (1978c) reported that in comparison to unshaded soybean, grain yield was decreased by 90, 75, 48, 18 and 2 % when it was shaded by 20, 47, 63, 80 and 93 %, respectively. Similarly, Sharma and Manchandra (1988) reported that effects of shading (50%) on chickpea (*Cicer arietinum*) applied at nodule initiation stage or anthesis decreased yield through lowering seeds/pod and 100-seed weight. It clearly indicates that shading reduced biomass, grain yield and number of pods/plant in intercropping. This finding is in agreement with Yunusa (1989), Weil and McFadden (1991), Khola *et al.* (1999), Allen and Obura (1981) and Carruthers *et al.* (2000) in maize/soybean, Blaise and Giri (1996) in groundnut/sunflower, Tariah and Wahua (1985) and Haizel (1974) in maize/cowpea, Santella *et al.* (2001) in maize/bean, Kavamahanga *et al.* (1995) in sorghum/pigeonpea, Subramanian and Rao (1988) in sorghum/pigeonpea, Rafey and Prasad (1992) in maize/pigeonpea and Refey and Verma (1988) in pigeonpea/soybean intercropping. Similarly, Dalal (1977) mentioned that the poor performance of intercropped soybean was attributed due to shading by the tall maize crop when grown together. May (1982) also reported that monoculture green gram produced more pods per plant than when intercropped.

Heavier grains were produced with intercropped soybean than sole crop. In intercropping, shading created more stress on the soybean plant causing more abortion of seed bearing pods compared to the sole crop. During the grain filling period, photosynthates manufactured in leaves are transported to a reduced number of pods resulting in heavier individual grains and hence the inverse relationship seen in 2002 (Table 4.27). The higher harvest index with intercropped soybean indicated that soybean plants reacted to stress caused by shading by partitioning more photosynthates to grains.

4.5.6.3 Nutrient content and uptake by soybean

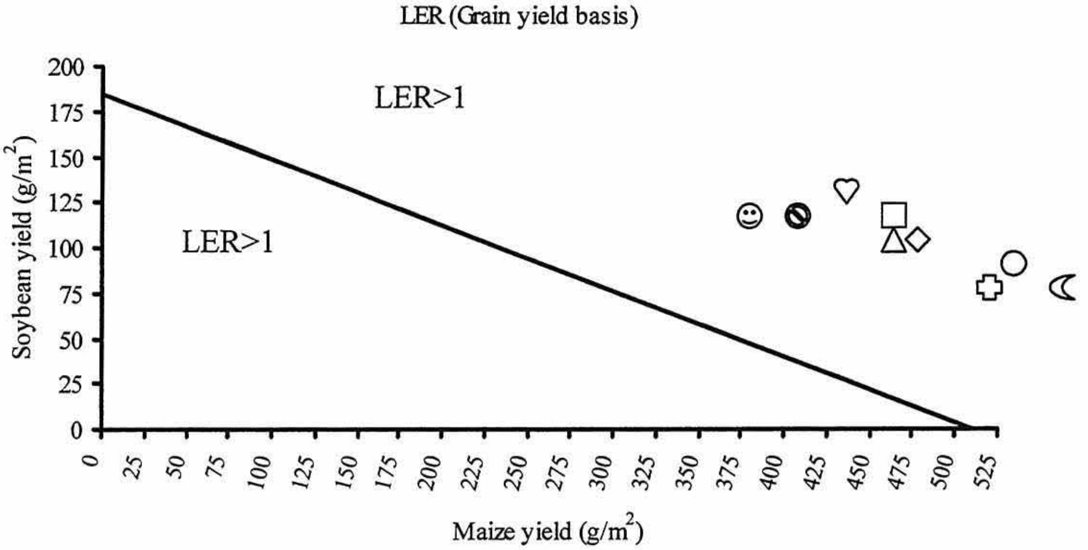
The results (Tables 4.21, 4.22) indicated that intercropped soybean had higher N, P, K content in straw than sole soybean but the difference in N and K content was not significant in the first season. Similarly, intercropped soybean had higher N and K content in grains in the first season. Chemical fertilizers were not applied to sole soybean whereas it was applied to maize in intercropping treatments. Intercropped soybean may have benefited from fertilizers applied to maize. Secondly, greater dry matter production of sole soybean might have decreased concentration of nutrients possibly due to a dilution effect, Thirdly, the intercropping treatment was an average of all populations some of which may have absorbed more nutrients at wider spacing. It was observed that (Table 4.23, 4.24) that N, P, K uptake by sole soybean was almost double compared to intercropped soybean. Higher biomass and grain yield with sole soybean contributed to higher uptake of N, P, K. This result agrees with Thakur and Gupta (1987) who reported that pure blackgram removed higher amounts of N, P, and K from soil than intercropped blackgram.

4.5.7 Effect of intercropping in totality

Yield advantage in intercropping is achieved only when component crops do not compete for same resources as a result they require these resources at different growth stages and from different layers of the soil. Intercropping gives total higher yields than their sole crops if their mutual competition is sufficiently weak i.e inter-specific competition is weaker than intra-specific. Comparisons between partial LERs can indicate the competitiveness of individual species. In the present experiment, the maize yield was higher than expected in all mixtures (Tables 4.14, 4.15). This indicated that maize utilized more environmental resources than those allocated to it at planting, and that maize was the more competitive species. On the other hand, mean partial LER value for soybean was lower than expected (Tables 4.14, 4.15) indicating that soybean was less competitive than maize. The greater competitive ability of maize can be explained in several ways. First, maize being a dominant cereal and having fast initial growth, intercepts most of the incoming solar radiation and casts shade on the soybean. Secondly, maize is a shallow rooted crop and its roots are extensively distributed in upper layers of soil and absorb most available plant nutrients and water in large quantities from a greater volume of soil. Ofori and Stern (1987) reported that in cereal-legume intercropping, the cereal component, with relatively higher growth rate, height advantage, and a more extensive rooting system, is favoured in competition with associated legumes. On the other hand soybean is less competitive due to its short stature and so is suppressed by shading by maize. Soybean has a deep rooted system, and exploits nutrients from deeper layers of soil where there is reduced competition (Cheema, 1987) and withstands drought to some extent. Beets (1975) also reported that soybean has many roots below the root system of maize where they capture nutrients which have slipped past the maize root hairs. It does not depend much on soil nitrogen, because it fulfils its requirement through biological nitrogen fixation. This complementarity in resource utilization resulted in higher total production.

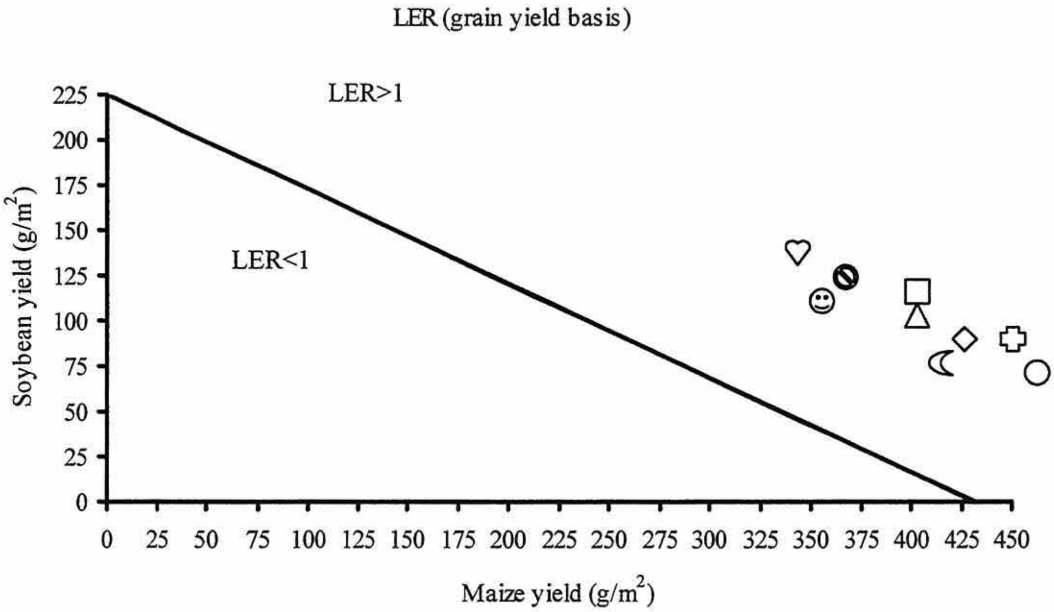
The sharing of light by two crops can be considered to be important in their ultimate performance in an intercropping system. In the present study (Figures, 4.47, Appendix 4.32), it was observed that sole maize was not efficient at intercepting all incoming solar radiation during the growing period. Maximum PAR interception was 85% at tasseling and during the early grain filling period and 40% PAR was not used at late maturity stage. The combined canopy of maize and soybean intercepted a higher proportion of % PAR throughout the growing season, resulting in efficient resource utilization and a higher total yield of the intercrop. Similar results were obtained by Ramakrishna and Ong (1994) that intercropping increased the amount of radiation intercepted due to faster canopy cover of component crops. Fisher (1976) also reported that in Tanzania, a mixture of maize and bean captured 13% more light than monocrop maize and 6% more than monocropped bean. Similarly, Ennin *et al.* (2002) reported that intercropped maize and soybean intercepted more PAR than sole maize.

Generally, intercropping allowed better exploitation of available resources by crops, resulting greater total yield as reflected in LER and M A. The graphical presentation of LER (Figures 3.53 and 3.54) showed a LER value greater than unity indicating that intercropping of maize and soybean at any combination of densities tested a gave yield advantage over both sole crops in both seasons. The intercept of the y axis represents sole soybean yield, and the intercept of the x axis represents sole maize yield. This shows that sole maize yields are identical or little higher at the same intercropped density of 53 x 10^3 plants ha^{-1}. However, there was a reduction in grain yield of maize due reduction in plant density but the difference was not significant. On the other hand, soybean yield was adversely affected by maize. Sole soybean produced highest grain yield of 183.9 and 225 (g/m^2) during the first and second seasons but there was a large reduction observed in grain yield of intercropped soybean. In both seasons, LER of maize density with soybean are clustered together indicating a major influence of maize density while soybean density has no effect on LER. Maize yield was reduced by 12% to 24 % and 8 % to 20 % in 2001 and 2002, respectively when maize density was reduced by 25 % and 50%. On other hand, soybean yield was increased by 52% to 98% in 2001 and 23% to 43% in 2002, respectively due to reduction in maize population. Reduction in maize density (increasing of row spacing from 75 to 150 cm) provided space for light penetration to the soybean canopy resulting in higher grain yield of soybean. Reduction in maize yield due to reduced plant population was compensated by increased yield of soybean. Similar results were reported by Ikeorgu and Oduruke (1986) that a yield loss of maize by reducing plant population 50% was compensated for by a 76 % pod yield increase of groundnut.



Note: The figures ♡ ⊘ ,☺ ◇ ,△ □ ,○ ,✜ ☾ indicate treatment combination of maize and soybean densities, D1S1, D1S2, D1S3, D2S1, D2S2, D2S3, D3S1, D3S2, D3S3, respectively

Figure 4.53. LER of different treatment combination of maize and soybean density on grain yield basis during 2001.



Note: The figures ⊘, ♡, ☺, ◇, △, □, ○, ✜, ☾ indicate treatment combination of maize and soybean densities, D1S1, D1S2, D1S3, D2S1 ,D2S2,D2S3, D3S1, D3S2, D3S3, respectively

Figure 4.54. LER of different treatment combination of maize and soybean density on grain yield basis during 2002.

LER and M A values of all treatment combinations were greater than unity indicating better exploitation of the resources zone by component crops in mixture than growing separately. In spite of lower grain yield of soybean, it results in greater financial benefits to the farmers because the price is three times higher than maize. There was no statistical difference in LER and M A of different treatment combinations, because maize yield was reduced while soybean yield increased when maize density was reduced. Even so, leaving aside, statistical significance a maize density of 26.5 x 10^3 with soybean of 100 x 10^3 plants ha^{-1} gave highest LER (1.43) and M A (1.73) during 2001 demonstrating an increased land use efficiency of 43 %. Similarly, the highest LER (1.50) and M A (2.11) was obtained with maize density of 40 x 10^3 and soybean density of 50 x 10^3 plants ha^{-1} in the second season indicating a 50% higher efficiency of intercropping over the sole crops. Similar magnitudes of increases have been reported in the case of maize/soybean mixtures by Yunusa (1987) that a 67:67 proportion of plant populations from their respective sole crop gave the highest LER of 1.35. Carruthers *et al.* (2000) also reported that intercropping of maize and soybean outyielded monocrop maize. Tariah and Wahua (1985) recommended that a mixture 33% and 50% of the normal sole crop population of maize and cowpea gives the highest LER of 1.48. Similarly, Upadhyay *et al.* (1990) reported that a combination of 100 % plant population of sorghum and 50% of pigeonpea proved the most efficient in term of sorghum equivalent yield, net return and water use efficiency

Higher rainfall favoured the maize growth resulting in higher yield in the first season, whereas low rainfall encouraged growth of soybean causing greater yield in the second season. The higher LER in the second season indicated that the reduction in maize grain yield due to drought was more than compensated for by increased production of soybean. It also confirms that intercropping provides security against crop failure due to variation in rainfall. Reddy and Reddy (1987) also reported that resources under stress moisture condition were utilized more efficiently with intercropping than with sole cropping.

4.6 Conclusion

The results clearly indicated that maize yield was not affected by the presence of soybean whereas grain yield of intercropped soybean was reduced by more than 50% in both seasons. The grain yield of maize increased with increasing maize density while grain yield of soybean was reduced as maize density increased. The agronomic advantages measured in term of LER were greater than unity in all treatments, indicating higher land use efficiency and production benefits to farmers. Farmers are reluctant to sacrifice maize yield by reducing plant population to 50%, in case production of soybean fails in years of high rainfall. On the other hand, grain yield of soybean under standard maize density was reduced drastically due to heavy shading. Therefore, it is suggested that soybean could be grown successfully by manipulating row spacing of maize from 75 to 100 cm to give a slightly reduced density of 40 x 10^3 plants ha^{-1} and planting soybean at a density of 100 x 10^3 in double rows between single maize rows, which would allow light penetration to the soybean canopy resulting in greater yield. The increased yield of soybean would more than compensate for any slight reduction in yield of maize.

CHAPTER FIVE

TIME OF THINNING EXPERIMENT

5.1 Introduction

In Nepal, farmers usually sow maize by broadcasting behind a bullock drawn plough without any row arrangement and thin maize plants throughout the cropping cycle for fodder for their livestock, retaining the highest yielding plants. They start to thin the maize plants after about one month of sowing and continue until the silking stage when they thin out the barren plants. At harvest, the plant population is usually fewer than 40,000/ha (Subedi, 1990) which is far below the recommended density. The plant population recommended for grain yield by the National Maize Research Programme (NMRP) of Nepal is 53 x 10^3 plants ha^{-1} (75 x 25 cm spacing), which is rarely achieved at harvest by farmers. Sthapit and Joshi (1990) conducted a survey of plant populations of maize in maize/millet systems in fields of forty farmers in the western hills of Nepal and found that at harvest, the farmers retained between 39,000 to 43,000 plants/ha after continuous thinning. A similar survey on plant population of maize under farmers' management in the western hills of Nepal conducted by Subedi and Dhital (1997) found that the initial plant population was 69,100 ± 1800 plants ha^{-1} which was reduced to 37,300 ± 1700 plants ha^{-1} at harvest.

Farmers start with a high plant population at the beginning and delay the start of thinning for one month to ensure security against poor germination, loss of plants due to drought, damage by insect/disease infestation and uprooting during weeding. Besides this, farmers also want to supply green fodder to their cattle so wait until the plants attain a reasonable biomass. On the other hand, high population of maize at an early vegetative growth stage causes weaker plants due to intra-specific competition resulting in smaller cobs and kernel numbers per cob and finally reduced yield at harvest (Remision and Lucas, 1982). Kurt (1987) reported that the yield of maize decreased as the thinning of extra maize plants was delayed because it maximized wasteful use of soil moisture and nutrients by the extra maize plants, and increased lodging (KARI, 2000). Additionally, in an intercropping system, delayed thinning reduces light penetration to younger soybean plants and suppresses soybean growth. Information on optimal maize density and time of thinning and their effects on soybean are limited in maize/soybean systems in hills of Nepal. Therefore, this study was initiated to understand more about existing farmers' practices, to assess the loss in grain yield of maize and soybean due to delay in thinning and to determine the optimum thinning time and density for giving maximum returns to farmers.

5.2 Objective

The objectives of these experiments were to determine the effect of time of maize thinning at different stages of crop growth, and the effect of differing plant densities of maize on growth parameters and yield attributes of maize and soybean grown together as an intercrop.

5.3 Material and methods

5.3.1 Thinning experiment 1, 2001

The experiment was conducted from May 2 to September 18, 2001 at Deorali during the summer season in Nepal. The experiment was conducted in a farmer's field at Deorali VDC of Palpa District, situated in the southern mid-hills of Western Development Region of Nepal. The experimental sites was located at $27^0 53'39''$ N and $83^0 26'72''$E and at an altitude of 1360 m above sea level. The detailed information on soil is given section 3.3.

5.3.1.1 Soil sampling

A composite soil sample was collected before planting of trials. Soil samples were taken from different locations within the experimental area using an auger and mixed together thoroughly to make a representative sample. A sub-sample was taken for analysis of physical and chemical properties. The methods of analysis used are described in section 3.3.

5.3.1.2. Treatments

The experiment consisted of nine treatments, including three sole maize densities, 66, 53 and 38 x 10^3 plants/ha at emergence. In the intercropped treatments, two maize densities of 53 and 38 x10^3 plants/ha were evaluated along with three different times of thinning, once at either 30 or 60 DAS, or twice at 30 and 60 DAS, which formed six treatment combinations. Maize row interval was fixed at 75 cm spacing, as recommended for general maize production in Nepal. Maize densities were adjusted by manipulating space between plants from 20 cm to 35 cm within the row at sowing time. Soybean was planted in a single row at a density of 133,000 plants ha^{-1}, at 10 cm spacing within row. Details of treatments are presented in Table 5.1.

5.3.1.3 Experimental Design

The experiment was laid out as a Randomised Complete Block Design with four replications. The gross plot size was 3 x 5 m. One metre space was provided between replications, and no spaces between plots. The central two rows, leaving one border plant on each side, were harvested for yield determination of maize. Similarly, the central two rows of soybean, leaving 0.5 m border on each side, were taken for yield determination of soybean. Layout of experiment is shown in Figure 5.1.

Table 5.1. Details of treatment combination in time of thinning experiment, 2001.

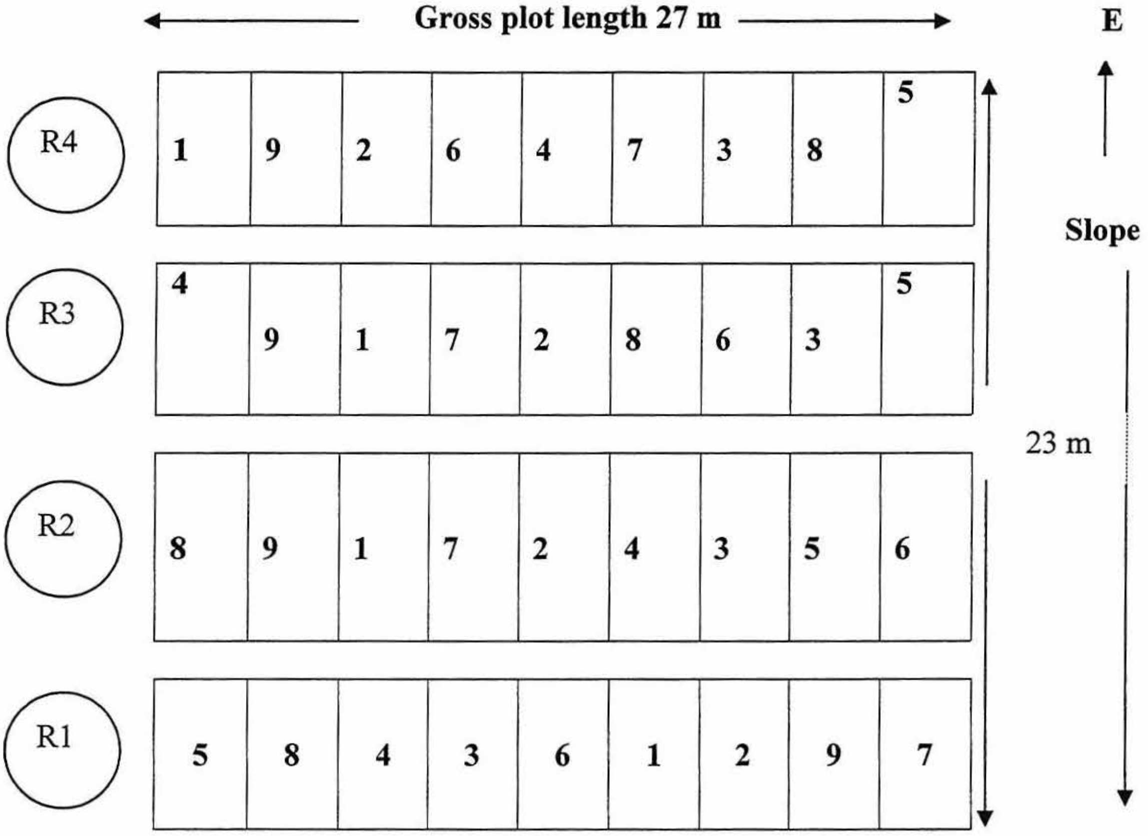
Treatments (maize density x 10^3)	Initial maize population	Final maize population	Spacing between row(cm)	Within row spacing	Time of thinning (Days after sowing)
1. 53 + TT2	116 (3.97)	53,000	75	25	30
2. 53 + TT3	98 (2.14)	53,000	75	25	60
3. 38 + TT2	96 (4.56)	38,000	75	35	30
4. 38 + TT3	72 (2.29)	38,000	75	35	60
5. 53+ TT4	126 (7.14)	53,000	75	25	30 & 60 (two stages)
6. 38 + TT4	98 (6.25)	38,000	75	35	30 & 60 (two stages)
7. 66 + TT1	66	66,000	75	20	Immediate in germination
8. 53 + TT1	53	53,000	75	25	Immediate in germination
9. 38 + TT1	38	38,000	75	35	Immediate in germination

Note:- TT1, TT2, TT3 and TT4 denotes thinning time at germination, 30, 60 and 30+60 DAS. Figure in parenthesis are standard deviation.

5.3.1.4 Crop establishment

The experimental area was ploughed after rain when there was sufficient moisture in the soil. Maize and soybean were planted on 2 May, 2001. The procedures for land preparation, planting and fertilizer application were as described in section 4.3. The

Figure 5.1. Layout of time of thinning experiment 1, 2001 at Deorali.



Gross plot size: four rows of 5 metre length

same Mankamana variety of maize and CN 60 variety of soybean were used. Two maize seeds per hill were sown at the specified distance within each row to create the required density. Soybean was sown in a single row in a shallow furrow between two maize rows. Two seeds per hill were sown at 10 cms interval within a row. Germinating seedlings of soybean were protected from bird damage by posting a regular watchman for one week.

Germination of maize was regularly monitored after five DAS, and number of plants per hill in treatments 7, 8 and 9 were reduced to one within 10 DAS. Excess maize plants of treatment 1 and 3 were removed at 30 DAS at both locations as specified the treatments. At the same time, about 50% of excess plants in treatments 5 and 6 were removed as required for the treatment. The first weeding was carried out manually after 35 DAS. Shallow furrows were opened besides maize rows and the required amount for the remaining quantity of urea was sprinkled in the furrow and covered with soil to avoid losses to the atmosphere. A second weeding was done between 54 to 60 DAS

Excess maize plants in treatments 2 and 4 were removed at 60 DAS as required for the treatments. The remaining excess plants in treatments 5 and 6 were completely removed on the same day. There was a strong wind at 65 and 69 DAS which caused lodging of some maize plants. Maize and soybean were harvested on August 26 and September 19, 2001, respectively. A operations of different activities during 2001 is presented in table 5.2

Table 5.2 A diary of operations for the experiment conducted during 2001 summer season.

Date	Activities
16.04.01	Demarcation of plots and collection of soil samples
18.04.01	Ploughing of land by bullock, clod breaking and levelling of land
02.05.01	Final lay out of experiment, planting of maize and soybean
11.05.01	Gap filling of soybean and thinning of maize in treatments 7, 8 & 9
02.06.01	Plant count and first thinning of maize in treatments 1-6
16.06.01	Leaf measurement of maize selected plants for LAI, plant height measurement and subsequent measurement at two week interval
06.06.01	Topdressing of maize with urea
16.06.01	First leaf sampling of soybean for LAI measurement
17.06.01	First PAR measurement and subsequent measurement at two week intervals
26.06.01	Second weeding of maize
27.06.01	Tassel initiation in maize started
30.06.01	Silk initiation in maize started
30.06.01	Flowering in soybean started
06-10.07.01	Strong wind causing lodging of some plants
26-27.08.01	Harvesting of maize completed
19.09.01	Harvesting of soybean completed

5.3.2 Thinning experiment 2, 2002

On the basis of results obtained from experiment 1 conducted during 2001, some treatments were modified for the experiment conducted during 2002 because there was no difference between two stage thinning (Treatment 5 and 6) and thinning at 60 DAS.

