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Tree crown pruning as a management tool to enhance the productivity of parklands in West Africa

Bayala, Jules

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TREE CROWN PRUNING AS A MANAGEMENT TOOL TO ENHANCE THE PRODUCTIVITY OF PARKLANDS IN WEST AFRICA



BAYALA Jules Ingénieur des Eaux et Forêts Institute of Rural Development University of Ouagadougou, Burkina Faso

A thesis submitted in fulfilment for the Philosophiae Doctor at the University of Wales, Bangor, UK

School of Agricultural and Forest Sciences University of Wales, Bangor, United Kingdom

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ABSTRACT

The effects of crown pruning of Vitellaria paradoxa C.F. Gaertn (karité) and Parkia biglobosa (Jacq.) Benth. (néré) on above and belowground interactions with associated crops of Pennisetum glaucum (L.) (millet) and Sorghum bicolor (L.) Moench (sorghum) were investigated as well as the use of the pruned material as mulch on soil fertility and millet production in an agroforestry parkland system in Burkina Faso. Three treatments of crown pruning (total-pruning, half-pruning and no-pruning) were applied to karité and néré. The area under each tree was divided into four concentric tree influence zones before pruning the trees (Zones A: up to 2 m from the tree trunk, B: up to half of the radius of the tree crown, C: up to the edge of the tree crown and D: up to 2 m away from the edge of the tree crown). Millet production under these zones and outside was assessed over two years' cropping seasons and sorghum over one cropping season. Crop production was analysed in relation to tree transpiration, light transmission, root distribution and soil fertility. Investigation on the use of the pruned material as mulch involved assessment of its decomposition and nutrient release patterns, its effects on soil properties and crop production and the existence of allelopathy in it. The results showed that tree crown pruning had significant effect on associated crop production. Total-pruned trees gave the highest crop production due to the reduction by crown pruning of the effects of large tree crowns on PAR transmission below crowns and rates of transpiration by trees. Root niche differentiation also occurred in which fine root length density of trees was reduced and crop roots dominated the upper soil layer due to crown pruning and as a consequence crop production of up to eight fold higher was achieved under totalpruned trees than under unpruned trees. Soil was more fertile closer to the tree trunks than outside tree crowns and therefore crop overall performed better under Zone B than outside tree crowns. The higher production of crop under Zone B than under Zone A, the zone closer to the tree trunk, may be due to lower light intensity and more intense competition for water and nutrients between trees and crops under Zone A. Pruned leaf litter of néré decomposed and released nutrients faster than karité. However, the slow rate of decomposition of karité leaves was beneficial to crops perhaps in terms of protecting the soil against excessive heat, surface runoff and erosion and due to the achievement of good synchrony between nutrient release from decomposing leaves of karité and crop nutrient demand. As a consequence of these, millet grain yield was increased by 120% and total dry matter by 43% by applying leaf litter of karité as mulch. The results of the laboratory allelopathy experiments were, however, contradictory to the field experiment. Leachate of karité showed more depressive effect on crop seed germination compared with néré. It was argued that this may be due to the fact that allelopathic effects under natural conditions are mediated by environmental conditions and decomposers community and therefore can show different results from the laboratory. Due to the results of the pruning and mulching experiments it was concluded that karité was a more suitable tree species than néré for semi-arid agroforestry parkland systems. Since the period of three years of the present study was too short to evaluate the effect of pruning on the overall productivity of the system it was finally recommended that the monitoring is continued over a longer period to determine if complete recovery of fruit production or an optimum compromise between fruit and crop production could be achieved before conclusions are made whether pruning is beneficial or not.

DEDICATION

To my wife Mireille Gabrielle, my son Aimé Kevin Yidia, my daughter Alexandra Reine Yisso, who shared the pains of loneliness while away for studies. To my parents Joseph and Emilienne, I am dedicating this piece of work to you as a symbol of determination, and trust in GOD. Finally, to my Uncle André and my Grandmother who died respectively at the beginning in 1999 and end in 2002 of this work. May your souls