High density treatment gave lowest LER value indicating no advantage of intercropping The treatments for two stage thinning and the high density control were removed. Pair rows as well as wider rows of maize (one metre spacing) with two rows of soybean between maize rows were included to see if there influenced maize and soybean yield. Soybean density was maintained at 133,000/ha (single row at 10 cm spacing) except in tr. 5 and 6 at the rate of 100,000/ha (two rows at 20 cm spacing). Two seeds/position were planted initially but reduced to the specified density one month after sowing. The details of treatments and diagrammatic representation of plant configuration used are given in Table 5.3 and Figure 5.2a.

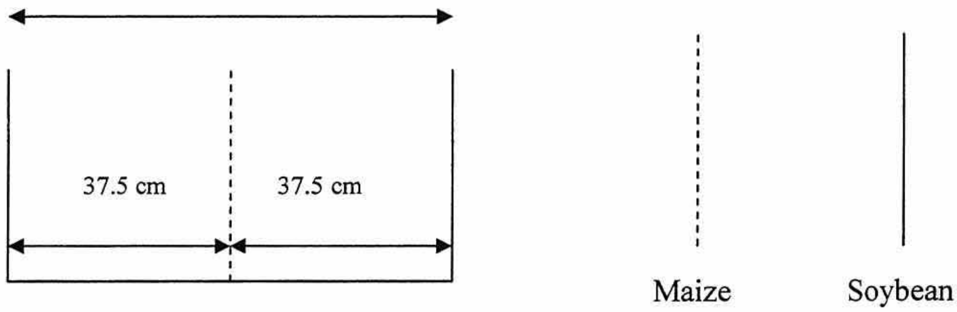
Table 5.3. The details of treatments in time of thinning experiment 2, 2002.

Treatments	Initial density (x 10^3)	Final density	Spacing of maize (cm)	Soybean density (x 10^3)	Time of thinning (Days after sowing)
1. 53 + TT2	103.7 (1.6)	53,000	75 x 25	133	30
2. 53 + TT3	103.6 (1.7)	53,000	75 x 25	133	60
3. 38 + TT2	74.5 (1.6)	38,000	75 x 35	133	30
4. 38 + TT3	71.0 (2.3)	38,000	75 x 35	133	60
5. 50 +TT2	90.2 (6.5)	50,000	100 x 20	100	30
6. 50 + TT3	90.0 (4.7)	50,000	100 x 20	100	60
7. 53 pair + TT2	102.7 (2.4)	53,000	60/90 x 25	133	30
8. 53 pair + TT3	100.5 (3.3)	53,000	60/90 x 25	133	60
9. 53 + TT1	53	53,000	75 x 25	133	Immediate in germination
10. 38 + TT1	38	38,000	75 x 35	133	Immediate in germination

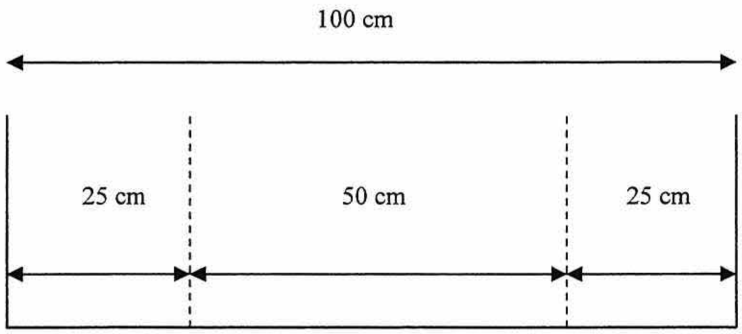
Note:- TT1, TT2 and TT3 denotes thinning time of thinning after germination, 30 and 60 DAS. Figure in parenthesis indicates standard deviation

The experimental design used, cultural requirements and observations were followed as for the time of thinning experiment 1, in 2001, except that the experiment was planted on May 1, 2002. Maize and soybean were harvested on 3-4 and 23-24 September respectively. A dairy of field operation is given in Table 5.4. Layout of the experiment is shown in Figure 5.2b.

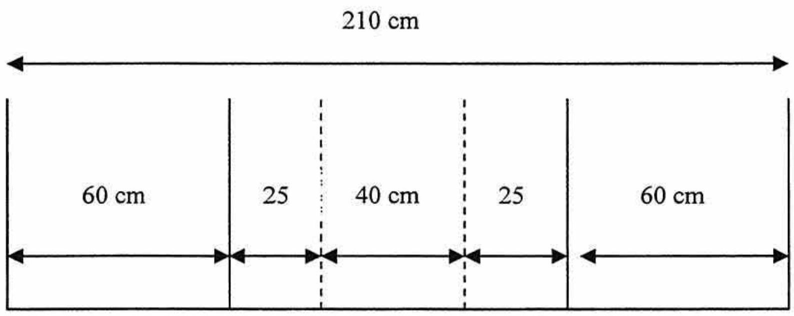
Figure 5.2a. Diagrammatic presentation of plant configurations Experiment 2, 2002



Maize 25 cm in row spacing, 53,000/ha or
Maize 35 cm in row spacing, 38, 000/ha



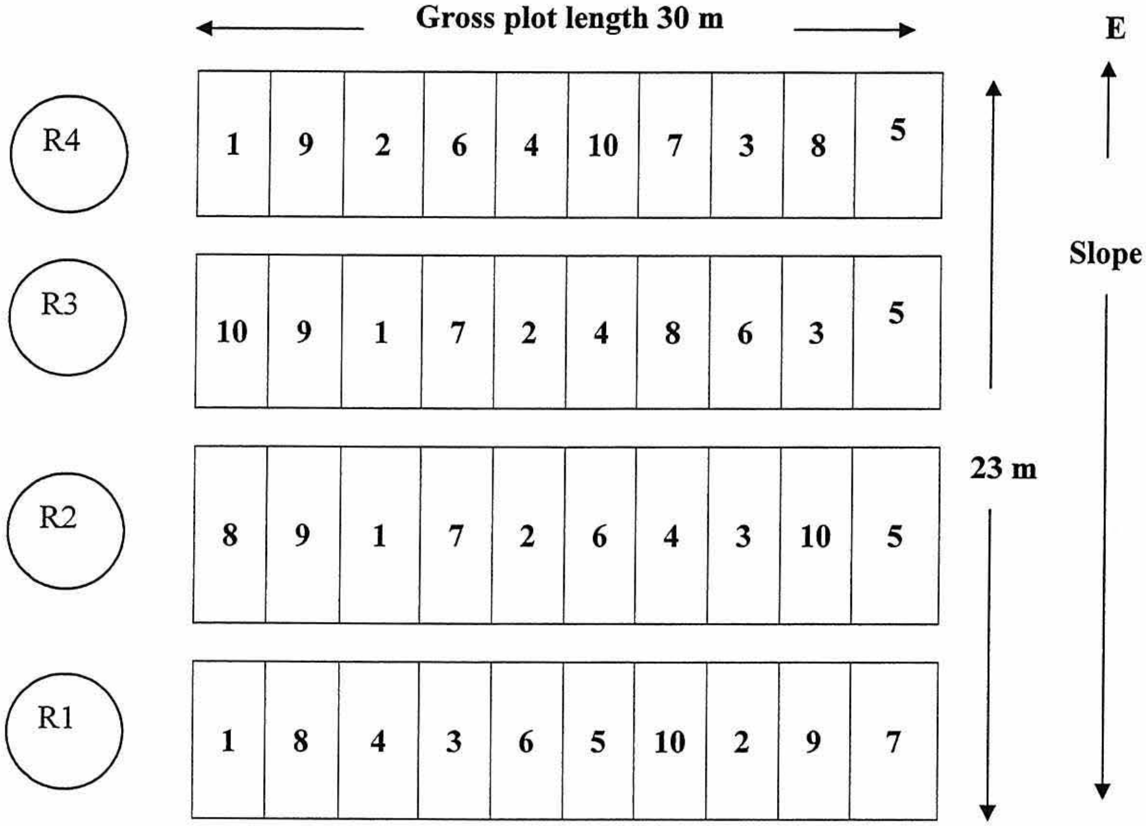
Maize 20 cm in row spacing, 50,000/ha



Maize 25 cm in row spacing but in paired rows (90/60 cm), 53,000/ha

Soybean population @ 133,000/ha in single row in alternate maize row or double rows in paired rows at 10 cm spacing within row and @ 100,000/ha in double rows between wide maize row (50,000 plants/ha) at 20 cm spacing within row.

Figure 5.2b. Layout of field experiment at Deorali during 2002.



Gross plot size: four rows of 5 metre length

Table 5.4. A diary of operations for experiment 2 conducted during 2002 season.

Date	Activities
18.04.02	Demarcation of plots and collection of soil samples
30.04.02	Ploughing of land by bullock, clod breaking and levelling of land
01.05.02	Final lay out of experiment, planting of maize
11.05.02	Thinning of maize in 9 & 10 treatments
17.05.02	First weeding of maize and soybean
31.05.02	Plant count and thinning of maize in treatments (1, 3, 5 & 7)
1.06.02	Leaf measurement of maize selected plants for LAI, Plant height measurement and subsequent measurement at two week interval
06.06.02	Topdressing of maize with urea
16.06.02	First leaf sampling of soybean for LAI measurement and subsequent measurement at two weeks interval up to 29 July

Date	Activities
30.06.02	Thinning of maize in treatments (2, 4, 6 & 8)
02.07.02	Tassel initiation in maize started
06.07.02	Silk initiation n maize started
06.07.02	Flowering in soybean started
18.08.02	Observation by Supervisor, Dr. R.M. Brook
03-04.09.02	Harvesting of maize completed
23-24.09.02	Harvesting of soybean completed

5.3.3 Recording

5.3.3.1 Non-destructive measurement of growth (both experiments)

There was insufficient space to lay out an experiment for destructive samples of maize for growth analysis. Therefore, a non-destructive assessment of growth was used. Germination of maize and soybean were monitored after 5 DAS and thinning of excess maize plants were carried out as specified for each treatment. Vacant spaces in soybean rows were gap filled by transplanting seedlings of soybean, dug up from places where they were not needed. Three maize plants were selected and marked in the second row of each treatment, leaving one border plant. These sampled plants were used to measure plant height and leaf area non-destructively at every observation event. Observation of plant height and leaf area was done fortnightly from June 16 to August 12, in both seasons. Plant height was measured as reported in section 4.3.1. Leaf area was obtained manually by measuring maximum width and length from base to the tip of leaf. Fully expanded leaves only were used to estimate leaf area. Leaves which were damaged or more than 50% yellow were discarded from measurement at each occasion. The leaf area of each leaf was computed by multiplying leaf length, maximum leaf width and a correction factor of 0.75 (McKee, 1964; Duncan and Hesketh, 1968)

$$LA = (L \times W) \times 0.75 \ldots\ldots\ldots\ldots \textit{Equation } 18$$

where LA denotes leaf area, L and W denote length of leaf and maximum leaf width. Finally Leaf Area Index was computed from total leaf area of three plants divided by land area occupied by these plants.

The measurement of photosynthetically active radiation (PAR) was carried out fortnightly after 46 DAS to 88 DAS during the first season. A Decagon Sunfleck

Ceptometer was used to measure PAR at midday above the whole canopy, above the soybean and below the soybean canopy by placing probe across the row at 5-6 locations in each plot. Percentage of intercepted PAR was computed as given in section 4.3.1.1

5.3.3.2 Destructive (classical) growth analyses

Leaf area of soybean was measured by a destructive method as non-destructive methods were too time consuming, as soybean leaves are complex in structure and there were sufficient soybean plants to sample. The measurements of leaf area and plant height were started after 46 DAS and done fortnightly in both years. Only two samples were collected during the first season due to insufficient soybean plants in the sample area but four samples were collected in the second season. At each sampling period, five plants were selected in the first row of each plot, leaving two guards row plants. The procedure of measuring leaf area of the sampled plants of soybean was as given in section 4.3.1.2. Finally, LAI for each treatment was calculated. At each sampling, another five plants were selected from the same row, leaving two guard plants. The same procedure was followed at each sampling period.

5.3.4 Yield and yield components

The central two rows of maize from each plot were selected for harvesting at maturity. One plant from the outer side of each row was discarded as a border plant. Four maize plants were selected randomly from the net plot harvest area and severed at ground level to measure yield components and dry weight. The total number of harvested plants was recorded. The remaining plants were harvested from ground level and cobs were separated and dehusked. Number and field weight of cobs and moisture of grain for each plot were recorded as described in section 4.3.4. Grain yield per plot was adjusted to 14% moisture. Fresh weight of straw was also recorded.

The procedures for measuring yield components of maize were as described in section 4.3.4. Two central rows of soybean were selected for harvest. A 50 cm area was discarded from both sides in each row to avoid border effects. A total of eight plants were randomly selected and separated from each plot to determine yield components as described in Section 4.3.4. Grain yield of soybean was adjusted to 12% moisture. Grain and biomass yield per plant and per square metre was calculated as for maize. Similarly, dry weight of grain and biomass per plant and per square metre were computed. The partitioning of dry matter into the reproductive portion of the plant was calculated to give the harvest index (Donald, 1962) and it was calculated by dividing the total dry weight of grains by the total above ground dry weight.

5.3.5. Land Equivalent Ratio (LER)

In the thinning experiment, there were no sole maize and soybean treatments. Therefore, LER of each treatment was computed as in section 4.3.4.1 by using data from the sole crop of maize and soybean from the intercropping experiment reported in Chapter Four, because these experiments were conducted in same field.

5.3.6. Statistical Analysis

Statistical analysis procedures were similar to those described in section 4.3.2 in which data of thinning experiment 1 were analysed as an unbalanced factorial design with 66 x 10^3 density as additional control in GenStat v 6. Data from experiment 2, 2002 were analysed in Minitab (v 13.1) and analysed as an incomplete factorial design using the general linear model procedure.

5.3.7. Meteorological data

Meteorological data for Deorali during 2001 and 2002 were presented in Figures 4.2 and 4.3 in Chapter Four.

5.4 Results: time of thinning experiment 1, 2001

5.4.1 Growth analysis of maize

Summary table of means, with significant effects are presented in the appendices. In this results section, graphs are used to illustrate particular significant effects, with tables where appropriate.

5.4.1.1 Plant height

Plant height in all treatments increased up to 73 DAS until the tasseling stage but there was a slight decrease at harvest due to drying and breakage of tassel at maturity. There was no effect of any treatments on plant height during the vegetative growth stage (Appendix 5.1) but a significant interaction effect between maize density and time of thinning on plant height was observed at harvest (Appendix 5.2). Plant height of maize with 53 x 10^3 plants ha^{-1} was suppressed (Figure 5.3) by thinning after 30 DAS (TT2).

5.4.1.2 Leaf area index (LAI)

Results of LAI measured over time are presented in Appendix 5.3. The significant treatment effects over time or within a particular observation date are presented in Figure 5.4. In general, LAI progressed curvilinearly over the season. At the beginning, it increased linearly up to 59 DAS in all treatments following a gradual increment between 59 and 73 DAS, and it declined thereafter due to senescence of lower leaves. The rate of decline in LAI was greatest in maize of density 66 x 10^3 plant ha^{-1}. Maize density had a significant effect on LAI at all measurement dates. LAI was ranked lowest at 38 x 10^3 plant ha^{-1} population density to greatest at 66 x 10^3 plant ha^{-1} but the difference between 53 and 66 x 10^3 plant ha^{-1} was not significant at 73 and 87 DAS. Time of thinning had no effect on LAI at any measurement dates. However, there was a reduction in plant vigour (on the basis of visual observation) during vegetative growth which was indicated by lower value of LAI in TT2 and TT3, although the difference was not significant.

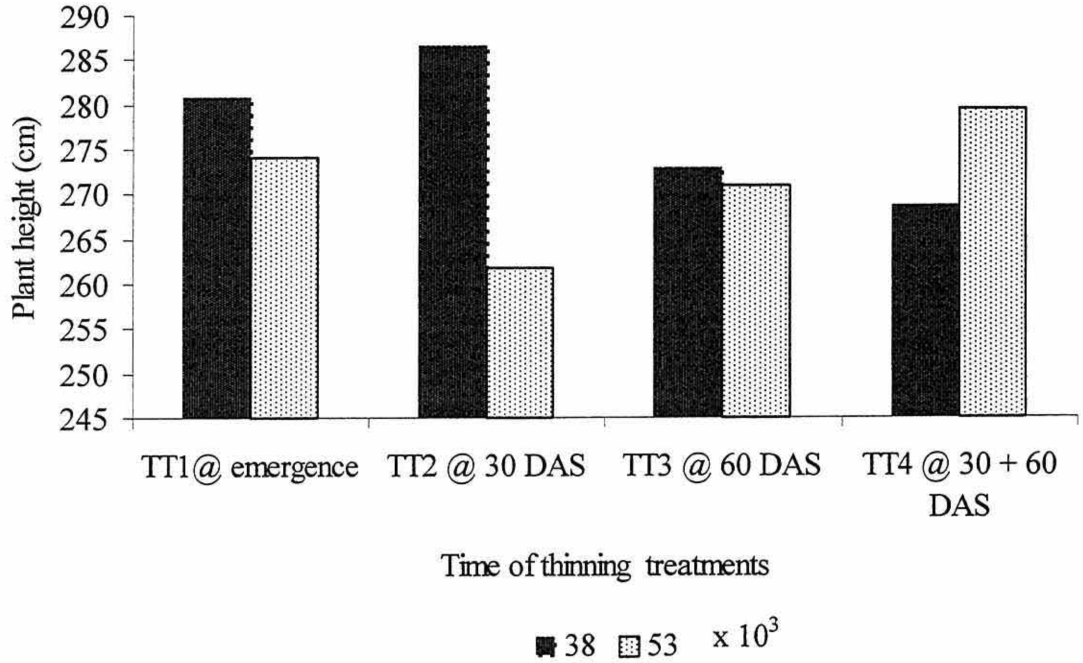


Figure 5.3. Effect of maize densities and time of thinning on plant height (cm) of maize at harvest in time of thinning experiment, 2001 (See Appendix 5.2 for data table).

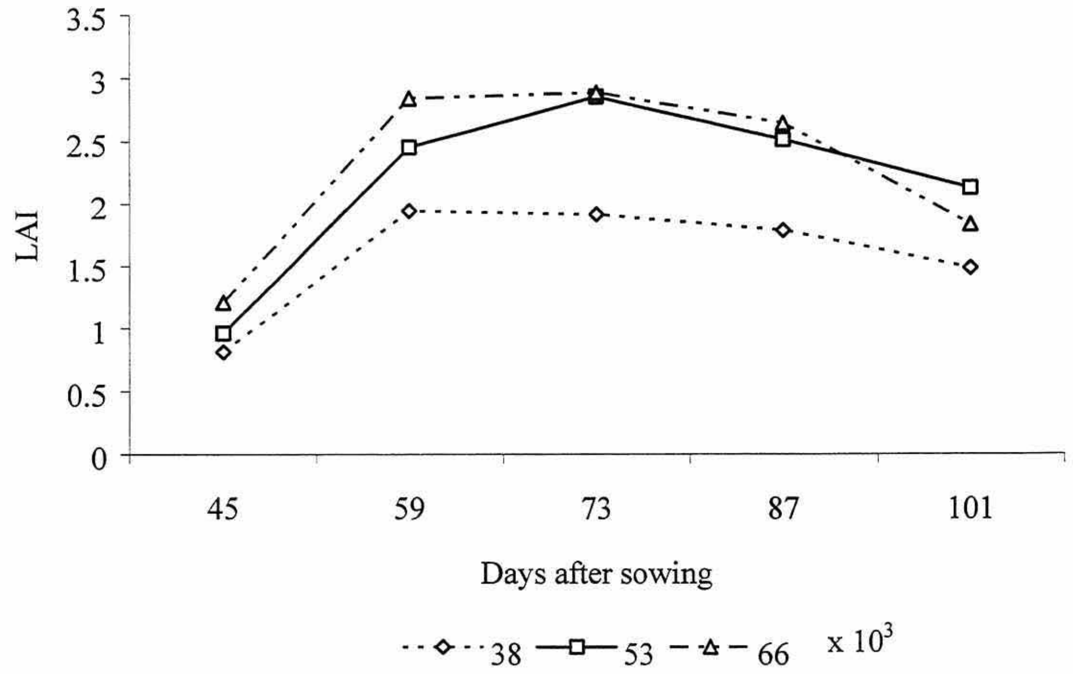


Figure 5.4. The effect of maize densities on LAI of maize measured over time in time of thinning experiment, 2001 (see Appendix 5.3 for data table).

5.2.2Yield and yield components of maize

5.2.2.1. Grain yield (g/m^2)

Full tables on means on yield and yield components of maize, with significant effects are presented in tabular form in Tables 5.5 and 5.6. At thinning after germination (TT1), maize density had significant effect on grain yield of maize. Maize density of 66 x 10^3 plants ha^{-1} produced the lowest grain yield while the recommended density (53 x 10^3) yielded greatest, but they did not differ significantly from 38 x 10^3 plant ha^{-1}. Grain yield of maize was reduced by 24.4 % and 10 % as density varied from the recommended to 66 and 38 x 10^3 plants ha^{-1}, respectively.

Time of thinning had a significant effect on grain yield of maize, ranked from greatest at thinning after germination (TT1) to least at thinning at 30 and 60 DAS (TT4). Maize thinning atr 60 (TT3) and 30+60 DAS (TT4) produced significantly lower grain yield compared to thinning after germination (TT1) and 30 DAS (TT2). The magnitude of reductions due to TT3 and TT4 were 17.6 % and 18.6 %, respectively compared to control (TT1).

5.4.2.2 Cobs/plant

The number of cobs/plant varied little, but nevertheless, this variable was significantly affected by maize density in treatment TT1 (control) and for density averaged over treatments T1 to T4. It was ranked greatest at 38 x 10^3 plants ha^{-1} to lowest at 66 x 10^3 plants ha^{-1}. However, it was not affected by time of thinning of maize plants.

5.4.2.4 Number of grains/cob

Maize does not usually tiller, and number of cobs per plant is not responsive to the growing environment, so among the yield components, the number of grains/cob has an important role in determining total grain yield and is most often affected by stress during both vegetative and reproductive stages. Maize density had a significant effect on the number of grains/cob when compared at the same thinning time after germination (TT1) as well as averaged over time of thinning (TT1 to TT4). It was ranked greatest at 38 x 10^3 plants ha^{-1} to least at 53 x 10^3 plants ha^{-1} but this latter did not differ from 66

$x10^3$ plants ha^{-1}. The number of grains/cob increased by 23.7 % when density was reduced from standard density to 38 x 10^3 plants ha^{-1}.

Table 5.5. The effect of maize densities and time of thinning of maize on grain yield and cobs/plant of maize in time of thinning experiment during 2001.

Treatments	Grain yield (g/m^2)			Cobs/plant		
Densities (x 10^3)	38	53	mean	38	53	mean
Time of thinning						
TT1	413	459	436	1.1	1.0	1.0
TT2	420	427	423	1.1	0.9	1.0
TT3	383	334	359	1.1	0.9	1.0
TT4	364	350	357	1.1	1.0	1.0
Mean density	395	393		1.1	1.0	
66 x 10^3 with TT1		356			0.8	
Lsd (0.05)						
Density	NS			0.05**		
Time of thinning	50.4**			NS		
Density x TT	NS			NS		
Density at TT1[a]	71.2*			0.10**		

Note: [a] denotes lsd for comparing different densities at TT1 level only. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. NS, * and ** indicate non significant, significant at 5 and 1 % level, respectively

Table 5.6. The effect of maize densities and time of thinning of maize on number of grains/cob, 1000 grain weight and harvest index of maize in time of thinning experiment during 2001.

Treatments	Grains/cob			1000 grain wt			Harvest index		
Densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	428	346	387	291.4	295.8	293.6	0.42	0.41	0.42
TT2	368	270	319	299.8	295.8	297.8	0.41	0.40	0.41
TT3	325	286	306	296.9	270.4	283.7	0.42	0.43	0.42
TT4	331	316	323	291.5	298.4	295.0	0.41	0.39	0.40
Mean density	363	304		294.9	290.1		0.42	0.41	
66 x 10^3 with TT1		329			278.0			0.37	
Lsd (0.05)									
Density	32.3**			NS			NS		
Time of thinning	45.7**			NS			NS		
Density x TT	NS			NS			NS		
Density at TT1 [a]	64.7**			NS			NS		

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicate non significant, significant at 5 and 1 % level, respectively.

Time of thinning had a significant effect on the number of grains/cob and thinning after germination (TT1) produced the significantly greatest number of grains/cob among the tested treatments. However, differences among the rest of the thinning times were not significant.

5.4.2.5 1000 grain weight

This component of yield also varied little, and there was no treatment effect on 1000 grain weight. Generally grain weight of a cultivar is stable and governed by the genome and is little affected by stress caused by variation in density within the tested range of densities.

5.4.2.6 Harvest index

Harvest index of maize was not significantly affected by any treatments.

5.4.3 Dry matter production

Data on dry matter of straw, grains and total biomass production, with significant effects are presented in Table 5.7.

5.4.3.1 Dry matter of straw yield.

Regardless of maize density, time of thinning had a significant effect on dry matter of straw. Thinning after 60 DAS (TT3) produced significantly lower dry matter of straw compared to thinning after germination and 30 DAS (TT1 and TT2) but did not differ from thinning after 30 + 60 DAS (TT4). The magnitude of reduction due to 60 DAS was 16.3 % and 18.4 % compared to thinning after germination and 30 DAS. There was no effect of maize density on dry matter of straw

5.4.3.2 Dry matter of grains yield

Like dry matter of straw, time of thinning had a significant effect on dry matter of grains and was ranked highest at thinning after germination (TT1) to lowest at thinning after 30 + 60 DAS (TT4) but the difference between TT3 and TT4 was not significant. Similarly, difference in dry matter of grain between TT1 and TT2 was not significant.

5.4.3.3 Total dry matter yield

Averaged over maize density, time of thinning had a significant effect on total dry matter production of maize. Thinning after 60 DAS (TT3) produced significantly lowest total biomass compared to thinning after germination and 30 DAS (TT1 and TT2) but did not differ from thinning after 30 + 60 DAS (TT4). Thinning of maize after 60 DAS(TT3) reduced total biomass production by 16 % and 16.4 % compared to thinning after germination (TT1) and 30 DAS (TT2), respectively.

Table 5.7. The effect of maize densities and time of thinning of maize on dry weight of grain, straw and total biomass (g/m^2) of maize in time of thinning experiment during 2001.

Treatments	DM of straw (g/m^2)			DM of grains (g/m^2)			Total biomass (g/m^2)		
Densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	481	549	515	357	387	373	839	937	888
TT2	539	517	528	381	355	368	920	872	896
TT3	473	389	431	344	292	318	817	681	749
TT4	466	473	469	328	306	317	794	779	787
Mean density	490	482	482	353	336		842	818	
66 x 10^3 with TT1		545			324			868	
Lsd (0.05)									
Density		NS			NS			NS	
Time of thinning		68.2*			47.5*			91.1**	
Density x TT		NS			NS			NS	
Density at TT1 [a]		96.4*			NS			128.8*	

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. [a] denotes lsd for comparing different densities at TT1 level only. . NS, * and ** indicate non significant, significant at 5 and 1 % level, respectively

5.5 Soybean: 2001

5.5.1 Yield and yield components of soybean

Full table of means on yield and yield components of soybean, with significant effects are given in Tables 5.8 and 5.9.

5.5.1.1 Grain yield

Maize density had a significant effect on grain yield of soybean intercropped with maize. There was a significant increase in grain yield of soybean when maize density was reduced from 53 to 38 x 10^3 plants ha^{-1}, the magnitude of increment being 32.1 %. The effect of time of thinning of maize on grain yield of soybean was not significant.

Table 5.8. The effect of maize densities and time of thinning of maize on grain yield, plant/m^2 and pod/plant of soybean in time of thinning experiment during 2001.

Treatments	Grain yield (g/m^2)			Plants/m^2			Pods/plant		
Maize densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	56.3	39.9	48.1	12.1	10.9	11.5	27.5	20.9	24.2
TT2	55.2	44.5	49.9	10.3	11.5	10.9	23.0	18.8	20.9
TT3	52.2	37.2	44.7	10.1	10.0	10.1	27.0	21.8	24.4
TT4	47.1	37.8	42.5	9.6	9.7	9.7	20.7	19.3	20.0
Mean density	52.7	39.9		10.5	10.6		24.5	20.2	
66 x 10^3 in TT1		41.7			9.1			18.6	
Lsd (0.05)									
Density		7.7**			NS			3.3*	
Time of thinning		NS			NS			NS	
Density x TT		NS			NS			NS	
Density at TT1 [a]		NS			NS			NS	

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively., [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicate non significant, significant at 5 and 1 % level

Table 5.9. The effect of maize densities and time of thinning of maize on seeds/pod, 100 seed weight and harvest index of soybean in time of thinning experiment during 2001.

Treatments	Seeds/pod			100 seed wt			Harvest index		
Densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	2.1	2.0	2.1	20.3	20.0	20.2	0.40	0.43	0.42
TT2	2.3	2.0	2.2	21.0	19.9	20.4	0.47	0.47	0.47
TT3	2.0	2.0	2.0	19.6	19.0	19.3	0.48	0.41	0.45
TT4	2.1	2.0	2.1	20.0	20.8	20.4	0.42	0.43	0.43
Mean density	2.1	2.0		20.2	19.9		0.45	0.43	
66 x 10^3 with TT1		2.4			19.8			0.46	
Lsd (0.05)									
Density		NS			NS			NS	
Time of thinning		NS			0.76*			NS	
Density x TT		NS			NS			NS	
Density at TT1 [a]		0.26*			1.07*			NS	

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicate non significant, significant at 5 and 1 % level

5.5.1.2 Plants/m^2

There was no treatment effect on plants/m^2 of soybean. This was probably due to planting of the same density of soybean in all treatments, although there was a trend for soybean survival to be greatest in the earliest thinned maize (TT1) and least in latest thinned maize (TT4)

5.5.1.3 Number of pods per plant

Soybean growing with the recommended maize density produced significantly lower numbers of pods/plant compared to low density of 38 x 10^3 plants ha^{-1}. The number of pods per plant of intercropped soybean increased by 20.3 % when maize densities reduced from 53 to 38 x 10^3 plants ha^{-1}. There was no effect of time of thinning.

5.5.1.4 Seeds/pod

There was no effect of either maize density averaged over time of thinning or time of thinning but maize density had a significant effect on seed/pod of soybean when compared at the same time of maize thinning after germination (TT1). A significantly greater number of seeds per pod was produced under maize density of 66 x 10^3 plants ha^{-1} compared to 38 and 53 x 10^3 plants ha^{-1} but the difference between these latter densities was not significant.

5.5.1.5. 100 seed weight

Time of thinning had a significant effect on 100 seed weight of soybean. Thinning after 60 DAS (TT3) produced lighter grains compared to other treatments but differences among these were not significant.

5.5.1.6 Harvest index

Harvest index of soybean was not affected by any treatments, indicating that all treatments adjusted partitioning of assimilates to grains proportionately.

5.5.2 Dry matter production

Data on dry matter of straw, grain and total biomass are presented in Table 5.10. Results are illustrated as follows:

5.5.2.1 Dry matter of straw yield

Regardless of time of thinning, maize density of 38 x 10^3 plants ha^{-1} resulted in significantly higher dry matter of straw of intercropped soybean compared to soybean planted under the recommended maize density.

5.5.2.2 Dry matter of grains yield

Like straw, dry matter of grains was affected by maize density and the recommended maize density suppressed dry matter of grains of intercropped soybean compared to low maize density of 38 x 10^3 plants ha^{-1}.

Table 5.10. The effect of maize densities and time of thinning of maize on dry weight of grain, straw and total biomass (g/m^2) of soybean in time of thinning experiment during 2001.

Treatments	DM of straw (g/m^2)			DM of grains (g/m^2)			Total biomass (g/m^2)		
Densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	76.9	49.5	63.2	50.6	35.9	43.3	127.5	85.4	106.4
TT2	54.7	45.8	50.3	49.1	39.8	44.4	103.8	85.6	94.7
TT3	49.5	48.0	48.8	46.4	33.3	39.8	95.9	81.3	88.6
TT4	59.9	44.6	52.2	42.2	34.0	38.1	102.1	78.6	90.3
Mean density	60.3	47.0		47.1	35.7		107.3	82.7	
66 x 10^3 with TT1		43.4			37.5			80.9	
Lsd (0.05)									
Density	10.1**			7.0**			14.1**		
Time of thinning	NS			NS			NS		
Density x TT	NS			NS			NS		
Density at TT1 [a]	NS			NS			28.2*		

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicate non significant, significant at 5% and 1 % level

5.5.2.3 Total dry matter

Averaged over time of thinning as well as at the same thinning time after germination (TT1), maize density had a significant effect on total biomass production of soybean and was ranked from greatest at maize density of 38 x 10^3 plants ha^{-1} to lowest at 66 x 10^3 plants ha^{-1}, but the difference between 53 and 66 x 10^3 plants ha^{-1} was not significant.

5.6 Measurement of intercropping efficiency

Data on partial LER of maize and soybean and LER are presented in Table 5.11. Data for sole crop controls in the adjacent 2001 intercropping experiment were used to compute LER.

5.6.1 Partial LER of maize and soybean

The much higher partial LER of maize indicated the dominant effect of maize on soybean. There was no effect of maize density on partial LER of maize when comparing the two main densities averaged over time of thinning, but maize density had a significant effect on partial LER of maize when compared with maize density of 66 x 10^3 plants ha^{-1} in treatment TT1. Maize density of 66 x 10^3 plants ha^{-1} gave a significantly lower partial LER than the other two densities.

The partial LER of soybean was significantly affected by maize density. The recommended maize density gave a lower partial LER compared to the low maize density of 38 x 10^3 plants ha^{-1}. However, it was not affected by time of thinning.

Time of thinning had a significant effect on partial LER of maize. Thinning of maize after germination and 30 DAS (TT1 and TT2) gave significantly higher partial LER compared to thinning after 60 and 30 +60 DAS (TT3 and TT4).

5.6.2 Land Equivalent Ratio

Maize density had a significant effect on LER when comparing densities in treatment TT1, the highest maize density giving a significantly lower LER compared to 38 and 53 x 10^3 plants ha^{-1}. LER values obtained with 38 and 53 x 10^3 densities were 1.14 and 1.06, indicating 14 % and 6 % higher land use efficiency than when the crops were grown separately.

LER was significantly affected by thinning time of maize, a significantly higher LER being obtained when maize plants were thinned after germination and 30 DAS (TT1 and TT2) compared to thinning after 60 and 30 +60 DAS (TT3 and TT4). LER obtained with TT1 and TT2 were 1.20 and 1.18 respectively which indicated that 20% and 18% more area would be required to produce the same yield from sole crops. Delaying thinning reduced any advantage of intercropping to zero

Table 5.11. The effect of maize densities and time of thinning of maize on partial LER of maize and soybean, and LER of maize/soybean system in time of thinning experiment during 2001.

Treatments	Partial LER of maize			Partial LER of soybean			LER		
Densities (x 10^3)	38	53	mean	38	53	mean	38	53	mean
Time of thinning									
TT1	0.89	0.99	0.94	0.30	0.21	0.26	1.20	1.20	1.20
TT2	0.90	0.92	0.91	0.30	0.24	0.27	1.20	1.16	1.18
TT3	0.82	0.72	0.77	0.28	0.20	0.24	1.11	0.92	1.01
TT4	0.78	0.75	0.77	0.25	0.20	0.23	1.04	0.96	1.00
Mean density	0.85	0.84		0.29	0.22		1.14	1.06	
66 x 10^3 with TT1		0.76			0.23			0.99	
Lsd (0.05)									
Density	NS			0.04**			NS		
Time of thinning	0.11**			NS			0.12**		
Density x TT	NS			NS			NS		
Density at TT1 [a]	0.15**			NS			0.17*		

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicate non significant, significant at 5% and 1% level

5.7 Photosynthetic active radiation (PAR) Measurement

The mean proportion of PAR intercepted by maize, soybean and the whole canopy, with significant effects, are presented in Appendix 5.4, 4.5, and 5.6. And results are illustrated with figures

5.7.1 PAR intercepted by maize

Maize density had a significant effect on proportion of PAR intercepted by maize Appendix 5.4), where the recommended maize density intercepted a higher proportion of PAR compared to 38 x 10^3 plant ha^{-1}, but the difference was significant at 60 and 88 DAS only (Figure 5.5).

5.7.2 PAR intercepted by soybean

There was no treatment effect on proportion of PAR intercepted by soybean intercropped with maize.

5.7.2 PAR intercepted by whole canopy

At the second recording date (60 DAS), maize density had a significant effect on proportion of PAR intercepted by maize + soybean canopy (Appendix 5.6) and a significantly higher proportion of PAR was intercepted by whole canopy of the

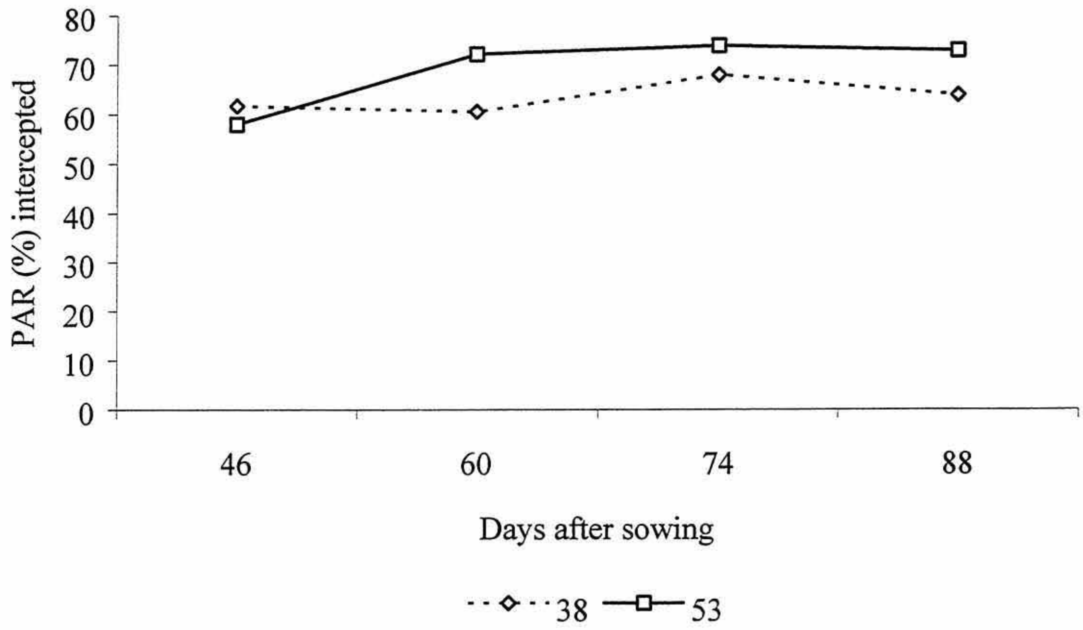


Figure 5.5. The effect of maize densities on PAR intercepted by maize canopy measured over time in time of thinning experiments (see Appendix 5.4 for data table)

recommended maize density intercropped with soybean compared to 38 x 10^3 maize plants ha^{-1} plus soybean. Time of thinning has a significant effect on percentage of PAR intercepted by whole canopy of maize and soybean. At the earliest measurement time (46 DAS), thinning after germination (TT1) intercepted the lowest proportion of PAR while thinning after 60 DAS intercepted the highest PAR but this was reversed at 60 DAS (Figure 5.6). A lower interception of PAR by the whole canopy was observed with thinning after 60 DAS at the last three recording dates but differences were significant at the second and fourth dates only.

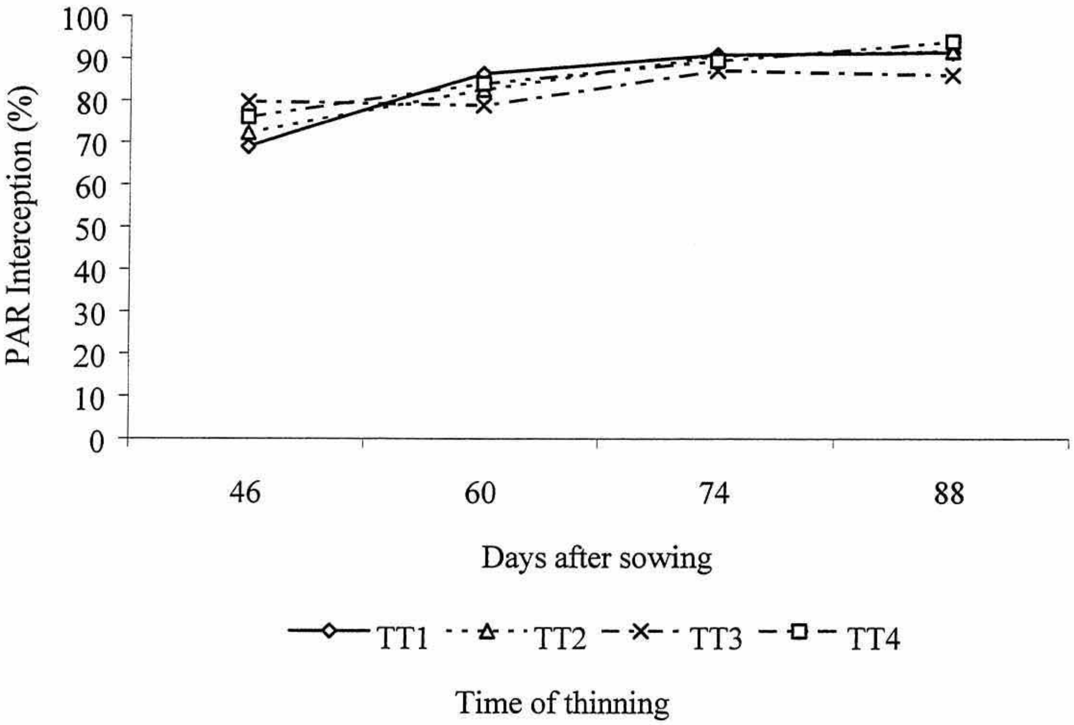


Figure 5.6.The effect of time of thinning of maize on total PAR intercepted by maize plus soybean canopy measured over time in time of thinning experiment, 2001 (See Appendix 5.6 for data table).

5.8 Thinning experiment 2, 2002

5.8.1. Growth measurement of maize

Data for growth measurement, with significant effects are presented in appendices 5.7 to 5.10. In the result section, graphs and tables are used to illustrated significant effects where appropriate.

5.8.1.1 Plant height

Plant height in all treatments increased up to 73 DAS at the tassel initiation stage and levelled off thereafter. There was no effect of any treatments on height of maize.

5.8.1.2 Leaf area index

Trends of LAI of maize throughout the season are presented in Appendix 5.7 and Figure 5.7. LAI of all treatments increased curvilinearly up to 73 DAS and declined thereafter due to senescence of lower leaves during the reproductive phase. Maize density had a significant effect on LAI of maize at all measurement occasions and was ranked from lowest at 38 x 10^3 plants ha^{-1} to greatest at 53 x 10^3 plants ha^{-1} but differences among maize densities of 50, 53 x 10^3 alternate and pair rows were not significant on any

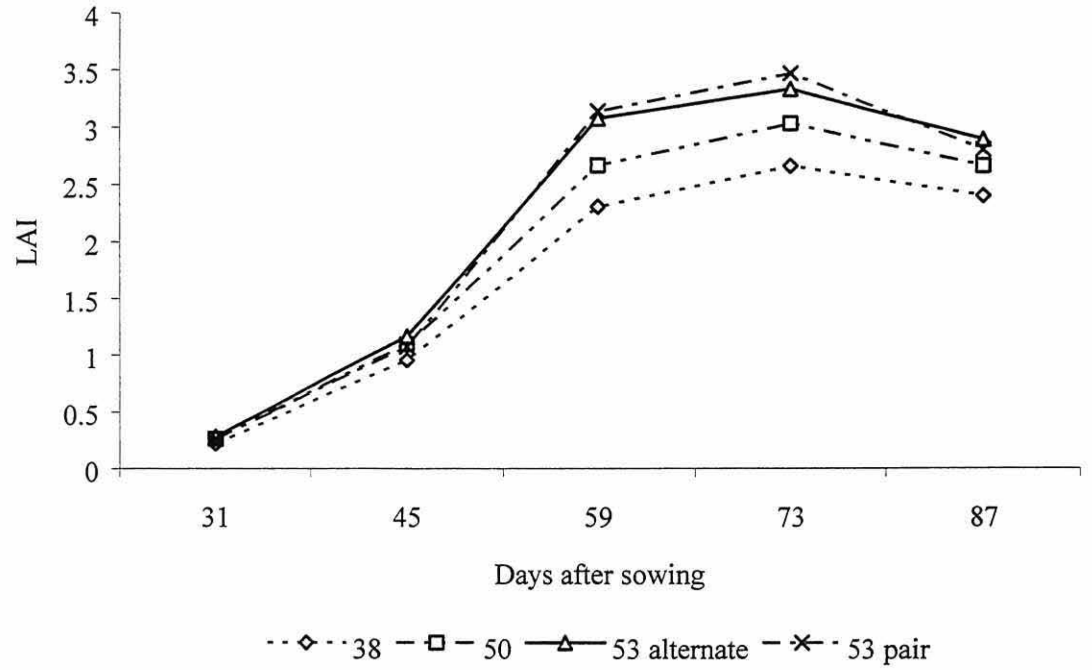


Figure 5.7. The effect of maize densities on LAI of maize measured over time in time of thinning experiment, 2002 (See Appendix 5.8 for data table).

measurement occasion. The LAI with 53 x 10^3 plants ha^{-1} pair rows declined faster than alternate row of same density after 73 DAS. However, LAI of maize was not affected by time of thinning.

5.8.2 Yield and yield components of maize

Data on yield and yield components of maize are presented in Table 5. 12

5.8.2.1 Grain yield (g/m^2)

Maize density had a significant effect on grain yield of maize but only the 50 x 10^3 plants ha^{-1} and the recommended spacing/arrangement were different significantly from each other. Time of thinning had a significant effect on grain yield. Delayed maize thinning to after 60 DAS (TT3) produced significantly lower grain yield compared to thinning after germination and 30 DAS (TT1 and TT2) but TT1 and TT2 did not differ significantly. The magnitude of reduction in grain yield due to thinning after 60 DAS was 13 %.

5.8.2.2 Cobs/plant

There was no effect of any treatments on cobs/plant which ranged from 0.78 to 0.88 cobs/plant.

Table 5.12. The effect of maize densities and time of thinning of maize on yield and yield components of maize in time of thinning experiment, 2002.

Treatments	Grain yield (g/m^2)	Cobs/ plant	1000 grain weight	Grains /cob
Densities (x 10^3)				
38	462.2	0.88	333.8	387.4
50	421.2	0.85	329.5	357.6
53 alternate row	487.3	0.80	294.8	338.8
53 paired rows	438.0	0.79	319.6	388.5
Time of thinning				
TT1	466.2	0.87	328.6	420.3
TT2	476.9	0.85	321.4	364.1
TT3	413.4	0.78	308.3	319.9
Probability				
Density	*	NS	*	NS
Time of thinning	**	NS	NS	**
lsd (0.05)	59.5		46.9	91.9

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively. NS, * and ** indicate non significant, significant at 5 and 1 % level

5.8.2.3 1000 grain weight

Maize density had a significant effect on grain weight of maize. Recommended density produced smaller grains compared to 38 and 50 x 10^3 plants ha^{-1}. However, it was not affected by time of thinning.

5.8.2.5 Number of grains/cob

The number of grains/cob was not affected by maize density but it was significantly affected by time of thinning. It was ranked from greatest at thinning after germination (TT1) to lowest at thinning after 60 DAS (TT3) but the difference between TT1 and TT2 was not significant. The magnitudes of reduction in number of grains/cob were 13 % and 24 % when thinning of maize was delayed by 30 and 60 DAS, respectively.

5.8.3 Dry matter production yield

Means of dry matter of straw, grains, total biomass, harvest index and the percentage of lodged plant at grain filling stage are presented in Table 5.13. Results are illustrated in separate section as given below.

5.8.3.1 Dry matter of straw yield

Dry matter of straw was significantly affected by time of thinning and ranked from highest at thinning after germination (TT1) to least at thinning after 60 DAS (TT3), but difference between thinning after germination and 30 DAS was not significant. The reductions in dry matter of straw due to thinning after 60 DAS were 20.0 % and 15.8 % compared to thinning after germination and 30 DAS, respectively.

5.8.3.2 Dry matter of grains yield

There was no effect of maize density on dry matter of grains but it was significantly affected by time of thinning and ranked lowest at thinning after 60 DAS (TT3) to highest at thinning after 30 DAS (TT2) but difference between thinning after germination and 30 DAS (TT1 and TT2) was not significant.

5.8.3.3 Total dry matter

Time of thinning had a significant effect on total biomass production. Thinning after 60 DAS (TT3) produced the lowest total biomass compared to thinning after germination and 30 DAS (TT1 and TT2) but the difference between these two treatments was not significant. Total dry matter due to thinning after 60 DAS were reduced by 15.7 % and 14.7 % compared to thinning after germination and 30 DAS.

5.8.3.4 Harvest index

Harvest index of maize was not affected by any treatments

Table 5.13. The effect of maize densities and time of thinning of maize on dry matter of straw, grains, total biomass, harvest index and percentage of lodged maize plant at late grain filling stage in time of thinning experiment, 2002.

Treatments	DM of straw (g/m^2)	DM of grains (g/m^2)	Total biomass (g/m^2)	Harvest index	Lodging (%)
Densities (x 10^3)					
38	537.3	367.1	904.5	0.41	10.0
50	588.2	363.4	951.5	0.38	21.5
53 alternate row	551.2	405.7	957.0	0.42	34.4
53 paired rows	558.5	355.4	913.8	0.39	31.1
Time of thinning					
TT1	609.4	377.7	987.0	0.38	19.4
TT2	579.2	396.7	975.9	0.41	19.1
TT3	487.8	344.3	832.1	0.41	34.1
Probabilty					
Density	NS	NS	NS	NS	**
Time of thinning	**	**	**	NS	**
lsd (0.05)	101.2	60.4	136.2		12.3

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively.. NS, * and ** indicate non significant, significant at 5 and 1 % level

ha^{-1} but it did not differ from paired row planting of 53 x 10^3 plants ha^{-1}. Time of thinning had no effect on harvest index of maize.

5.8.3.5 Percent of lodging at grain filling stage

Maize density had a significant effect on degree of lodging of plants at the grain filling stage. The significantly lowest degree of lodging was obtained with 38 x 10^3 plants ha^{-1} compared to both alternate or pair row planting of maize at 53 x 10^3 plants ha^{-1} but did not differ with 50 x 10^3 plants ha^{-1}. Time of thinning also had significant effects on degree of lodging. Thinning after 60 DAS (TT3) increased percentage of lodging of maize plants compared to thinning after germination and 30 DAS (TT1 and TT2).

5.8.4 Growth measurement of soybean

5.8.4.1 Plant height

Data of plant height measured over time are presented in Appendix 5.9. Plant height of soybean increased asymptotically as season progressed, but there was no effect of any treatments on plant height at any recording occasions.

5.8.4.2 Leaf area index

Changes in LAI throughout the growing season are presented in Appendix 4.10 and Figures 5.8 and 5.9. LAI of soybean increased in all treatments up to 74 DAS and the rate of increase slowed down thereafter at 88 DAS. Maize density had a significant effect on LAI of soybean at the third and fourth sampling occasions only. LAI was ranked greatest for maize density 38 x 10^3 plants ha^{-1} and least at 53 x 10^3 plants ha^{-1}, but the differences between 38 and 50 x 10^3 plants ha^{-1} was not significant. Similarly the difference in LAI between single and pair rows of 53 x 10^3 plants ha^{-1} was not significant. Time of thinning of maize also had a significant effect on LAI of soybean and was ranked highest at thinning after germination (TT1) to lowest at thinning after 60 DAS (TT3) but this effect was significant at the second sampling occasion only (Figure 5.9).

5.8.5 Yield components of soybean

Data on yield and yield components of soybean are presented in table 5.14.

5.8.5.1 Grain yield (g/m^2)

There was a significant effect of maize density on grain yield of soybean, ranked from greatest at maize density of 38 x 10^3 plants ha^{-1} to least at 53 x 10^3 plants ha^{-1} with pair rows but the difference between single and pair rows at the same density was not significant. Similarly, the difference in grain yield of intercropped soybean between 38 and 50 x 10^3 plants ha^{-1} was not significant. Grain yield of soybean increased by 40 % when maize density was reduced from recommended to 38 x 10^3 plants ha^{-1}. Time of

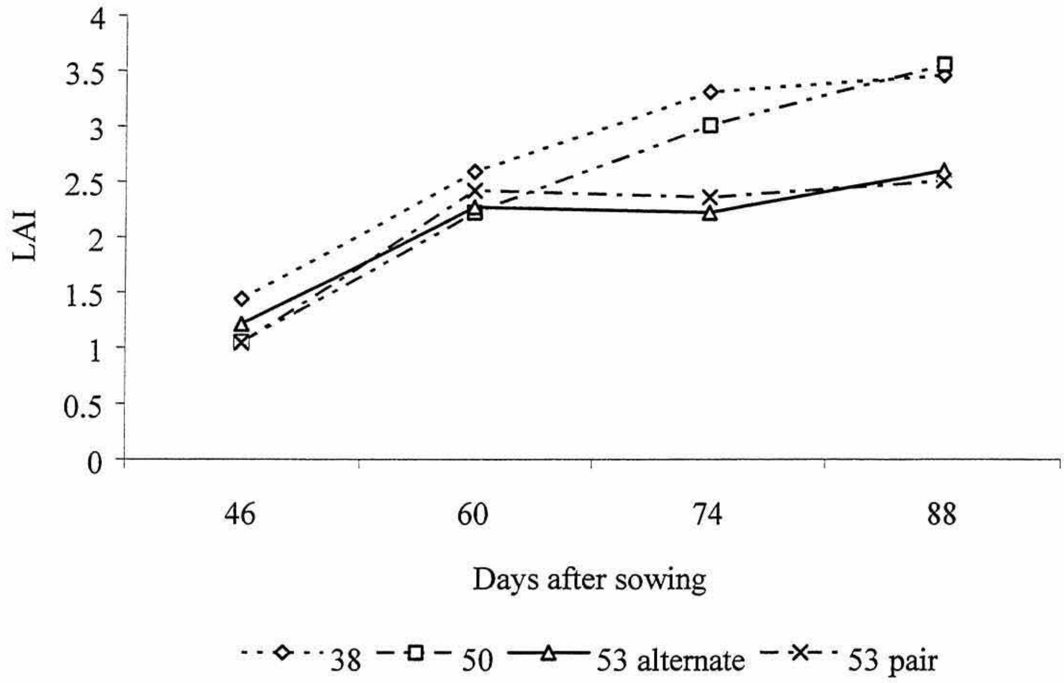


Figure 5.8.The effect of maize density on LAI of soybean measured over time in time of thinning experiment, 2002 See Appendix 5.10 for data table).

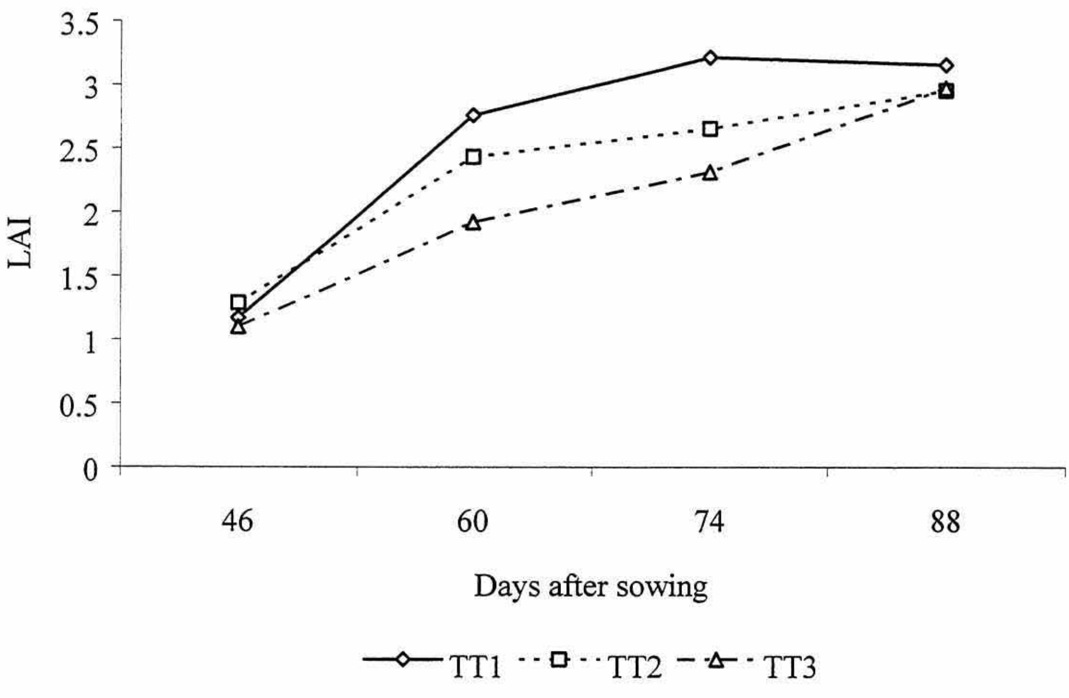


Figure 5.9. The effect of time of thinning of maize on LAI of soybean measured over time in time of thinning experiment, 2002 (See Appendix 5.10 for data table)

thinning had a significant effect on grain yield of soybean and was ranked from highest at thinning after 60 DAS (TT3) to lowest at thinning after germination (TT1) but this did not differ from thinning after 30 DAS (TT2). Delayed thinning of maize after 60 DAS increased grain yield of soybean by 27.8 %.

Table 5.14. The effect of maize densities and time of thinning of maize on yield and yield components of soybean in time of thinning experiment, 2002.

Treatments	Grain yield (g/m^2)	Plants/m^2	pods/ plant	Seeds/pod	100 seed weight
Densities (x 10^3)					
38	69.9	13.1	23.6	1.91	24.57
50	61.5	9.4	27.4	1.89	24.34
53 alternate row	52.2	12.6	19.3	1.92	23.80
53 paired rows	47.1	12.4	18.5	1.85	23.52
Time of thinning					
TT1	50.0	11.5	20.6	1.78	24.01
TT2	59.1	12.0	22.0	1.98	24.09
TT3	63.9	12.2	23.9	1.92	24.09
Probabilty					
Density	**	**	**	NS	*
Time of thinning	**	NS	NS	NS	NS
lsd (0.05)	12.33	0.95	6.0		1.19

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively. . NS, * and ** indicate non significant, significant at 5 and 1 % level

5.8 .5.2 Soybean population density (plant/m^2)

Maize density had a significant effect on soybean population density at maturity and a significantly lower population was obtained at 50 x 10^3 maize plants ha^{-1}. This was due to reduced density at planting compared to other densities. It is realised that this was an imposed treatment, but implications are considered later, in discussion.

5.8.5.3 Pods/plant

Pods/plant was significantly affected by maize density. Soybean planted under maize density of 50 x 10^3 plants ha^{-1} produced a higher number of pods per plant compared to 53 x 10^3 plants ha^{-1}, but this did not differ significantly from 38 x 10^3 plants ha^{-1}.

5.8.5.4 Seeds/pod

There was no treatment effect upon number of seeds/pod. It is generally an unresponsive variable, because it is fixed quite early in the reproductive phase (no. of ovules fertilized) and was not affected by stress provided by the tested range of treatments.

5.8.5.5 100 seed weight

Maize density had a significant effect on 100 seed weight. Soybean planted under a low maize density of 38 x 10^3 plants ha^{-1} as well as wider row spacing of 50 x 10^3 plants ha^{-1} produced heavier grains than when planted under recommended density, either single or pair row planting.

5.8.6 Dry matter of soybean yield

Data on dry matter of straw, grains, total biomass and harvest index are presented in Table 5.15. Significant results are described in separate sections below.

5.8.6.1 Dry matter of straw yield

A significantly higher dry matter of straw was produced under the lowest maize density of 38 x 10^3 plants ha^{-1} compared to the other densities but the difference among the other densities was not significant. Recommended density reduced dry weight of straw by 19.5 % compared to 38 x 10^3 plants ha^{-1}. However, straw dry weight was not affected by time of thinning.

5.8.6.2 Dry matter of grains yield

Dry matter of soybean grains was significantly affected by maize density and was ranked from highest under maize density of 38 x 10^3 plants ha^{-1} to lowest under 53 x 10^3 plants ha^{-1} with pair row planting but the difference between single and pair rows at 53 x 10^3 plants ha^{-1} was not significant. Similarly, the difference between 38 and 50 x 10^3 plants ha^{-1} in dry matter of grains was not significant.

Time of thinning had a significant effect on dry matter of soybean grains and a significantly higher dry matter of grains was produced when maize plants were thinned after 60 DAS (TT3) compared to immediate thinning after germination (TT1) but this did not differ from thinning after 30 DAS (TT2).

5.8.6.3 Total dry matter

Being grown in combination with maize at 38 x 10^3 plants ha^{-1} produced significantly higher biomass compared to 53 x 10^3 plant ha^{-1} with single or pair row planting but did not differ from 50 x 10^3 plants ha^{-1}. The total biomass production of soybean was

Table 5.15. The effect of maize densities and time of thinning of maize on dry weight of straw, grains, total biomass and harvest index of soybean in time of thinning experiment, 2002.

Treatments	DM of straw (g/m^2)	DM of grains (g/m^2)	Total biomass (g/m^2)	Harvest index
Densities (x 10^3)				
38	126.3	65.2	191.4	0.34
50	109.9	57.3	167.2	0.34
53 alternate row	101.6	48.8	150.4	0.32
53 paired rows	93.4	44.0	137.3	0.32
Time of thinning				
TT1	101.7	46.6	148.3	0.32
TT2	116.3	55.3	171.6	0.32
TT3	105.3	59.5	164.8	0.36
Probability				
Density	**	**	*	NS
Time of thinning	NS	**	NS	*
lsd (0.05)	23.9	11.6	28.7	0.06

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively. . NS, * and ** indicate non significant, significant at 5 and 1 % level

reduced by 21.4 % when it was planted under recommended maize density compared to maize density of 38 x 10^3 plant ha^{-1}.

5.8.6.4 Harvest index

Harvest index of soybean was significantly affected by time of thinning, the greatest being obtained when thinning of maize was carried out at 60 DAS (TT3) compared to thinning after germination and 30 DAS (TT1 and TT2).

5.8.7 Measurement of intercropping efficiency

Means of partial LER of maize and soybean and LER are presented in Table 5.16 and significant effects are presented in the result section as follows:

5.8.7.1 Partial LER of maize and soybean

The higher value of the partial LER of maize indicated that this crop was more dominant than soybean. Maize density had a significant effect on partial LER of both crops but the effects were more or less reversed. A significant higher partial LER of maize was obtained with the recommended maize density compared to 50 x 10^3 plants ha^{-1} whereas partial LER of soybean under maize at recommended density was significantly lower than 38 and 50 x 10^3 plants ha^{-1}.

Time of thinning had a significant effect on partial LER of maize and soybean but again, the trends were opposite to each other. Thinning at 60 DAS (TT3) reduced partial LER of maize compared to thinning at 30 DAS (TT2). On the other hand, thinning at 60 DAS increased partial LER of soybean compared to thinning after germination (TT1).

5.8.7.2 Land equivalent ratio

Biological efficiency measured as LER of all treatments was greater than unity indicating higher land use efficiency of intercrops over sole cropping. Maize density of 38 x 10^3 plants ha^{-1} gave significantly higher LER than 53 x 10^3 plants ha^{-1} with pair row planting but difference among other densities were not significant.

Time of thinning had a significant effect on LER, with a significant higher LER being obtained when maize plants were thinned after 30 DAS (TT2) compared to thinning after 60 DAS (TT3), but this did not differ with thinning after germination (TT1). The LER value of 1.40 with TT2 indicated that 40 % more area would be required to produce same yield from sole crops.

Table 5.16. The effect of maize densities and time of thinning of maize on partial LER of maize and soybean, and LER of maize/soybean system in time of thinning experiment during 2002.

Treatments	Partial LER of maize	Partial LER of soybean	LER
Densities (x 10^3)			
38	1.07	0.35	1.42
50	0.97	0.31	1.28
53 single row	1.12	0.26	1.39
53 paired rows	1.01	0.23	1.25
Time of thinning			
TT1	1.08	0.25	1.33
TT2	1.10	0.29	1.40
TT3	0.95	0.32	1.27
Probability			
Density	*	**	*
Time of thinning	**	**	*
lsd (0.05)	0.14	0.06	0.16

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively. NS, * and ** indicate non significant, significant at 5 and 1 % level

5.4 Discussion

5.4.1 Effect of maize density on growth and yield attributes of maize

In both seasons, the results (Appendix 5.1, 5.7) showed that maize density had no effect on plant height of maize. Generally, plant height of a cultivar of maize is genetically determined and is not influenced by minor stress. The range of tested densities did not create sufficient stress to influence plant height.

The results of the first (2001) experiment (Appendix 5.3, Figure 5.4) showed that LAI of maize increased with increasing density of maize but differences between 53 and 66 x 10^3 plants ha^{-1} were not significant. Similar results were obtained during the second season but differences between 50 and 53 x 10^3 plants ha^{-1}, alternate and pair rows, were not significant. This indicated that population densities above 50 x 10^3 plants ha^{-1} produced the maximum LAI, whilst 38 x 10^3 plants ha^{-1} was sub-optimal. When plants are grown in association, there is an interaction between plants and these develop different relationships, manifesting themselves as cooperative, neutral and active competition. In case of density relationship, there may be cooperation at low density and gradually this changes to neutral and active competition as density increases (Donald, 1963). At an early growth stage, plant growth is independent of density due to low intra-specific competition for growth resources but competition among plants increases as the canopy achieves closure, as the season progresses. In experiments described here, LAI increased with increasing density up to a maximum at the optimum density and declined thereafter due to intense intra-specific competition. The increment in LA per plant was slower at higher densities but total leaf area was greater at higher density due to greater number of plant per unit area.

Secondly, the interception of solar radiation depends on leaf area. In this study, the standard maize density (53 x 10^3) had higher interception of PAR than low maize density (Figure 5.5) because of a greater LAI at standard maize density. This result is in agreement with Tekio-kagho and Gardener (1988), who reported that LAI increased parabolically up to maximum at 10.0 plants m^2 in maize.

The results of present study (Tables 5.5, 5.12) showed that maize density had a significant effect on biomass and grain yield in treatments thinned after germination, where the standard density produced greater biomass and grain yield than 66 x 10^3 plants ha^{-1} during the first season. However, cobs/plant and grains/cob were highest at the low maize density of 38 x 10^3 plant ha^{-1} and declined as maize density increased. In the second season, standard density produced a higher grain yield and harvest index than 50 x 10^3 plants ha^{-1} while lowest grain weight per grain was produced at standard density compared to the low maize density of 38 x 10^3 plants ha^{-1}. At low maize density, due to greater penetration of light down the canopy, all leaves are more active and participate in photosynthesis whereas at a higher density, mutual shading of lower leaves may reduce net assimilation rate resulting in low biomass and grain production per plant. Grain yield of maize is most sensitive to variation in plant density and maximum grain yield is obtained at an optimum population, and deviation from this decreases the grain yield. Sangoi (2002) reported that plant populations beyond the optimum causes a series of consequences that are detrimental to ear ontogeny and result in degrees of barrenness. First, ear differentiation is delayed in relation to tassel differentiation. Later initiated ear shoots have a reduced growth rate, resulting in fewer spikelet primodia being transformed into functional florets by the time of flowering. These functional florets extrude silks slowly, decreasing the number of fertilized spikelets due to the lack of synchrony between anthesis and silking. Limitation in carbon and nitrogen supplies to the ear due to intra- specific competition stimulates young kernel abortion immediately after fertilization. Sangoi *et al.* (2002) also found that the increase in plant population increased barrenness, lengthened the anthesis to silking interval and decreased kernel set per ear more drastically. This may explain the lower grain yield at higher maize density. Secondly, the lower grain yield of maize at the highest density (66 x 10^3) is attributed due to lower number of cobs/plant and grains/cob whereas the higher number of cob/plant and grains/cob at low density (38 x 10^3) compensated for the lower plant population in first season. Similar observations were made by Prior and Russel (1975) that an increase in grain yield with plant population density up to 51 x 10^3 plants ha^{-1} was followed by decreasing yield with further increases of plant population up to 72 x 10^3 plants ha^{-1}, i.e. a parabolic response. Maize is particularly sensitive to intra-specific competition due to its almost totally uniculm growth habit

In the 2002 season, the planting geometry of the 50 x 10^3 plants ha^{-1} maize treatment (100 x 20 cm, Table 5.3) adversely affected grain yield. The close within-row spacing may have increased soybean intra-specific competition and the planting of two rows of soybean between maize rows may have increase inter specific competition, resulting in low grain yield production but heavier grains (Table 5.12). Lighter weight grain of maize at standard density could have been due to high intra-specific competition among plants. Correlation coefficients between grain yield and grains/cob show (Table 5.17) that grain yield was positively correlated with the number of grains/cob in both seasons. Standard maize density had higher lodging (%), recorded at dough stage, indicating plants were too weak to withstand a strong wind. In spite of the highest lodging (%) being recorded at standard density alternate rows, grain yield of maize was not affected because the major development of grains was completed before onset of strong wind.

In the first season, the harvest index of maize was not affected (Table 5.6), suggesting that maize reacted to competition by reducing the grains yield to balance the loss of vegetative biomass rather than altering its partitioning of resources. On other hand, in 2002, lower HI of maize at 50 x 10^3 plant ha^{-1} indicated that maize plants reacted to stress caused by intra-specific competition due to closer interplant space which reduces allocation of photosynthates to grains, indicating lower efficiency of maize for grain production (Table 5.13).

Table 5.17 Correlation between grain yield and yield components (plant/m^2, cob/plant, 1000 grain weight and grain/cob) of maize during 2001 and 2002 seasons.

Yield and yield components	Correlation (2001)				Correlation (2002)			
	Cobs/ plant	Plants/ m^2	Grain weight	Grains /cob	Cobs/ plant	Plants/ m^2	Grain weight	Grains/ cob
Grain yield	0.23ns	0.07ns	0.26ns	0.41*	0.04ns	-0.05ns	0.01ns	0.42**
Cob/plant		0.74ns	0.35*	0.17ns		-0.34ns	0.15ns	0.06ns
Plant/m^2			0.18ns	0.34ns			-0.29ns	0.26ns
Grain wt.				0.15ns				0.36*

* ** indicates significance at $p \leq 0.05$ and $p \leq 0.01$, respectively, ns indicates that the correlation was not significant.

5.4.2 Effect of time of thinning on growth and yield attributes of maize

The results (Appendix 5.1, 5.2) of the present study showed that maize density had no effect on plant height of maize at all sampling dates but a significant interaction (Figure

5.3) between maize density and time of thinning on plant height was observed at harvest during 2001. Plant height of maize at standard density was suppressed significantly when thinning was delayed by 60 DAS. The traditional practice of hill farmers of Nepal is to grow maize very densely as an insurance against drought, insect damage and subsequently deliberately reduce population density through removal of barren, lodged and diseased plants. This results in intense inter-plant competition during early vegetative growth. Secondly, farmers delay thinning of maize until plants are large enough to supply of fodder from increased biomass which is often in short supply during the pre-monsoon dry period. Delayed thinning increases competition for growth resources resulting in poor growth, barren plants and finally reduced grain yield. Therefore, KARI (2000) suggested that early thinning will minimize wasteful use of soil moisture and nutrients resulting from presence of extra plants and reduce root lodging. Generally, plant height of a cultivar is genetically determined. The presence of excessive plants due to delayed thinning (60 DAS) at standard density resulted in competition for limited growth resources and created sufficient stress to reduce height of maize. This may explain the reduced plant height at standard maize density compared to low maize density when thinning was delayed to 60 DAS. The result (Appendix 5.3) indicated that the trend of LAI of maize at thinning after germination was higher than thinning after 30, 60 and 30 + 60 DAS but differences were not significant. It indicates that the times of thinning tested were not sufficient to create enough stress to reduce LAI significantly.

In the first season, time of thinning had a significant effect on biomass, grain yield and grains/cob (Tables 5.5, 5.6, 5.7). Thinning after 60 and 30 + 60 DAS reduced biomass and grain yield of maize compared to thinning after germination and 30 DAS, while the greatest number of grains/cob was obtained at thinning of maize immediately after germination. Similarly, in the second season, thinning after 60 DAS resulted in significantly reduced biomass and grain yield compared to early thinning after germination and 30 DAS (Table 5.12, 5.13). Data on LAI of maize presented in this thesis is based on single plant/position at different sampling occasions but the LAI of extra plants was not considered in first and second sampling occasions which were present up to 60 DAS before thinning. Presence of greater leaf area reduced light interception by existing plants resulting in reduced photosynthesis and finally grain production. In the present study, the proportion of PAR intercepted by the maize plus soybean canopy was lower when maize was thinned after 60 DAS (Figure 5.6). When plants are thinned earlier, maize plants get an opportunity to develop fully with less competition, resulting in increased LAI and canopy closure which intercept PAR more efficiently. On the other hand, the presence of extra plants for a longer duration increases competition among plants for growth resources, resulting in a lower LAI and poor plant vigour causing less interception of PAR. Similarly, Andrade and Ferreir (1996) also reported that thinning increased the amount of radiation intercepted by 100 % in maize and sunflower and up to 130 % in soybean. This may explain the reason for lower biomass and grain yield when thinning was delayed by 60 DAS or 30 + 60 DAS. This result is in agreement with Subedi (1990) who reported that delayed thinning caused barren plants, fewer ears and lower grains per ear resulting in lower grain yield. Similarly Hallauer and Sears (1969) observed a significant reduction in grain yield due to delay thinning. Adhikari (1990) also reported that thinning delayed after 30 DAS had a detrimental effect on final crop yield. Kurt (1987) obtained the highest grain yield from hybrid maize variety TT81.19 when maize was thinned at the 4th leaf stage and observed that the yield decreased as the thinning was delayed. Furthermore, the number of grains/cob is the most sensitive yield component influencing grain yield. The lower grain yield of maize with delayed thinning was attributed due to lower number of grains/cob (Tables 5.5, 5.12).

The result of the present study indicated that thinning after 60 DAS increased the percentage of lodging of maize plant compared thinning after germination and 30 DAS (Table 5.13, only recorded in 2002). Delayed thinning increases competition among plants for growth resources due to presence of a high population for a longer duration, resulting in weak stems, which lodged after strong wind. It may explain the cause of more lodging when thinning was delayed to 60 DAS compared to thinning after germination and 30 DAS. This result suggests that delayed thinning may cause greater reduction in yield when plants experience strong wind after a long vegetative growth stage.

5.4.3 Effect of maize density on yield and yield attributes of soybean

The result of second experiment (Figure 5.8) indicated that LAIs of soybean were greater when planted under low maize density compared to standard maize density, either alternate or paired row system, but the effect was significant at third and fourth sampling occasions only. As explained earlier in section 4.4.4.1 in Chapter Four, maize has a tall stature and fast growth and casts dense shade on soybean. At high density, the maize canopy intercepted more light due to presence of greater LAI and thus reduced penetration of light to the intercropped soybean canopy compared to lower density of maize. The greater light availability at standard density in intercropped maize reduced light incident upon the soybean canopy resulting in reduced growth and lower LAI of soybean compared to low maize density. This result is in agreement with and Tetio Kagho (1988) and Bos *et al.* (2000) who reported that LAI of intercropped soybean cvs Cobb and Davis were significantly reduced as maize density increased. Haraguchi *et al.* (2000) also found that the interception of light by an intercropped mungbean canopy was reduced as planting density of maize increased.

The results of the first experiment (Table 5.8, 5.9) showed that maize density had a significant effect on biomass, grain yield and the number of pods/plant of soybean. Standard maize density reduced the biomass, grain yield and pods/plant compared to lower density of 38 x 10^3 plants ha^{-1}. Similarly, in 2002, lower biomass and grain yield of soybean were obtained when planted under standard maize density, either alternate or paired row planting arrangement (Tables 5.14, 5.15), whereas, the highest number of pods/plant was obtained at maize density of 50 x 10^3 plants ha^{-1} where maize rows were 100 cm apart. A rational explanation of reduction of soybean yield in this study would be the shading of soybean by fast growing maize. As explained earlier in section 4.4.4.2 of Chapter Four, the interception of PAR by maize canopy increased with increasing maize density due to greater LAI, consequently reducing the penetration of light to soybean canopy. Reduced light under the standard maize density to the soybean canopy caused reduced photosynthesis resulting in lower biomass and grain yield of soybean under standard maize density. This result is in agreement with Putnam *et al.* (1985) and Heibsch *et al.* (1995) who reported that the yield of intercropped soybean was suppressed at high maize density and correlated negatively with maize density. Pods/plant is most important yield component of soybean influencing grain yield. The lower number of pods/plant under standard maize density indicates abortion of pods due to suppressed growth caused by shading, resulting in lower grain yield. Grain yield of soybean is significantly correlated with pods/plant (Table 5.18).

Table 5.18 Correlation between grain yield and yield components (pods/plant, plants/m^2, 100 seed weight and seeds/pod) of soybean during 2001 and 2002 seasons.

Yield and yield components	Correlation (2001)				Correlation (2002)			
	pods/ plant	Plant/ m^2	100 seed weight	seed/ pod	pods/ plant	Plant/ m^2	100 seed weight	Seed/ pod
Grain yield	0.40*	0.45**	0.12ns	0.22ns	0.61**	0.03ns	0.27ns	0.12ns
pod/plant		0.17ns	0.42ns	0.15ns		-0.31*	-0.07ns	0.10ns
Plant/m^2			-0.42ns	0.15ns			-0.13ns	-0.06ns
Seed wt.				0.16ns				-0.12ns

* ** indicates significance at $p \leq 0.05$, respectively, ns indicates that the correlation was not significant

Light was a major factor in reduction of grain yield of intercropped soybean. Spatial arrangement i.e. positioning of plant of one component relative to others at the same planting density, offers the greatest scope to maximize inter-specific complementarity (Midmore, 1993). In this experiment, spacing of maize at 50 x 10^3 plants ha^{-1} was increased from the standard 75 cm to 100 cm and the same density was maintained by adjusting inter-plant spacing from 25 to 20 cm which provided more space for penetration of light to the intercropped soybean. This resulted in production of the highest number of pods/plant resulting in a higher grain yield compared to standard density in spite of significantly lower numbers of plant stand/m^2 at harvest (Table 5.14). Another way of increasing inter-specific complementarity is planting of dominant maize in double rows and planting double rows of soybean in the increased width between maize rows to minimize competition for light, called paired row planting (60/90 cm). In the present study, the differences in yield and yield components due to alternate and paired row were not significant. This result is in agreement with Gupta and Singh (1988) who reported that intercropping of soybean in wide and paired rows did not affect the yield of soybean. Similarly, the paired row (30/90 cm) system showed no specific yield advantage over the alternate row (60 cm) system in maize/soybean intercropping (Chandel *at al.*, (1987). Prasad and Shriwastawa (1999) also reported that planting of pigeonpea with soybean either paired row (30/90 cm) and alternate row (60 cm) gave similar LER (1.53 and 1.54). On the other hand Singh and Singh (2001) reported that among different intercropping pattern of maize and soybean, paired maize row (either 30/90 or 45/90 cm) with two rows of soybean gave the highest total yield, LER and net financial return. Ali (1993) mentioned that 2:2 rows ratio allowed more light interception and transmission to lower canopy and gave significantly higher wheat yield equivalent. One possible reason for non-significant results in the present study is a relatively small plot size (5 x 3 m^2) allowing some degree of shading from other treatments due to changing position of the sun during the daytime.

5.4.4 Effect of time of thinning on growth and yield attribute of soybean

The results of experiment 2 (Figure 5.9) showed that thinning time had a significant effect on LAI of intercropped soybean. LAI of soybean was greatest when extra maize plants were thinned immediately after germination but lowest as time of thinning was delayed, but the difference was significant at the second sampling occasion only. The presence of extra maize plants for longer duration (60 DAS) resulted in competition for solar radiation above ground, and water and soil nutrients lower ground due to greater LAI and high root density in the soil. On the other hand, in the case of early thinning, intercropped soybean plants experienced less competition from maize. Competition for soil nutrients by presence of extra plants for longer duration and reduced light to soybean canopy were likely reasons for lower LAI of soybean when thinning of maize was delayed to 60 DAS.

The result of the first experiment showed that time of thinning had no effect on biomass and grain yield of soybean (Table, 5.8, 5.9. 5.9) but weight/grain was significantly affected when thinning of maize was delayed by 60 DAS compared to other times of thinning. The 100 seed weight gives an indication of the ability of a plant to meet sink demands during grain filling (Putnam *et al.*, 1992). The higher number of pods/plant with thinning at 60 DAS indicated less abortion of pods due to increased light penetration at flowering and pod formation stage. Photosynthates manufactured in leaves are distributed among greater number of pods developed in thinning at 60 DAS resulting in lower weight per grain. It also confirms the results discussed in section 4.4.4.2 of Chapter Four showing a negative correlation between the number of pods/plant and seed weight.

The result of experiment 2 (Table 5.14, 5.15) showed that the grain yield of intercropped soybean increased as thinning time of maize was delayed. When maize plants were removed earlier, the existing maize plants that experienced less competition and had a more favourable environment to grow in a dominant compared when thinning was delayed where growth of maize plants was restricted due to high intra-specific competition. It cast more shade on the intercropped soybean due to greater LAI resulting in suppressed growth of soybean during late vegetative and reproductive growth stage. Secondly, presence of extra maize plants for a longer duration absorbed more water and soil nutrients and depleted soil nutrients more quickly. Efficient depletion of mineral N from the soil by extra maize plants can force soybean plant towards N_2 fixation (Wahua and Millar 1978b; Giller and Wilson, 1993) because high levels of mineral N in the soil depress both nodulation and N_2 fixation (Streeter, 1988) and pushes the legume towards dependence on soil N. Thirdly, delayed thinning of maize provides more light penetration to intercropped soybean canopy during flowering and pod formation stage. These results indicate that in the second season soybean was less adversely affected by early competition from maize than in the first season. Odeleye *et al.* (2001) reported that reduced light intensity was most damaging to soybean performance at the pod filling stage resulting in greater yield reduction. Jiang and Egli (1993) also reported that shade imposed from first flower to early pod fill reduced flower production and increased flower and pod abscission. Higher harvest index at thinning after 60 DAS during the second season indicated that soybean plants were more efficient in partitioning of resources to grains once competition had been reduced.

5.4.5 Effect of intercropping on total productivity

Intercropping provides a yield advantage only when component crops do not compete for same growth resources and complement to each other in efficient utilization of light, nutrients and water during time and space. For example, combined canopies of short statured legumes under tall cereals are more efficient in utilization of solar radiation, resulting higher total production. In the present study, the results (Appendix 5.4, 5.5, 5.6) showed that interception of PAR by the maize canopy only ranged from 56 to 74 % but the combined canopy of maize and soybean intercepted 72 to 92 %, indicating more efficient utilization of solar radiation by the combined crops. The comparison of partial LER of component crops indicates their degree of competitiveness in the mixture. In the present study, higher partial LER of maize in both experiments (Tables 5.11, 5.16) shows a higher maize yield than the expected yield in all mixtures indicating that maize utilizes more growth resources than allocated to it at planting. It showed a very dominant effect on soybean crop. On the other hand, the lower partial LER of soybean indicates that soybean was less competitive than maize and utilized less environmental resources than maize. The reasons for higher competitiveness of maize has been already discussed in section 4.4.7 of Chapter Four.

In both experiments, the results showed that partial LER of maize was decreased as time of thinning was delayed. Thinning of extra maize plants at an early stage provided a better environment for the remaining maize plants to grow. In both experiments, partial LER of soybean was higher at low maize density compared to standard maize density indicating soybean plants under low maize density are more competitive than standard density because low maize density provides more penetration of light and reduced inter-specific competition. The results of the first experiment showed that time of maize thinning had no effect on partial LER of soybean but a significantly higher partial LER of soybean was obtained, when thinning was delayed by 60 DAS in second season. Increased light penetration to the soybean canopy at the flowering stage due to delayed thinning of maize may allow increased photosynthesis in soybean. Additionally, depletion of soil nutrients by extra plants for a longer duration may push soybean plants towards N_2 fixation and increased competitiveness of plants compared to early thinning.

In the present study, the advantage of intercropping over sole crops measured in terms of land equivalent ratio (LER) of all intercropped treatments in both experiments were greater than unity except in thinning after 60 and 30 + 60 DAS in the first experiment, indicating higher land use efficiency of intercrops. Overall, LER of all intercrops in second season were higher than first season. Low rainfall during second season favoured the growth and production of soybean resulting in a higher LER. The LER of all intercrops in second season ranged from 1.25 to 1.42 showing at least a 25 % higher land use efficiency.

In the first season, highest maize density of 66 x 10^3 plant ha^{-1} had lowest LER (<1) indicating a disadvantage of intercropping. This may be attributed to a reduction in maize yield per plant caused by high plant population. In the second season, standard maize density with paired planting had a lower LER than low maize density of 38 x 10^3 plant ha^{-1}. In both seasons, LER was significantly affected by time of thinning and LER was reduced as thinning of maize was delayed. In the first season, LER with thinning after 60 and 30 + 60 DAS was equal to unity indicating no advantage over sole cropping. Maize yield was more affected by delayed thinning and the magnitude of reduction during first season was 17.6 % and 18.1 % when thinning was delayed to 60 and 30 + 60 DAS, respectively. Similarly, maize grain was reduced by 11 % as thinning was delayed to 60 DAS during the second season.

5.5 Conclusion

The results indicated that the standard maize density produced greatest grain yield of maize, whilst higher density (66 x 10^3 plants ha^{-1}) and lower density (38 x 10^3 plants ha^{-1}) gave significantly lower yields, indicating the optimum population for maize. However, the low maize density increased grain yield of intercropped soybean by allowing greater light through to the soybean canopy and thus increased overall land use efficiency. Therefore, it is suggested that farmer adapt a maize population of 38 x 10^3 plants ha^{-1} for intercropping of soybean with maize. Delaying thinning of maize beyond 30 DAS reduced grain yield of maize, resulting in a lower LER. It is suggested that farmers should remove surplus maize plants within 30 DAS to obtain a higher production of maize, if the main objective is to produce grains. Farmers should keep separate area for fodder supply, if their main objective is to supply fodder for cattle.

The planting of maize in wide row (50 x 10^3) and paired row (53 x 10^3) arrangements produced a lower grain yield of maize but increased grain yield of soybean compared to standard planting arrangement of maize. This experiment was conducted in small plot size of 3 x 5 m^2. These treatments should be further investigated in larger plot sizes to avoid shading effect of neighbouring treatments.

CHAPTER SIX

PHOTOSYNTHESIS IN SOYBEAN

6.1 Introduction

Intercropping as an option for higher land use efficiency and more efficient utilization of resources is a common practise in hills of Nepal, particularly in small holding farming communities where supply of external inputs are limited due to poor access to transportation and physical barriers. The practice of growing soybean as an intercrop with maize is predominant in the western hills and southern hills where annual rainfall is less than 1500 mm, because it can withstand drought and provide security against crop failure in addition to maintaining soil fertility. Generally, as discussed in the literature and review section in Chapter Two, the productivity of intercropped soybean is lower than for a sole crop due to inter- and intra-specific competition for growth resources above ground (light) and below ground (water and nutrients). Competition for solar radiation is a major factor in reduction of biomass and grain production of soybean and is dependent on population density of component crops especially, a tall cereal like maize. Maize has a tall stature and quick growth, becomes dominant and casts shade on soybean (Maingi *et al.*, 2000) by reducing penetration of light to the soybean canopy. Several authors reported that maize yield was not affected by the presence of soybean but soybean yield was reduced under maize and this was greater with increasing density of maize (Weils and Mc Fadden, 1991; Putnam *et al.*, 1985), by reducing the photosynthetic rate of soybean (Vandermeer, 1989). Wahua and Millar, 1978c) reported that in comparison to unshaded, the grain yield of soybean was reduced to 90, 75, 48, 18 and 2% when it was shaded by 20, 47, 63, 80 and 93% respectively. Similarly, in maize/soybean intercropping, Gardener and Craker (1981) reported that soybean received 50 % incident light at low maize density compared to 20 % at the highest maize density.

The experiment conducted on a maize/soybean intercropping discussed in chapter three demonstrated that the biomass and grain yield of maize was not affected by presence of soybean while the biomass and grain yield of intercropped soybean was reduced by 58% and 60 %, and 59 % and 53 % during 2001 and 2002, respectively. The reductions in biomass and grain yield were greatest at standard density and least in the lowest maize density of 26 x 10^3 plants ha^{-1}, due to higher interception of PAR by the maize canopy. The standard maize density intercepted more PAR throughout the growing period compared to low maize density.

The experiment described in this chapter was initiated to quantify the photosynthetic rate of soybean in open and shade (50% artificial shading or mixed cropping) in a semi-controlled environment (greenhouse) and its effect on the growth of soybean. It is recognised that an intercropping system in a pot experiment in a glasshouse does not truly represent field conditions due to the smaller soil volume and differences in soil environment, but it may provide some basic information on net assimilation rate of soybean under different light regimes.

6.2 Objective

- To quantify net assimilation rate of soybean in open and shade (50% artificial shading or intercrop) at different level of incident PAR and to determine to what extent soybean exhibits adaptation to shade.

- To determine if shaded resulted in changes in allometric relationships in soybean and dry matter accumulation.

6.3 Material and methods

The experiment was conducted in pots a greenhouse at Henfaes Research Centre, University of Wales, Bangor during summer 2003 season. The experiment consisted of three treatments: no shade, 50 % artificial shading and mixed cropping with maize. Rectangular pots of 41 x 28 cm were used for sole and shaded soybean treatments and circular pot of 48 cm diameter for mixed cropping. Four pots were used for each treatment. Pots were cleaned and rinsed with antiseptic liquid and dried. All pots were filled with top soil thoroughly mixed with compost in a 1:1 ratio. Soybean seeds were inoculated with the appropriate strain of rhizobium. Maize and soybean seeds were sown on 13 May 2003. Maize seed was sown in the centre of the circular pots at two locations at spacing of 24 cm apart. Two seeds were sown at each position and thinned out to one after germination. Soybean seeds were sown closely in two rows, one on each

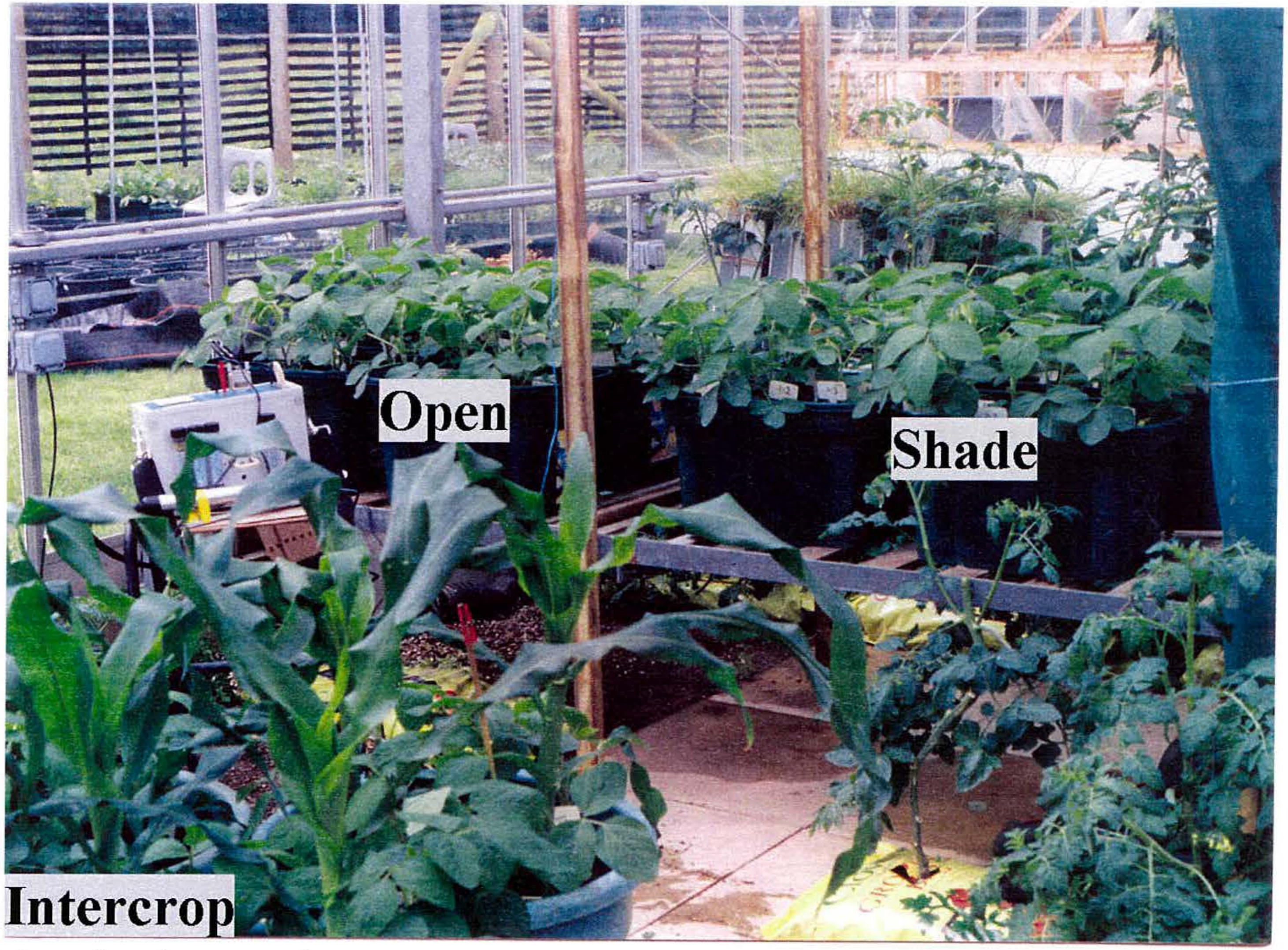


Plate showing experiment on measurement of photosynthesis in soybean under open, shade and intercrop by IRGA in glass house side of a equidistance from the maize row. Four plants in each row at equal distances were allowed to grow after germination. For the sole crop treatments, soybean seeds were sown in two rows in the rectangular pot 15 cm apart. Initially two seeds were sown at each position and thinned out one after germination. Water was applied to provide sufficient moisture for germination and at regular intervals during the whole growing period. Soybean plants in the shaded treatment were covered with a net after 38 days of planting to simulate maize overtaking the soybeans after initially growing without shade.

6.3.1 Measurement of Photosynthesis

A portable PP Systems infrared gas analyser (IRGA) was used to record net photosynthesis of soybean leaves. Measurements were started 38 DAS and thereafter at seven day intervalS until 5 August, 2003. The IRGA was calibrated at 300 ppm CO_2 content in air, and at constant atmospheric pressure. The area of the leaf cuvette was 2.5 cm^2, which the leaves filled. The topmost fully expanded leaf was selected and inserted into the cuvette and held horizontally until a constant reading of net CO_2 uptake was obtained and the recording was taken. Steady net CO_2 evolution usually occurred within 60 – 90 seconds. Two plants per pot were recorded at two hourly intervals from 10.00 to 16.00 hours. Photosynthesis of maize leaves was also recorded on two sunny days to determine the light saturation point.

6.3.2 Measurement of leaf area and dry matter

After 84 DAS, two pots from each treatment were selected. The ninth leaf of each soybean plant was selected and separated from its petiole for leaf area measurement. The remaining above ground biomass was cut into small pieces and put in a paper bag for dry weight determination. The leaf area of the sample leaf or leaflets were measured by a leaf area meter and recorded separately. After taking leaf area measurements, samples were dried in an oven at 80^0C for 48 hours and weights were recorded to 0.001 g accuracy. Similarly, the rest of the plant samples were dried in the oven and weights were recorded. Total dry weight of each plant was computed by adding dry weight of sample leaf and the remaining plant. Specific leaf area (SLA) of the ninth leaf of each plant was computed by dividing leaf area by weight. This is a measure of density or of relative thinness of the leaf. This may decrease systematically with time as leaves mature but increase systematically with depth in the canopy as the light available for leaf development decreases (Beadle, 1993). The objective was to determine whether soybean leaves adapted to shade by increasing leaf area per unit dry weight.

6.3.3 Statistical analysis

Data from the IRGA were downloaded to a computer as comma separated variables (csv) and entered into an Excel spreadsheet. Light response curves were obtained by plotting net photosynthesis (calculated using the IRGA's internal alogarithms) against PAR. As the light response curve was logarithmic in form, to convert the curves to straight lines, the PAR axis was logarithmically transformed. The slopes of the linear regressions were then compared to determine whether treatments affected response to PAR.

6.4 Results

6.4.1 Photosynthesis

The relationships between net photosynthesis rate and incident PAR in maize in open, and soybean in open, under artificial shade and when intercropped with maize are presented in Figures 6.1 and 6.2, respectively. The observed assimilation rate in maize was lower than expected, because observation was made at a late vegetative growth stage when plants were senescent due to the unusually hot weather. The net photosynthesis rate in maize was approximately double that of soybean at the same level of incident PAR but it was not possible to determine the light saturation point due to insufficient solar radiation. In soybean, the net photosynthesis rate increased with increasing level of PAR to 500 μmol $m^{-2}s^{-1}$ and levelled off, with only a slight increment being observed at higher levels of PAR. The net photosynthesis rate and PAR incident on open soybeans were higher than artificial shade and intercropped soybean (Table 6.1). Levels of PAR recorded using the IRGA sensor showed that the level of artificial shade was 50% of ambient PAR. The response of photosynthesis rate was similar between artificial shade and intercropped plants, indicating that the maize canopy provided a similar level of shade to soybean as the artificial shade. The analysis of variance in Table 6.2 shows that interaction between slopes of the regressions for the three treatments was not significant, indicating that shading had no effect upon the potential of the leaves to photosynthesise, and that soybean crop does not adapt to shade. This explained why soybean performed poorly under shade when intercropped with maize when levels of PAR incident on the soybean, at 370 $\mu molm^{-2}s^{-1}$,were well below the light saturation level of 500$\mu molm^{-2}s^{-1}$. When assimilation rate was plotted against the natural logarithm of PAR there was no significant difference in either the slope or intercept of the relationship for open and shaded either artificial or under maize canopy (Figure 6.3). The higher net photosynthesis rate of soybean in open was only because of the higher incident PAR.

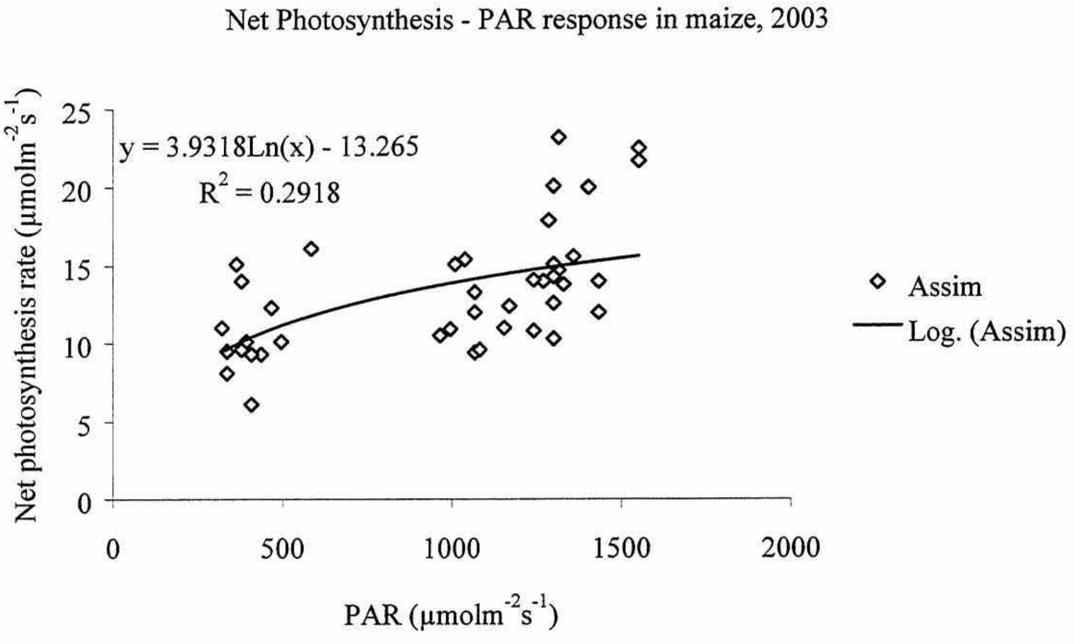


Figure 6.1. The rate of net photosynthesis in maize grown with soybean in pot experiment recorded at late vegetative growth stage, 2003

6.4.2. Specific leaf area (SLA)

SLA of the ninth leaf of soybean in artificial shade (Table 6.3) was significantly greater than open for leaves grown in the land when intercropped with maize, but the difference in SLA between open and intercrop was non significant.

6.4.3. Dry weight per plant

Dry weight per plant of soybean measured after 84 DAS was not affected by shading (Table 6.3)

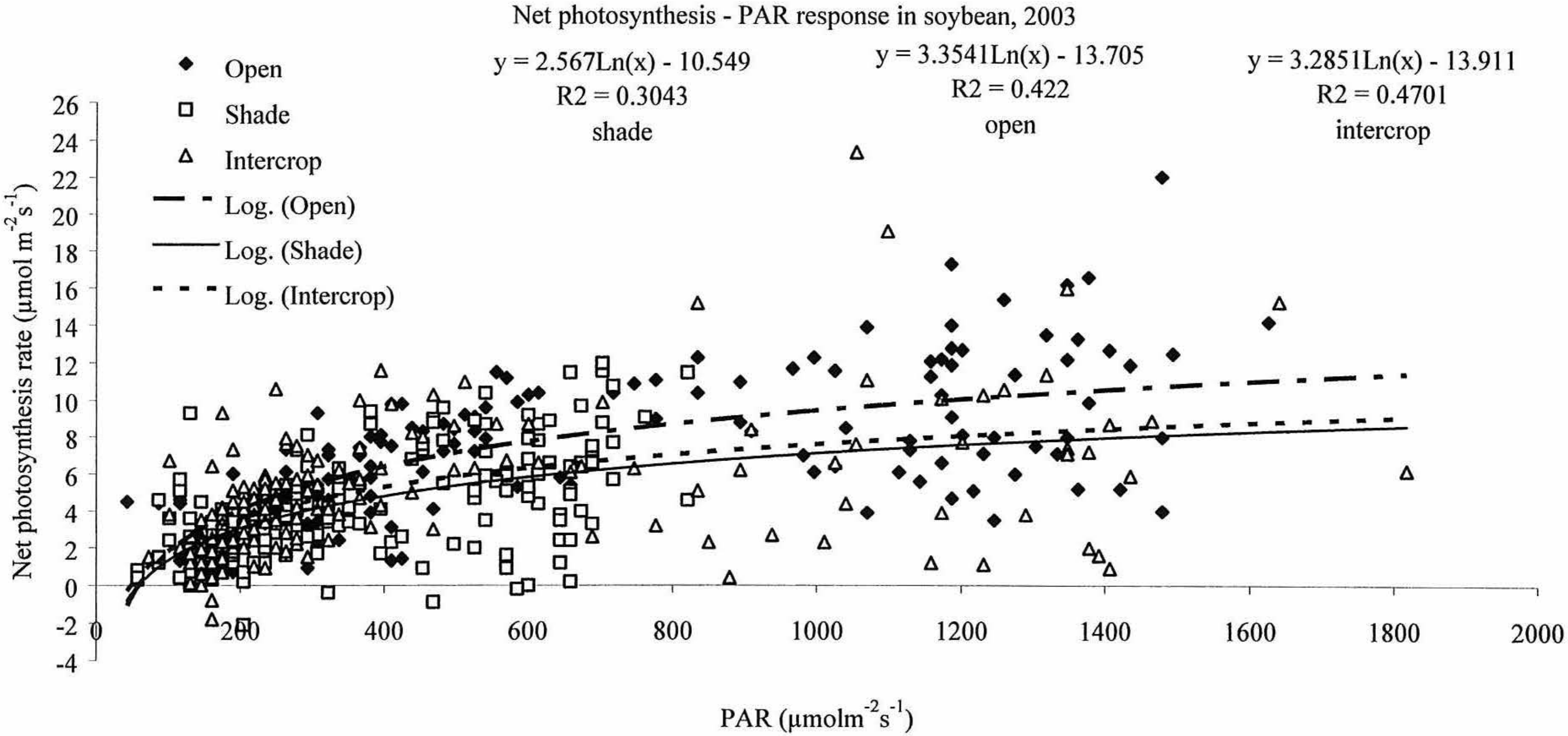


Figure 6.2. The relation between net photosynthesis rate and incident PAR in soybean grown in the open, artificial shade (50%) and intercropped with maize, measured during the vegetative growth in pot experiment, 2003.

Table 6.1. Mean PAR incident on leaves used in IRGA recordings and their mean net photosynthesis rates on soybean grown in open, under artificial shade (50%) and intercropped with maize in pot experiment, 2003.

Treatments	Mean incident PAR	Net photosynthesis rate ($\mu molm^{-2}s^{-1}$)
Open sun	696	7.45
Artificial Shade (50 %)	360	4.09
Intercrop under maize	448	4.79
lsd (0.05)	94.1**	0.90**

Table 6.2. Analysis of Variance for net photosynthesis rate and Log_e PAR, using adjusted SS for tests for soybean grown under open, artificial shade (50%) and intercropped with maize.

Source	DF	Seq SS	Adjusted SS	Adjusted MS	F Value	P value
Treatment[1](intercept)	2	983.32	19.73	9.86	1.27	0.281
Log PAR[2])	1	1945.24	1922.69	1922.69	248.14	0.000
Treat * Log PAR[3]	2	37.67	37.67	18.83	2.43	0.089
Error	499	3866.41	3866.41	7.75		
Total	504	6832.63				

Note: [1] Tests whether intercepts differ significantly, [2] tests significance of overall relationship between x and y and [3] tests whether slopes of regression differ significantly

Table 6.3. Specific leaf area (SLA) of ninth leaf and dry weight per plant after 84 DAS of soybean grown under open, artificial shade (50%) and intercrop under maize in pot experiment conducted in glass house during 2003.

Treatments	Specific Leaf area (cm^2mg^{-1})	Dry weight/plant
Open sun	0.296	25.82
Artificial Shade (50 %)	0.457	24.05
Intercrop under maize	0.286	27.79
lsd (0.05)	0.04**	NS

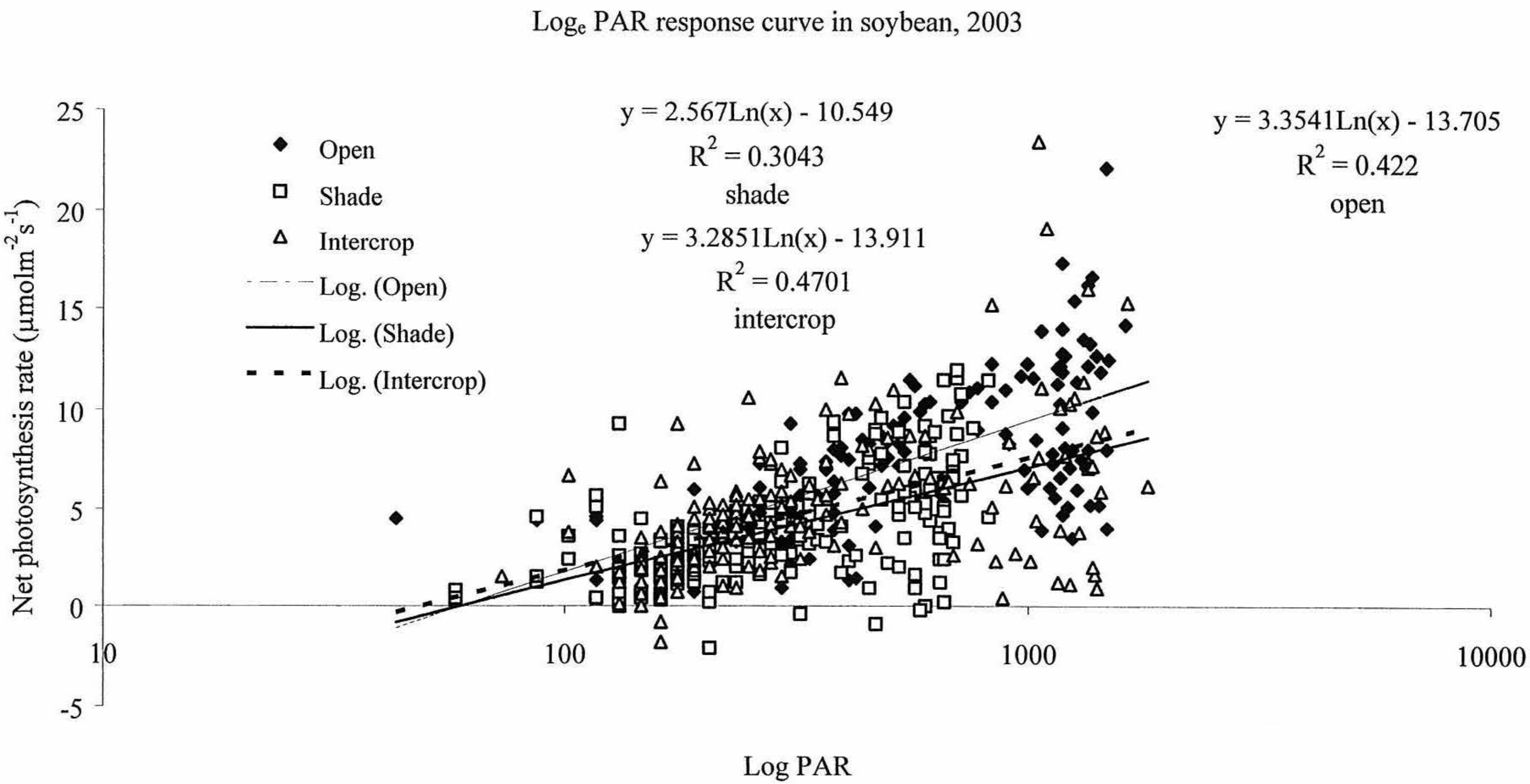


Figure 6.3. The rate of net photosynthesis of soybean grown in open, shade (50%) and intercrop with maize measured during vegetative growth stage, 2003.

6. 5. Discussion

The results (Figures 6.1, 6.2) showed that net assimilation rate in maize was greater than soybean and the rate of photosynthesis in maize increased with increase in incident PAR within the ranged tested, whereas it reached at plateau in soybean at 500 μmol m^{-2} s^{-1} PAR. Maize, being a C_4 plant, has a different carbon fixation pathway than soybean which is a C_3 plant. In C_4 plants, photosynthesis does not saturate until high levels of sunlight are reached and can continue at very low concentrations of CO_2 (Lawlor, 1987).The saturation point is in maize about 1500 μmol m^{-2} s^{-1} (Stirling *et al.*, 1993). The lower photosynthesis rate in soybean is typical of plants with the C_3 pathway, which have half the photosynthetic rate of efficient C_4 plants, and rates level off at lower light intensities (Devlin and Barker, 1971). This experiment demonstrated clearly that whereas upper leaves of soybean were light saturated when not shaded, photosynthesis was significantly reduced by intercropping with maize or being grown under artificial shade approximately equivalent to a maize canopy. Similarly Christy and Porter (1982) reported that 50 % continuous shading of soybean reduced photosynthesis by 25 to 35 %. Comparison of light response curves (Figure 6.3, table 6.2) indicates that photosynthesis rate in soybean follows a similar response in open and shade. Ephrath *et al.* (1993) reported similar findings. It suggests that soybean does not physiologically adapt to shade. The results of Chapter Three indicated that PAR incident upon intercropped soybean was 370 μmol m^{-2} s^{-1} with a range of 171 to 540 which was only 30 % of the sole soybean where incident of PAR was 1237 μmol m^{-2} s^{-1} with a range of 733 to 1914. The reduction of incident PAR upon intercropped soybean by the maize canopy caused reduced grain yield compared to the sole crop. Despite the effects of maize shade, hill farmers are forced to intercrop due to limited land holding. It suggests that soybean yield could be improved by increasing inter-row spacing of maize with a slightly reduced density and planting soybean between maize rows rather than broadcasting, increasing light penetration to the soybean canopy resulting in a higher grain yield of soybean. Farmers could benefit from a higher combined total yield.

SLA of ninth leaf of soybean under shade was significantly greater than when grown in the open and when intercropped with maize. This result is similar to the findings of Redfearn *et al.* (1999) who reported that thinner and wider leaves of soybean are produced under shade. Anonymous (2000b) mentioned that adaptation of shade leaves to low light includes the development of larger and thinner leaves. Even though soybean leaves do not adapt physiologically to low light levels, the increase in SLA shows that they adapt morphologically so that by increasing surface area, shaded leaves may capture as much light as possible. The intercropped treatment of maize/soybean did not represent true field conditions due to the small pot size and leaves received transmitted light from the side resulting in non significant differences in SLA between the open and intercropped.

Dry matter per plant at 84 DAS were similar in open and shade in spite of significant differences in PAR and net photosynthesis rate. Before sampling, bright sunny days caused burning of some upper leaves of soybean in open but not in shaded plants. In addition, lower leaves dried faster in the open. This, along with the initiation of a greater number of leaves and taller plants in shade (data not shown), may have resulted in non–significant differences in plant dry weight between shade and sun plants.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 Introduction

Intercropping is an extremely important farming practice in many developing countries especially in the tropics. It is commonly practiced by subsistence farmers in the hills of Nepal to maximize use of moisture of the short rainy season and to obtain diversified food for their own consumption because of limited land holdings. Farmers grow maize as their staple food but also grow finger millet, soybean, potatoes and beans as intercrops under maize. Many intercropping studies suggest that intercropping provides a yield advantage due to complementarity in resource use over time and space. However, hitherto there has been no systematic information on optimum proportions and optimum densities of maize and soybean to obtain the best yield advantages in the hills of Nepal. This thesis has focussed attention on the need for a better understanding of intercropping systems under mid and high hills environments.

When two crop species are grown together in association, one of them may able to exploit more resources and as a result, produce more yields, while the yield of other is reduced, creating a situation of relative dominance and suppression (Donald, 1963). Evans (1977) suggested that two cultural practices which have considerable influence on the yield of plants growing together are density and arrangement of plants and the resultant competition for available resources. The most commonly suggested reason for higher yield in intercropping over monoculture is that the component crops are in some way able to utilize growth resources rather differently. They complement each other by using total resources more efficiently than when grown separately (Willey, 1979). Planting of a tall cereal like maize at wider spacing provides sufficient space for growing companion crops, because maize plants do not utilize all available resources in their early growth stages. Fisher (1976) reported that growing of beans with maize captured 13 % more light than monocrop maize. The component crops proved more efficient in capturing environmental resources and their effective utilization in mixture resulted in higher yields than in a pure stand. Inter-specific competition for growth resources in mixture is less than intra-specific competition in monocrops, as they may require those at different growth stages and from different vertical layers. For example, deep rooted soybean extract water and nutrients from deeper layers of soils than maize, which has a shallower adventitious root system, resulting in better use of available resources and a higher combined yield. There is now aboundant evidence available to indicate that such mixtures often have a yield advantage over pure stands. For example, Heremath *et al.* (1994) reported that the highest productivity came from maize planted at 90 x 20 cm spacing with soybean, which was higher than sole cropping of maize or soybean.

7.2 Effect of population density on maize and soybean

It was observed that maize density had a significant effect on intercropped maize and soybean whereas maize yield was not affected by differing soybean densities, as explained in Chapters Three and Four. Mean grain yield of intercropped maize and soybean from four different experiments conducted during 2001 and 2002 is summarized in Table 7.1. The results indicated that grain yield of maize tended to be greatest at standard density (53 x 10^3 plants ha^{-1}) in both seasons but trends were not distinct. On the other hand, grain yield of intercropped soybean increased in both seasons as maize density reduced particularly where between row spacing was greatest. However, the relationship between soybean yield and maize planting geometry was not a simple one. When maize density was reduced to 40 and 26.5 x 10^3 plants ha^{-1} from standard density, respectively the magnitude of reduction in maize grain yield was 12 % and 24 % in 2001 and 8 % and 20% in 2002, whereas grain yield of soybean increased by 52 % and 97% in 2001 and 23 % and 43 % in 2002. However, maize densities of 38 and 53 x 10^3 plant ha^{-1} gave similar grain yield of maize in both seasons in time of thinning experiments (Chapter Four) but a significantly higher grain yield of soybean was obtained under a maize density of 38 x 10^3 plants ha^{-1} compared to standard density. At low maize densities, a significantly greater number of cobs/plant and grains/cob were obtained due to low intra-specific competition which compensated for yield reduction due to reduced plant population to some extent. Maize rarely tillers and often bears only one cob per plant, so scope for adjusting yield components by changing planting density is limited in scope to seed per cob and weight per grain. Thus, maize yield is fairly insensitive to changes in population density. To illustrate this, Fisher

(1977) reported that yield per plant of maize was 30 % lower at high density (60 x 20 cm) compared to low maize density (135 x 45 cm) despite a five-fold difference in population density. Higher grain yield at standard maize density was attributed only due to greater number of plants/m^2. In both seasons, the total shoot dry weight per m^2 and LAI were greater at standard maize density which also contributed to higher grain yield compared to low maize density.

Table 7.1. Summary of effects of maize density on mean grain yield (g/m^2) of intercropped maize and soybean from different experiments conducted during 2001 and 2002 season.

Maize density (x 10^3 m^2)	Planting arrangement (cm)	Chapter	Maize		Soybean	
			2001	2002	2001	2002
26.5	150 x 25	3	400	361	98.8	125.1
40	100 x 25	3	464	414	76.4	107.7
53	75 x 25	3	526	450	50.2	87.7
38	75 x 35	4 (Exp I)*	395	462	52.7	69.9
53Alternate	75 x 25	4 (Exp I)	393	487	39.9	52.2
53 Pair	60/90	4 (Exp II)	-	438	-	47.1
66	75 x 20	4 (Exp I)	356	-	41.7	-
50	100 x 20	4 (Exp II	-	421	-	61.5

* For time of thinning experiment, results are for no-thinning treatments

Maize has a tall stature and fast growth, so quickly becomes dominant and cast shade on soybean (Maingi et al., 2000). The intensity of shade increases with increasing maize density due to greater leaf area. Low maize density allows more light penetration to soybean canopy resulting in increased photosynthesis, and consequently higher biomass and grain yield of soybean. Higher grain yield of soybean under low maize density is also attributed due to greater numbers of pods/plant. Similar results were obtained by Putnam *et al.* (1985) and Heibsh *et el.* (1995) who reported that yield of soybean was suppressed at high maize densities. In the current work, from both experiments, it was concluded that there was little reduction in grain yield of maize but a significant increase in grain yield of soybean when maize density was reduced by 25 % from standard density. Thus increased grain yield of soybean at low maize density compensated for slightly reduced yield of maize and contributed to total system productivity of intercrop. Therefore, a maize density of around 40 x 10^3 plants ha^{-1}

should be the optimum for intercropping with soybean, without much influencing the grain yield of maize.

The highest maize density of 66 x 10^3 plants ha^{-1} produced the lowest grain yield of maize during 2001. It confirms that the standard (53 x 10^3 plants ha^{-1}) density is the optimum density for grain production. Any deviation from the optimum population decreased grain yield. Similarly, Sangoi (2002) reported that higher plant populations beyond the optimum are detrimental to ear ontogeny and resulted in barrenness. Prior and Russel (1975) found maximum grain yield of maize at 51 x 10^3 plant ha-1, and this declined thereafter as density increased.

Standard density paired rows (53 x 10^3) and wider rows with close (20cm) within row spacing (50 x 10^3) produced significantly lower maize grain yields compared to standard density alternate rows and the low maize density of 38 x 10^3 plants ha^{-1}, whereas wider row maize planting produced higher grain yield of soybean (Table 4.14). In both planting arrangements, maize plants experienced more intra-specific competition due to close inter-plant spacing between rows in paired row and within row in the wider row arrangement (50 x 10^3), resulting in lower grain production of maize. Wider row planting of maize allows more light penetration to the soybean canopy, resulting in higher grain yield of the soybean compared to standard density. These results support the above conclusion that a maize density of 40 x 10^3 plant ha^{-1} with a planting arrangement of 100 x 25 cm is the optimum for intercropping, which has little effect on maize yield but gives a significant increase in soybean yield.

It was observed that in general, grain yield of maize was higher in the first season compared to second season, whereas the opposite trend was observed for grain yield of soybean (Chapter Four). However, this did not hold true for grain yield of maize in the thinning experiment, (Chapter Five) due to a strong site effect, as this experiment was located on less fertile soil in the first season. Neverthless grain yield of soybean was higher in the second season compared to the first season. High rainfall during the first season (Figures 4.3, 4.4) favoured the growth of maize resulting in higher grain production compared to the second season, whereas low rainfall favoured production of soybean in the second season. This result supported by the findings of the crop sampling in farmers' fields (Chapter Three) in which high rainfall during first season favoured the production of maize but the reverse was true in the second season due to low rainfall.

Grain yield of intercropped soybean was not affected by soybean densities in the first season (Table 4.12) and the difference between soybean densities of 100 and 150 x 10^3 plants ha^{-1} was not significant in the second season (Table 4.13). It is concluded that grain yield of soybean does not increase above 100 x 10^3 plants ha^{-1} when soybean is intercropped with maize, indicating the optimum density which should be recommended to farmers for cultivation. The practical implication of this is that, in areas where maize is the major crop, more attention should be paid to fixing the density of the maize population than to find the optimum population for the associated soybean.

The result of both thinning experiments showed that time of thinning had a significant effect on biomass and grain yield of maize (Tables 5.5, 5.7). A significant reduction in grain yield of maize was obtained when maize plants are thinned after 60 and 30 + 60 DAS compared to immediate after germination and 30 DAS. The traditional practice of farmers is to grow maize very densely as an insurance against drought, insect/pests damage and subsequent plant losses through removal of barren, lodged and diseased plants which leads to intense inter-plant competition during early vegetative growth period. Additionally, farmers delay thinning of maize to obtain a constant supply of fodder for cattle. The greater leaf area due to presence of surplus plants reduced light incident upon existing plants resulting in reduced photosynthesis and eventually grain yield. The implications of this study are that farmers should thin out extra maize plants within 30 DAS, which maximizes better utilization of available resources which contributes to both greater production of maize and higher land use efficiency. Early thinning allows more light interception by existing plants and reduces intra-specific competition among plants. Additionally, it also allows more light penetration to intercropped soybean resulting higher grain yield.

7.3 Assessing advantage of intercropping

The advantage of intercropping over sole crops is commonly expressed in terms of land equivalent ratio (LER) which is simply an expression of the land required for production of the same yield in the sole crop compared to the intercrop (Willey, 1979).

The results of all experiments in both seasons showed that LER of all intercropping treatments were greater than unity except in thinning after 60 and 30 + 60 DAS and for maize density of 66 x 10^3 plants ha^{-1} in first thinning experiment during first season, Overall, this indicated higher land use efficiency of intercrops.

Given equipment available for this study, it was only possible to measure capture of one external resource, solar radiation. In the present study, the maize crop alone was unable to exploit all incoming solar radiation during the growing season (Figure 4.47), whereas sole soybean could not utilize all incoming solar radiation at an early growth stage. The combined canopy of maize and soybean intercepted the highest proportion of PAR (92 to 97 %) from 70 to 112 DAS whereas the sole maize canopy intercepted a maximum of 85 % of PAR at 84 DAS and declined gradually to 60 % of PAR at 112 DAS (Figure 4.46, Appendix 4.31). The higher interception of light by the combined canopies was attributed due to greater combined LAI compared to sole maize over whole growing season (Figures 7.1, 7.2).

Higher productivity of mixtures over the pure stand was partly due to better distribution of light over the mixture canopy and greater interception of light energy by the two crop components, as Hedley and Ambrose (1981) showed with a correlation between light interception and biological yield. Ramakrishna and Ong (1994) also reported that intercropping increased the amount of radiation interception due to faster development of the canopy cover of component crops. The rhizosphere may also be very important under field condition, as where the soil depth is not limited, root penetration of the species is not restricted and since soybean and maize have different root structures, they do not compete with each other for the same resources (Natarajan and Willey, 1980b). Better utilization of available resources in mixed cropping was also perceived by 70% of surveyed farmers (Chapter Three), although they lacked the scientific knowledge to explain this. They knew that maize yield was not affected by intercropping with soybean and that the soybean component provided them with additional grain as a bonus, which LER calculated in the present study showed. Additionally, they are aware that the presence of soybean suppresses weed growth and reduces the cost of second weeding and contributes indirectly in reducing costs of cultivation.

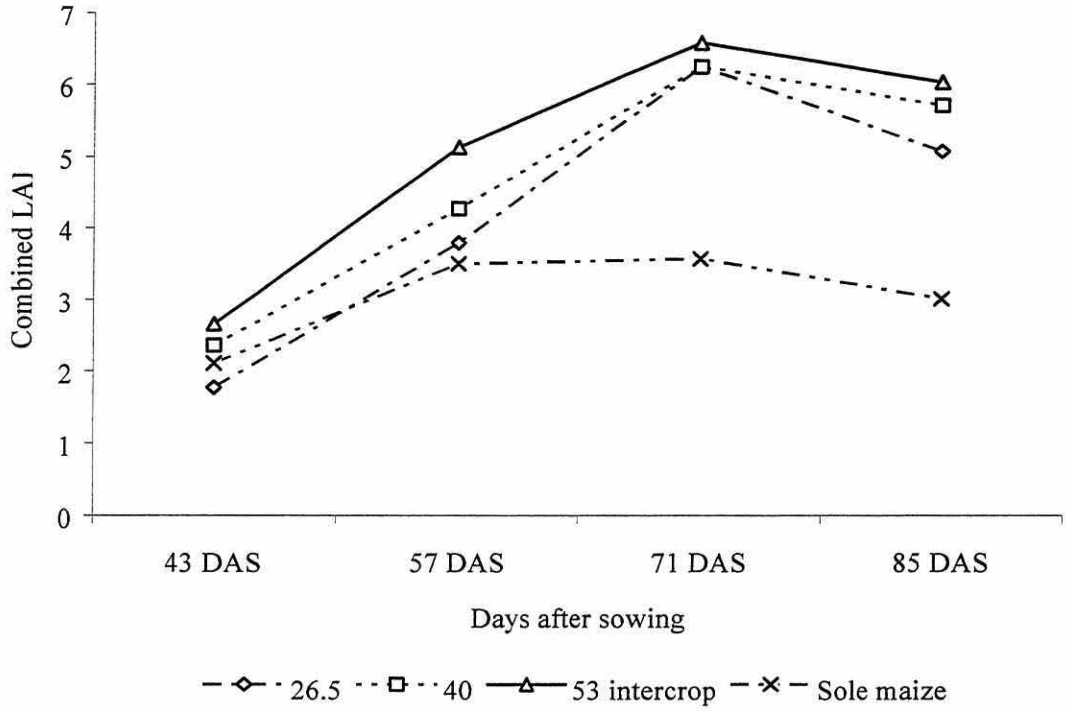


Figure 7.1. Effect of maize densities on combined LAI of intercropped maize and soybean and sole maize during 2001 (Appendix 7.1)

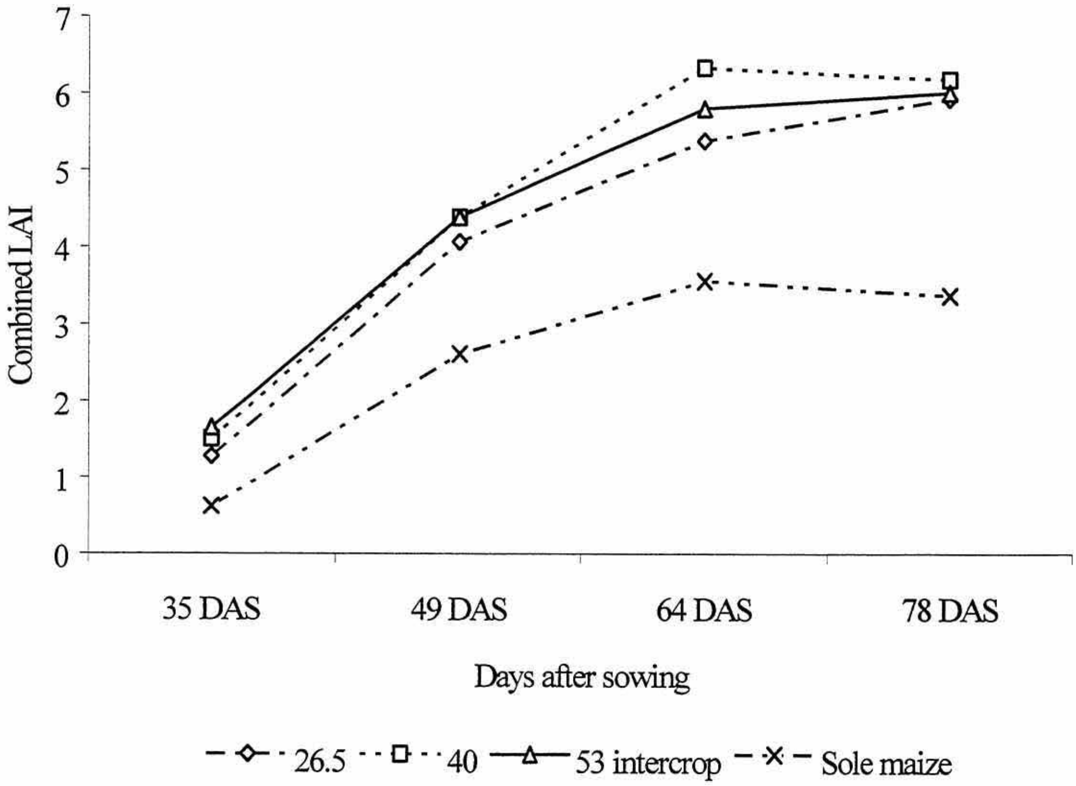


Figure 7.2. Effect of maize densities on combined LAI of intercropped maize and soybean and sole maize during 2002 (Appendix 7.1)

Overall, the LER of all intercrops in second season were higher than the first season. Rainfall plays a significant role in production of maize and soybean. Higher rainfall during the first season favoured the production of maize while lower rainfall (Figure 4.3, 4.4) during the second season favoured the production of soybean, which resulted in the somewhat greater advantage from intercropping in the second season. It is apparent that the yield advantages in mixtures were based on the yield of intercropped soybean. This confirmed the finding of the survey (Chapter Three) in which farmers reported that intercropping provides a stable overall yield despite fluctuations in rainfall and also provides security against crop failure. These results were corroborated by crop sampling from in farmers' fields showing that maize yields were higher in first year with normal rainfall than the second season with low rainfall, while the reverse was true with soybean.

A comparison of partial LERs of component crops indicates their degree of competitiveness in the mixture. Partial LER of maize in all experiments were higher indicating a higher maize yield than expected. It shows that maize utilizes more growth resources than allocated to it at planting, indicating a dominant effect on soybean. conversely, soybean has a lower partial LER, indicating that it is less competitive than maize and utilizes less environmental resources. The reason for high competitiveness of maize has been already discussed in section 4.4.7 of Chapter Four.

7.4 Is soybean suitable as an under-storey crop ?

The results shown in of Table 6.2 and Figure 6.3 indicated that response of photosynthesis in soybean was similar in open and under shade, indicating that soybean does not adapt to shade. However, SLA of soybean leaves in artificial shade was greater than in the open and when intercropped with maize, showing that leaves expanded to compensate for lower rate of photosynthesis under shade. Therefore, soybean performs poorly in shade when intercropped with maize, so it does not seem to be ideal choice for an under-storey species. However, the survey report (Chapter Three) indicated that farmers grow soybean as cash crop due to its high market price as well as providing diversified food needed for their home consumption. Additionally, it provides plant protein to population of remote areas of the hills where there is a limited supply of animal protein. Other legumes such as beans are not suitable for intercropping due to low rainfall during growing season and less priority given by farmers. Soybean is only legume crops that is suited to that agro-ecological zones and fetches high income.

The results suggest that soybean can be grown successfully as an intercrop by manipulating row arrangement of maize with a slightly reduced plant population of around 40 $x10^3$ plants ha^{-1} and planting soybean between maize rows which provides better penetration of light to the soybean, consequently increasing grain yield of soybean.

7.5 Potential cropping system

The results of this study show that soybean is not adapted to shade and it requires high solar radiation for optimum growth. It is suggested that for intercropping, maize could be planted with a slight modification in planting arrangement, by increasing row spacing of from 75 cm to 100 cm with 25 % reduced density from that recommended for sole crops and planting soybean in double rows between the wider maize rows at 100 x 10^3 plants ha^{-1}. This allows more light penetration to intercropped soybean resulting in more vigorous growth and higher grain yield. Increased yield of soybean more than compensates for slightly reduced yield of maize due to the threefold higher market price for soybean. Farmers may start with a higher population of maize but should thin to 40 x 10^3 plants ha^{-1} by no later than 30 DAS. Farmers should preferably manage alternative sources for fodder supply and not integrate it with grain production, if their main objective is to produce grains. Alternatively, they should keep small areas aside for dual purposes, if fodder supply is the main objective

Farmers should be encouraged to follow planting of maize and soybean in rows which facilitates application of fertilizer to maize only and so minimize contact of fertilizer with soybean plants, because an application of fertilizer to soybean suppresses N_2 fixation by reducing nodulation.

7.6 Future Research work

This experiment was conducted at one location in the mid hills. These findings need to be verified in future across the range of altitudes, aspects and soil conditions of different agro-ecological zones of hills of Nepal for wider adaptation among the farmers.

Farmers reported that growing of soybean with maize has residual effect on soil fertility and the succeeding crop (Table 3.4 Chapter Three), but this effect was not assessed in these experiments due to time constraints. Therefore, it is suggested that the effect of maize/soybean intercropping on soil fertility and their effect on succeeding crops should be evaluated in future by conducting long term experiments on the same land. It has practical importance for the farmers, to help sustain soil fertility in the long term and to obtain constant yields of both crops.

Farmers of this area are using only two varieties of soybean namely *seto* and *Khairo* and they have done so far a long time as reported by farmers (In section 5.4.6, Chapter Five), indicating poor diversity. The results suggest that due consideration should be given to develop shade adapted soybean varieties which can fit under intercropping system and fulfil the demand of farmers.

7.7 Conclusion

Farmers are usually broadcast soybean seed before ploughing and sow maize seed behind the plough as early monsoon showers start in April. Although farmers use high seed rates for both crops at sowing, nevertheless plant populations at harvest are far below the recommended population resulting in low production of both crops. Continuous thinning of maize from one month after sowing as security against drought, insect/pest damage and supply of fodder was the maize cause of low plant population and poor yield of both crops. From these experiments, it is concluded that soybean is not adapted to shade and requires higher levels of light for better production. Manipulation of planting arrangement; e.g. increasing row spacing of maize from 75 to 100 cm, could increase light penetration to the soybean canopy resulting in increased grain yield of soybean, which would more than compensate for any yield reduction of maize.

Farmers should be encouraged to follow row planting to allow them to establish optimum plant populations of component crops and to avoid direct contact of fertilizer applied to maize on soybean plants. Maize can be sown in rows behind plough by dropping seeds in alternate furrows, and soybean can be planted manually between maize rows after germination. This may require minor additional costs for labour, but this can be compensated for by increased yield of intercropped soybean. Conducting demonstrations with few simple treatments in farmers' own field to demonstrate the outcome of these practices would encourage them to adopt similar husbandry methods. Secondly, farmers meetings should be organised to provide training about these technologies and to acquaint them with the economic benefits of these improved technologies. Thirdly, a simple leaflet/folder in should be prepared in the local language and distributed among beneficiary farmers. This would help in wider dissemination and more rapid adoption of new agronomic techniques.

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Appendix 3.1. Mean plant population (no./m^2) of intercropped maize and soybean at different crop growth stages in different farmers' fields at Deorali VDC of Palpa District during 2001 (n = 21).

Crop growth stages	Maize	Soybean
Initial population before weeding at 20-25 days after sowing of maize (no./m^2)	4.64 ± 1.13 (3.00 - 6.90)	4.77 ± 1.13 (2.90 - 7.70)
Plant population after first weeding at 45 DAS(no./m^2)	3.83 ± 0.76 (2.60 - 5.20)	4.21 ± 0.93 (2.7 - 6.00)
Plant population after second weeding at 75 DAS(no./m^2)	3.61 ± 0.61 (2.60 - 4.90)	4.04 ± 0.81 (2.70 - 5.80)
Plant population at harvest(no./m^2)	2.77 ± 0.66 (1.80 - 3.80)	3.84 ± 0.78 (2.0 - 5.80)
Reduction in plant population (%)	40.3	19.5

Note: Figure in parenthesis is range of observation

Appendix 4.1 Chemical properties of soil (pH, organic matter %., total nitrogen %, available Phosphorus, exchangeable potassium) of plots receiving different treatments of experiment mentioned in section three during 2001

Treatments	Before planting					After crop harvest				
	pH	OM %	TN %	Available P (mg/g)	Exch, K me/100g	pH	OM %	TN %	Avail able P (mg/g	Exch, K me/100g
D1S1	5.9	1.43	0.07	39.3	0.44	5.8	1.07	0.29	36.7	0.45
D1S2	5.8	1.72	0.11	35.6	0.44	5.7	1.44	0.12	29.0	0.46
D1S3	5.9	2.07	0.09	45.3	0.27	5.8	1.34	0.13	42.5	0.28
D2S1	5.9	1.33	0.09	42.1	0.40	5.7	1.26	0.11	41.0	0.41
D2S2	5.8	1.23	0.09	36.7	0.34	5.9	1.34	0.06	42.0	0.35
D2S3	5.8	1.88	0.12	37.8	0.34	5.8	1.07	0.27	27.2	0.36
D3S1	5.9	2.02	0.09	37.4	0.41	5.7	1.41	0.11	40.5	0.42
D3S2	5.9	1.94	0.11	39.7	0.36	5.8	1.73	0.11	44.7	0.37
D3S3	5.8	2.12	0.10	38.0	0.39	5.8	1.63	0.10	39.7	0.41
S. Maize	5.8	1.67	0.11	40.1	0.42	5.8	1.47	0.08	40.7	0.44
S. soybean	5.8	1.25	0.11	32.7	0.42	5.8	1.91	0.10	34.2	0.43
Mean	5.8	1.70	0.10	38.6	0.38	5.8	1.42	0.13	38.0	0.40
Probability	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: D1, D2, D3 and S1, S2, S3 are densities of maize (26.5, 40 and 53 103/ha) and soybean (200, 150 and 100 x10^3/ha), respectively

Appendix 4.2 Chemical properties of soil (pH, organic matter %., total nitrogen %, available Phosphorus, exchangeable potassium) of plots receiving different treatments of experiment mentioned in section three during 2002

Treatments	Before planting					After crop harvest				
	pH	OM %	TN %	Avail P (mg/g)	Exch, K me/100g	pH	O.M. %	Total N %	Avail P (mg/g)	Exch, K me/100g
D1S1	5.8	1.52	0.09	27.5	0.45	5.5	1.59	0.14	18.8	0.37
D1S2	5.9	1.53	0.10	28.1	0.44	5.6	1.59	0.15	17.7	0.42
D1S3	5.8	1.72	0.09	28.6	0.36	5.5	1.81	0.12	17.2	0.38
D2S1	5.8	1.80	0.11	31.0	0.44	5.5	1.36	0.17	24.0	0.33
D2S2	5.8	1.62	0.10	29.4	0.45	5.4	1.92	0.15	19.3	0.36
D2S3	5.8	1.57	0.10	25.7	0.45	5.5	1.40	0.15	23.2	0.41
D3S1	5.8	1.60	0.11	27.4	0.40	5.5	1.72	0.40	23.5	0.30
D3S2	5.8	1.73	0.09	28.0	0.49	5.6	1.74	0.14	23.1	0.43
D3S3	5.7	1.57	0.11	31.7	0.43	5.5	1.70	0.14	20.9	0.40
S. Maize	5.8	1.70	0.12	29.8	0.49	5.5	1.30	0.17	21.1	0.40
S. soybean	5.8	1.75	0.14	36.9	0.41	5.4	1.55	0.12	17.2	0.41
Mean	5.8	1.65	0.11	29.5	0.44	5.5	1.61	0.17	20.6	0.38
Probabilty	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: D1, D2, D3 and S1, S2, S3 are densities of maize (26.5, 40 and 53 103/ha) and soybean (200, 150 and 100 x10^3/ha), respectively

Appendix 4.3 Effect of maize and soybean densities on plant height of maize at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	43DAS	57DAS	71DAS	85DAS	At harvest
Maize					
26.5	124.4	211.8	271.6	289.2	235.8
40	126.3	213.6	269.9	287.7	239.4
53	127.0	216.2	283.9	299.1	251.5
Soybean					
100	116.4	205.6	279.1	295.5	245.3
150	129.6	219.1	279.6	293.7	239.2
200	131.7	216.8	266.2	287.0	242.2
Sole maize	124.8	217.9	274.7	278.4	243.1
Intercrop	125.9	213.8	275.0	292.0	242.2
lsd					
Maize density	NS	NS	NS	NS	17.72
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.4 Effect of maize and soybean densities on plant height of maize at different growth stages in maize/soybean intercropping during 2002 season.

Density (x 10^3)	35DAS	49 DAS	64 DAS	78DAS	At harvest
Maize					
26.5	91.8	180.9	263.1	282.9	276.8
40	94.9	179.5	255.6	285.5	279.5
53	94.7	175.4	257.5	297.5	288.4
Soybean					
50	101.2	180.2	262.4	289.4	277.5
100	88.7	178.0	258.3	288.2	284.5
150	91.6	177.6	255.4	288.3	282.8
Sole maize	85.2	176.5	245.4	279.9	289.6
Intercrop	93.8	178.6	258.7	288.6	281.6
lsd					
Maize density	NS	NS	NS	NS	NS
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.5. Effect of maize and soybean population densities on leaf area index (LAI) of maize at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	43DAS	57DAS	71DAS	85DAS
Maize				
26.5	0.75	1.63	2.11	1.75
40	1.22	2.18	2.92	2.45
53	1.50	3.17	3.69	3.17
Soybean				
100	1.11	2.28	2.85	2.44
150	1.20	2.19	3.05	2.59
200	1.17	2.51	2.83	2.34
Sole maize	2.11	3.50	3.57	3.01
Intercrop	1.16	2.32	2.91	2.46
lsd (0.05)				
Maize density	0.35**	0.48**	0.43**	0.27**
Soybean density	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	0.45**	0.62**	0.56*	0.35*

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.6 . Effect of maize and soybean population densities on leaf area index (LAI) of maize at different growth stages in maize/soybean intercropping during 2002 season.

Density (x 10^3)	35DAS	49 DAS	64 DAS	78DAS
Maize				
26.5	0.35	1.46	2.07	2.05
40	0.53	1.98	2.79	2.86
53	0.72	2.48	3.31	3.30
Soybean				
50	0.63	2.12	2.73	3.21
100	0.47	1.91	2.76	2.50
150	0.51	1.91	2.68	2.50
Sole maize	0.62	2.61	3.55	3.36
Intercrop	0.53	1.98	2.72	2.74
lsd				
Maize density	0.11**	0.26**	0.41**	0.44**
Soybean density	0.11*	NS	NS	0.44**
Maize x soybean	NS	NS	NS	0.77**
Int x sole crop	NS	0.33**	0.53**	0.57**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.7. Effect of maize and soybean densities on leaf area index (LAI) of maize measured at 78 DAS during 2002 season

Density (x 10^3)	Soybean density (x 10^3)			
Maize	50	100	150	Mean
26.5	2.06	2.16	1.94	2.05
40	3.72	2.73	2.13	2.86
53	3.86	2.62	3.42	3.30
Mean	3.21	2.50	2.50	
lsd (0.05) for maize x soybean	0.77*			

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.8. Effect of maize and soybean population densities on total dry matter (g/m^2) of maize at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	43DAS	57DAS	71DAS	85DAS	At harvest
Maize					
26.5	50.2	213	337	531	975
40	84.9	290	442	661	1101
53	93.2	387	563	862	1337
Soybean					
100	69.3	273	440	683	1192
150	79.4	307	438	723	1118
200	79.6	321	464	648	1103
Sole maize	117.6	370	615	723	1231
Intercrop	76.1	297	447	685	1138
Lsd (0.05)					
Maize density	22.8**	54.9**	83.9**	108.4**	169.5**
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	29.4**	70.9*	108.3**	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.9 Effect of maize and soybean population densities on total dry matter (g/m^2) of maize at different growth stages in maize/soybean intercropping during 2002 season.

Density (x 10^3)	35 DAS	49 DAS	64 DAS	78 DAS	At harvest
Maize					
26.5	23.1	128	412	562	767
40	35.5	171	473	704	942
53	47.4	217	577	831	1033
Soybean					
50	43.7	185	508	775	938
100	30.6	166	484	648	908
150	31.9	164	471	674	894
Sole maize	38.8	225	507	859	940
Intercrop	35.4	172	488	699	914
lsd (0.05)					
Maize density	8.3**	30.1**	85.9**	95.2**	105.6**
Soybean density	8.3**	NS	NS	134.6*	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	30.1*8	NS	122.9*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.10. Effect of maize and soybean population densities on crop growth rate (CGR) of maize during different growth period in maize/soybean intercropping during 2001 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	43-57 DAS	57-71 DAS	71-85 DAS	85-125 DAS
Maize				
26.5	11.7	8.8	13.9	11.1
40	14.7	10.8	15.7	11.0
53	21.0	12.6	21.4	11.9
Soybean				
100	14.6	11.9	17.3	12.7
150	16.3	9.3	20.4	9.9
200	16.5	10.9	13.2	11.3
Sole maize	18.0	17.5	7.7	12.7
Intercrop	15.8	10.7	17.0	11.3
lsd (0.05)				
Maize density	4.2**	NS	NS	NS
Soybean density	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.11. Effect of maize and soybean population densities on crop growth rate (CGR) of maize during different growth period in maize/soybean intercropping during 2002 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	35-49 DAS	49-64 DAS	64-78 DAS	78-127 DAS
Maize				
26.5	7.5	20.3	10.7	4.1
40	9.6	21.6	16.5	4.7
53	12.1	25.7	18.1	4.0
Soybean				
50	10.1	23.1	19.0	3.3
100	9.7	22.7	11.7	5.2
150	9.4	21.9	14.5	4.4
Sole maize	13.3	20.1	25.1	1.6
Intercrop	9.8	22.5	15.1	4.3
lsd (0.05)				
Maize density	1.85**	NS	NS	NS
Soybean density	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	2.39**	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.12. Effect of maize and soybean population densities on net assimilation rate (NAR) of maize during different growth period in maize/soybean intercropping during 2001 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	43-57 DAS	57-71 DAS	71-85 DAS
Maize			
26.5	10.3	4.9	7.1
40	8.8	4.5	6.0
53	9.7	3.6	6.5
Soybean			
100	9.2	5.2	6.7
150	9.9	3.7	7.5
200	9.7	4.1	5.4
Sole maize	6.8	5.0	2.4
Intercrop	9.6	4.4	6.5
lsd (0.05)			
Maize density	NS	NS	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.13. Effect of maize and soybean population densities on net assimilation rate (NAR) of maize during different growth period in maize/soybean intercropping during 2002 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	35-49 DAS	49-64 DAS	64-78 DAS
Maize			
26.5	9.7	11.6	5.3
40	8.8	9.2	5.7
53	8.5	8.9	5.5
Soybean			
50	8.3	9.9	6.3
100	9.5	10.1	4.5
150	9.3	9.8	5.7
Sole maize	9.7	6.5	7.6
Intercrop	9.0	9.9	5.5
lsd (0.05)			
Maize density	NS	2.34*	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	NS	3.03*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.14. Effect of maize and soybean population densities on leaf area ratio (LAR) of maize during different growth period in maize/soybean intercropping during 2001 season (cm^2g^{-1}).

Density (x 10^3)	43-57 DAS	57-71 DAS	71-85 DAS
Maize			
26.5	116	71.3	48.3
40	111	72.5	52.5
53	125	75.9	52.2
Soybean			
100	123	75.6	50.9
150	113	72.1	52.8
200	116	71.9	49.3
Sole maize	143	79.0	51.4
Intercrop	117	73.2	51.0
lsd (0.05)			
Maize density	NS	NS	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	18.7*	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and Lsd value calculated at 5%

Appendix 4.15. Effect of maize and soybean population densities on leaf area ratio (LAR) of maize during different growth period in maize/soybean intercropping during 2002 season (cm^2g^{-1}).

Density (x 10^3)	35-49 DAS	49-64 DAS	64-78 DAS
Maize			
26.5	136	83.2	43.8
40	134	88.2	49.9
53	138	88.0	49.4
Soybean			
50	130	85.3	47.5
100	137	87.2	48.4
150	140	86.9	47.2
Sole maize	144	94.4	55.5
Intercrop	136	86.4	47.7
lsd (0.05)			
Maize density	NS	NS	4.7*
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	NS	7.89*	6.1*

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.16. Effect of maize and soybean densities on leaf area duration (Days) of maize during 2002 season

Density (x 10^3)	Soybean density (x 10^3)			
Maize	50	100	150	Mean
26.5	127	125	115	122
40	199	164	145	169
53	226	176	204	202
Mean	184	155	155	
lsd (0.05) for maize x soybean	28.2*			

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.17 Effect of maize and soybean densities on plant height of soybean (cm) at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	47DAS	61DAS	75DAS	89DAS	At harvest
Maize					
26.5	22.9	53.5	86.5	101.1	103.7
40	28.0	59.9	93.1	105.3	103.8
53	32.94	63.7	100.0	103.8	92.7
Soybean					
100	28.67	57.9	93.1	102.3	98.1
150	27.89	59.8	94.7	105.4	96.4
200	27.3	59.4	91.8	102.6	105.7
Sole soybean	21.37	45.2	80.7	110.0	120.4
Intercrop	27.95	59.0	93.2	103.4	100.1
lsd (0.05)					
Maize density	4.2**	5.9**	NS	NS	NS
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	5.4*	7.62**	NS	NS	17.1

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.18. Effect of maize and soybean densities on plant height of soybean (cm) at different growth stages in maize/soybean intercropping during 2002 summer.

Density (x 10^3)	45DAS	59DAS	73DAS	87DAS	At harvest
Maize					
26.5	34.3	70.9	107.0	117.2	117.3
40	38.4	77.4	115.1	125.5	123.1
53	38.2	75.8	119.1	127.3	129.9
Soybean					
50	35.4	68.8	102.9	114.4	110.3
100	36.1	80.2	115.0	124.9	133.0
150	39.4	75.0	123.4	130.6	127.0
Sole soybean	37.6	64.6	104.5	113.4	109.3
Intercrop	37.0	74.7	113.7	123.3	123.4
lsd (0.05)					
Maize density	NS	NS	NS	NS	NS
Soybean density	NS	8.3*	10.38**	12.7*	10.7
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	NS	NS	NS	13.8

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.19. Effect of maize and soybean population densities on leaf area index (LAI) of soybean at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	47DAS	61DAS	75DAS	89DAS
Maize				
26.5	1.02	2.16	4.14	3.32
40	1.14	2.09	3.33	3.26
53	1.16	1.96	2.89	2.83
Soybean				
100	0.84	1.53	2.71	2.67
150	1.19	2.05	3.49	3.01
200	1.29	2.62	4.14	3.73
Sole soybean	1.36	3.57	5.40	5.48
Intercrop	1.10	2.10	3.45	3.14
lsd (0.05)				
Maize density	NS	NS	NS	NS
Soybean density	0.34*	0.26**	NS	0.76*
Maize x soybean	NS	NS	NS	NS
Int x sole crop	NS	0.34*	1.48*	0.98**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.20. Effect of maize and soybean population densities on leaf area index (LAI) of soybean at different growth stages in maize/soybean intercropping during 2002 season.

Density (x 10^3)	45DAS	59DAS	73DAS	87DAS
Maize				
26.5	0.93	2.60	3.30	3.86
40	0.98	2.40	3.53	3.30
53	0.94	1.92	2.48	2.69
Soybean				
50	0.49	1.42	1.92	2.31
100	0.93	2.51	3.33	3.25
150	1.43	3.00	4.06	4.29
Sole soybean	1.87	4.56	5.57	5.39
Intercrop	0.95	2.31	3.10	3.28
lsd (0.05)				
Maize density	NS	0.51*	NS	0.54**
Soybean density	0.36**	0.51**	0.93**	0.54**
Maize x soybean	NS	NS	NS	NS
Int x sole crop	0.46**	0.65*	1.20**	0.69**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.21. Effect of maize and soybean population densities on total dry matter (g/m^2) of soybean at different growth stages in maize/soybean intercropping during 2001 season.

Density (x 10^3)	47DAS	61DAS	75DAS	89DAS	At harvest
Maize					
26.5	48.1	96.6	201	245	256
40	45.0	90.7	151	235	238
53	46.1	82.3	135	193	127
Soybean					
100	35.5	69.5	123	190	190
150	50.8	89.9	166	216	192
200	52.9	110.3	197	267	239
Sole soybean	60.4	190.2	296	496	474
Intercrop	46.4	89.9	162	224	207
lsd (0.05)					
Maize density	NS	NS	51.1*	NS	72.2*
Soybean density	10.0**	16.3**	51.1*	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	12.9**	21.1**	65.9**	99.9	93.8**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.22. Effect of maize and soybean population densities on total dry matter (g/m²) of maize at different growth stages in maize/soybean intercropping during 2002 season.

Density (x 10^3)	45DAS	59DAS	73DAS	87DAS	At harvest
Maize					
26.5	51.3	147	126	297	430
40	53.4	130	131	229	303
53	49.1	97	92	182	280
Soybean					
50	25.8	76	71	167	277
100	50.2	139	120	231	329
150	77.7	160	158	310	407
Sole soybean	113.2	278	244	529	1043
Intercrop	51.2	125	116	236	337
lsd (0.05)					
Maize density	NS	24.4**	32.4*	39.5**	99.1*
Soybean density	19.9**	24.4**	32.4**	39.5**	99.1*
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	25.8**	31.5**	41.8**	51.0**	128.0**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.23. Effect of maize and soybean population densities on crop growth rate (CGR) of soybean during different growth period in maize/soybean intercropping during 2001 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	47-61 DAS	61-75 DAS	75-89 DAS	89-139 DAS
Maize				
26.5	3.46	7.44	3.1	0.23
40	3.27	4.28	6.0	0.05
53	2.58	3.74	4.2	-1.29
Soybean				
100	2.42	3.81	4.8	0.01
150	2.79	5.42	3.6	-0.47
200	4.10	6.22	5.0	-0.55
Sole soybean	9.27	7.58	14.3	-0.36
Intercrop	3.10	5.15	4.4	-0.34
lsd (0.05)				
Maize density	NS	NS	NS	NS
Soybean density	1.14*	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	1.48**	NS	7.7*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.24. Effect of maize and soybean population densities on crop growth rate (CGR) of soybean during different growth period in maize/soybean intercropping during 2002 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	45-59 DAS	59-73 DAS	73-87 DAS	87-142 DAS
Maize				
26.5	6.86	-1.50	12.17	2.38
40	5.47	0.04	7.02	1.30
53	3.44	-0.36	6.36	1.76
Soybean				
50	3.56	-0.37	6.90	1.96
100	6.37	-1.36	7.87	1.74
150	5.84	-0.09	10.78	1.73
Sole soybean	11.80	-2.40	20.33	9.17
Intercrop	5.26	-0.60	8.51	1.81
lsd (0.05)				
Maize density	1.64**	NS	3.8**	NS
Soybean density	1.64**	NS	NS	NS
Maize x soybean	NS	NS	NS	NS
Int x sole crop	2.12**	NS	4.91**	2.88**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.25. Effect of maize and soybean population densities on net assimilation rate (NAR) of soybean during different growth period in maize/soybean intercropping during 2001 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	47-61 DAS	61-75 DAS	75-89 DAS
Maize			
26.5	2.42	2.39	0.99
40	2.21	1.55	1.93
53	1.78	1.57	1.34
Soybean			
100	2.23	1.80	1.77
150	1.91	1.92	1.18
200	2.27	1.79	1.32
Sole soybean	4.04	1.68	2.76
Intercrop	2.14	1.84	1.42
lsd (0.05)			
Maize density	NS	NS	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	0.99**	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.26. Effect of maize and soybean population densities on net assimilation rate (NAR) of soybean during different growth period in maize/soybean intercropping during 2002 season ($gm^{-2}d^{-1}$).

Density (x 10^3)	45-59 DAS	59-73 DAS	73-87 DAS
Maize			
26.5	4.45	-0.48	3.42
40	3.80	-0.11	2.31
53	2.66	-0.10	2.59
Soybean			
50	4.07	-0.18	3.27
100	4.05	-0.47	2.45
150	2.78	-0.03	2.61
Sole soybean	4.12	-0.53	3.87
Intercrop	3.63	-0.23	2.78
lsd (0.05)			
Maize density	1.18**	NS	NS
Soybean density	1.18**	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	NS	NS	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.27. Effect of maize and soybean population densities on leaf area ratio (LAR) of soybean during different growth period in maize/soybean intercropping during 2001 season (cm^2g^{-1}).

Density (x 10^3)	47-61 DAS	61-75 DAS	75-89 DAS
Maize			
26.5	214	207	117
40	238	227	125
53	245	230	125
Soybean			
100	230	225.2	128
150	229	218.8	121
200	238	220.6	119
Sole soybean	206	184.8	103
Intercrop	232	221.5	122
lsd (0.05)			
Maize density	24.6*	17.6*	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	NS	22.9**	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.28 Effect of maize and soybean population densities on leaf area ratio (LAR) of soybean during different growth period in maize/soybean intercropping during 2002 season (cm^2g^{-1}).

Density (x 10^3)	45-59 DAS	59-73 DAS	73-87 DAS
Maize			
26.5	178	221	198
40	184	228	208
53	197	236	209
Soybean			
50	191	233	207
100	182	229	209
150	186	222	199
Sole soybean	165	195	164
Intercrop	186	228	205
lsd (0.05)			
Maize density	13.9*	NS	NS
Soybean density	NS	NS	NS
Maize x soybean	NS	NS	NS
Int x sole crop	18.0*	16.4**	13.7**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.29 Grain yield (14% and 12 % moisture for maize and soybean, respectively) and land equivalent ratio (LER) of different treatment combination of maize and soybean density grown as intercropping during 2001 and 2002.

Treatment combination	2001		2002		LER	LER
	Maize (g/m^2)	Soybean (g/m^2)	Maize (g/m^2)	Soybean (g/m^2)	(2001)	(2002)
1. D1 S1	435	101.3	374.1	123.1	1.43	1.43
2. D1S2	400	96.0	343.7	130.4	1.34	1.38
3. D1S3	367	98.4	364.8	121.7	1.30	1.40
4. D2S1	471	74.8	438.9	94.9	1.34	1.46
5. D2S2	462	73.2	395.4	109.2	1.33	1.40
6. D2S3	460	81.1	396.9	119.1	1.32	1.50
7. D3S1	517	47.2	482.9	72.4	1.28	1.45
8. D3S2	512	54.0	449.1	99.6	1.29	1.51
9. D3S3	549	49.5	417.0	91.1	1.34	1.38
10 Sole crop	513	183.9	433.0	225.4		

Note: D1, D2, D3 denote maize density of 26.5, 40 and 53 x 10^3 while S1, S2, S3 indicate soybean density of 100, 150 and 200 and 50, 150 and 150 x 10^3 plants ha^{-1} during 2001 and 2002 respectively

Appendix 4.30 Effect of maize and soybean densities on % PAR intercepted by maize canopy under maize/soybean intercropping measured over time during 2001 season.

Density (x 10^3)	56 DAS	70 DAS	84 DAS	98 DAS	112DAS
Maize					
26.5	50	67	62	61	51
40	62	72	76	68	68
53	77	75	83	78	61
Soybean					
100	62	73	75	74	61
150	58	70	76	69	54
200	67	71	70	65	65
Sole maize	78	79	84	82	60
Intercrop	62	71	74	69	60
lsd					
Maize density	14.6**	NS	6.0**	8.4**	12.2*
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	NS	7.8**	10.8*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.31 Effect of maize and soybean population densities on % PAR intercepted by soybean during different growth period in maize/soybean intercropping during 2001 season.

Density (x 10^3)	56 DAS	70 DAS	84 DAS	98 DAS	112DAS
Maize					
26.5	49	68	92	83	90
40	54	73	88	92	92
53	62	71	81	82	88
Soybean					
100	49	69	82	80	86
150	55	64	88	86	93
200	61	79	91	91	91
Sole soybean	55	86	99	99	97
Intercrop	55	70	87	86	90
lsd (0.05)					
Maize density	NS	NS	8.0*	NS	NS
Soybean density	NS	12.1*	NS	8.8	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	NS	15.6*	10.4*	11.4*	NS

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 4.32 Effect of maize and soybean densities on % PAR intercepted by whole intercrop canopy measured at different dates during 2001 season.

Density (x 10^3)	56 DAS	70 DAS	84 DAS	98 DAS	112DAS
Maize					
26.5	75	90	97	94	96
40	84	93	97	97	97
53	92	94	97	96	95
Soybean					
100	82	91	96	95	95
150	81	91	97	96	96
200	89	94	98	97	97
Sole maize	78	79	85	82	60
Sole soybean	55	86	99	99	97
Intercrop	84	92	97	96	96
lsd					
Maize density	9.8**	3.3*	NS	NS	NS
Soybean density	NS	NS	NS	NS	NS
Maize x soybean	NS	NS	NS	NS	NS
Int x sole crop	12.6**	5.3**	2.0**	4.7**	3.1**

Note: NS, *, and ** stand for non significant, significant at 1 and 5% respectively and lsd value calculated at 5%

Appendix 5.1 The effect of maize densities and time of thinning of maize on plant height (cm) of maize in time of thinning experiment, 2001.

Treatments	45 DAS	59 DAS	73 DAS	116 DAS
Densities (x 10^3)				
38	154.2 (153.3)	213.5 (210.1)	279.6 (276.3)	277.3 (280.9)
53	151.5 (154.4)	214.9 (217.8)	276.6 (285.6)	271.6 (274.1)
66	(149.3)	(211.2)	(276.1)	(271.8)
Time of thinning				
TT1	153.9	213.9	281.0	277.5
TT2	150.1	212.6	279.0	274.3
TT3	157.3	216.6	278.2	272.0
TT4	150.1	213.6	274.3	274.1
lsd (0.05)				
Density	NS	NS	NS	NS
Time of thinning	NS	NS	NS	NS
Density x TT	NS	NS	NS	*
Density at TT1[a]	NS	NS	NS	NS

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. Figure in parentheses indicates grain yield at TT1. [a] denotes lsd for comparing densities at TT1 level only. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively

Appendix 5.2. The interaction effect of maize densities and time of thinning of maize on plant height (cm) of maize in time of thinning experiment, 2001.

Time of thinning	Densities (x 10^3)		
	38	53	Mean time of thinning
TT1	280.9	274.1	277.5
TT2	286.7	261.8	274.3
TT3	272.9	271.0	272.0
TT4	268.8	279.5	274.1
Mean density	277.3	271.6	
lsd (0.05) for D x TT	15.3*		

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively.

Appendix 5.3. The effect of maize densities and time of thinning of maize on leaf area index (LAI) of maize in time of thinning experiment, 2001.

Treatments	45 DAS	59 DAS	73 DAS	87 DAS	101 DAS
Densities (x 10^3)					
38	0.78 (0.81	1.85 (1.94)	1.96 (1.91)	1.84 (1.78)	1.51 (1.48)
53	0.94 (0.96)	2.32 (2.45)	2.44 (2.85)	2.26 (2.51)	1.94 (2.12)
66	(1.21)	(2.84)	(2.88)	(2.64)	(1.83)
Time of thinning					
TT1	0.88	2.20	2.38	2.15	1.80
TT2	0.82	2.02	2.16	2.03	1.77
TT3	0.86	2.07	2.12	1.93	1.63
TT4	0.88	2.05	2.16	2.10	1.70
lsd (0.05)					
Density	0.11**	0.19**	0.21**	0.23**	0.27**
Time of thinning	NS	NS	NS	NS	NS
Density x TT	NS	NS	NS	NS	NS
Density at TT1[a]	0.23**	0.18**	0.42**	0.46**	NS

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. Figure in parentheses indicates LAI at TT1. [a] denotes lsd for comparing densities at TT1 level only. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively.

Appendix 5.4. The effect of maize densities and time of thinning of maize on % PAR intercepted by maize canopy measured at different dates in time of thinning experiment, 2001.

Treatments	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)				
38	61.7 (57.1)	60.6 (60.3)	68.0 (73.6)	63.9 (61.8)
53	58.0 (57.8)	72.2 (78.1)	73.9 (74.7)	72.9 (63.6)
66	(56.4)	(72.6)	(71.2)	(76.3)
Time of thinning				
TT1	57.5	69.2	74.2	62.7
TT2	58.9	65.6	70.2	71.9
TT3	63.5	60.2	65.1	65.5
TT4	59.4	70.4	74.4	73.4
lsd (0.05)				
Density	NS	10.6**	NS	7.3*
Time of thinning	NS	NS	NS	NS
Density x TT	NS	NS	NS	NS
Density at TT1[a]	NS	14.9*	NS	NS

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. Figure in parentheses indicates % PAR at TT1. [a] denotes lsd for comparing densities at TT1 level only. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively.

Appendix 5.5. The effect of maize densities and time of thinning of maize on % PAR intercepted by soybean in time of thinning experiment, 2001.

Treatments	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)				
38	36.5 (26.6)	46.0 (53.2)	59.4 (58.7)	74.3 (73.5)
53	36.7 (27.1)	48.5(51.0)	62.7 (59.8)	63.4 (76.1)
66	(52.1)	51.7	(58.4)	(67.0)
Time of thinning				
TT1	26.9	52.1	59.3	74.8
TT2	33.1	49.1	64.3	68.3
TT3	43.9	42.7	62.8	56.7
TT4	42.5	45.0	57.9	75.7
Lsd (0.05)				
Density	NS	NS	NS	NS
Time of thinning	NS	NS	NS	NS
Density x TT	NS	NS	NS	NS
Density at TT1[a]	NS	NS	NS	NS

Note:-. TT1, TT2, TT3 and TT4 denote thinning time after germination, 30, 60 and 30 +60 DAS respectively. Figure in parentheses indicates % PAR at TT1 [a] denotes lsd for comparing different densities at TT01 level only. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively.

Appendix 5.6. The effect of maize densities and time of thinning of maize on % PAR intercepted by maize and soybean canopy in time of thinning experiment, 2001.

Treatments	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)				
38	75.1 (68.6)	80.0 (82.1)	88.1 (90.6)	90.4 (90.4)
53	73.3 (69.3)	86.0 (90.7)	91.0 (91.2)	91.3 (92.5)
66	(79.2)	(88.1)	(90.2)	(92.6)
Time of thinning				
TT1	69.0	86.4	90.9	91.5
TT2	72.3	82.6	90.7	91.8
TT3	79.7	78.8	87.2	86.1
TT4	76.0	84.1	89.5	94.1
lsd (0.05)				
Density	NS	3.7**	NS	NS
Time of thinning	7.8*	5.3*	NS	5.4*
Density x TT	NS	NS	NS	NS
Density at TT1[a]	NS	7.4*	NS	NS

Note:-. TT1, TT2, TT3 and TT4 denote thinning after germination, 30, 60 and 30 +60 DAS respectively. Figure in parentheses indicates % PAR at TT1. [a] denotes lsd for comparing different densities at TT1 level only. NS, * and ** indicates non significant, significant at 5% and 1% level, respectively.

Appendix 5.7. The effect of maize densities and time of thinning of maize on plant height (cm) of maize in time of thinning experiment, 2002.

Treatments	32 DAS	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)					
38	84.6	172.3	256.3	290.8	291.6
50	82.6	168.3	244.9	289.9	293.8
53 alternate row	80.0	169.1	250.2	296.0	290.4
53 paired rows	84.3	162.5	153.0	296.1	290.6
Time of thinning					
TT1	78.9	163.7	251.1	297.8	298.5
TT2	85.7	167.7	252.5	293	291.2
TT3	84.0	172.7	249.6	288.9	285.1
Probability					
Density	NS	NS	NS	NS	NS
Time of thinning	NS	NS	NS	NS	NS
lsd (0.05)					

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively.

Appendix 5.8. The effect of maize densities and time of thinning of maize on leaf area index (LAI) of maize in time of thinning experiment, 2002.

Treatments	32 DAS	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)					
38	0.22	0.95	2.30	2.65	2.39
50	0.26	1.09	2.66	3.02	2.65
53 alternate row	0.28	1.16	3.07	3.32	2.88
53 paired rows	0.29	1.07	3.13	3.46	2.79
Time of thinning					
TT1	0.26	1.08	2.92	3.37	2.97
TT2	0.25	1.06	2.82	3.03	2.50
TT3	0.28	1.07	2.62	2.93	2.55
Probability					
Density	**	*	**	**	*
Time of thinning	NS	NS	NS	NS	NS
lsd (0.05)	0.07	0.24	0.52	0.61	0.59*

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively and NS, * and ** indicate non significant, significant at 5 and 1 %, respectively.

Appendix 4.9. The effect of maize densities and time of thinning of maize on plant height (cm) of soybean in time of thinning experiment, 2002.

Treatments	46 DAS	60 DAS	74 DAS	88 DAS	144 DAS
Densities (x 10^3)					
38	41.2	89.6	132.6	130.7	141.3
50	40.6	92.7	126.8	122.1	134.7
53 alternate row	40.8	90.8	122.9	133.7	135.2
53 paired rows	43.1	101.3	135.2	135.4	137.9
Time of thinning					
TT1	39.6	93.2	131.8	129.0	140.4
TT2	41.7	93.3	132.0	132.0	136.5
TT3	43.1	94.2	124.2	130.5	135.0
Probability					
Density	NS	NS	NS	NS	NS
Time of thinning	NS	NS	NS	NS	NS
lsd (0.05)					

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively and NS, * and ** indicate non significant, significant at 5 and 1 %, respectively.

Appendix 5.10. The effect of maize densities and time of thinning of maize on leaf area index (LAI) of soybean in time of thinning experiment, 2002.

Treatments	46 DAS	60 DAS	74 DAS	88 DAS
Densities (x 10^3)				
38	1.44	2.59	3.31	3.43
50	1.05	2.22	3.01	3.56
53 alternate row	1.21	2.27	2.22	2.60
53 paired rows	1.04	2.41	2.36	2.51
Time of thinning				
TT1	1.17	2.76	3.21	3.15
TT2	1.29	2.43	2.65	2.95
TT3	1.10	1.92	2.31	2.97
Probability				
Density	NS	NS	**	**
Time of thinning	NS	**	NS	NS
lsd (0.05)	NS	0.68	1.14	0.97

Note:-. TT1, TT2 and TT3 denote thinning after germination, 30 and 60 DAS respectively and NS, * and ** indicate non significant, significant at 5 and 1 %, respectively.

Appendix 7.1. Effect of maize densities on combined Leaf area index of sole and intercropped maize with soybean during 2001 and 2002 seasons.

Maize density (x 10^3)	2001				2002			
	43 DAS	57 DAS	71 DAS	85 DAS	35 DAS	49 DAS	64 DAS	78 DAS
26.5	1.77	3.79	6.25	5.07	1.28	4.06	5.37	5.91
40	2.36	4.27	6.25	5.71	1.51	4.38	6.32	6.16
53	2.66	5.13	6.58	6.03	1.66	4.38	5.79	5.99
Sole maize	2.11	3.50	3.57	3.01	0.62	2.61	3.55	3.36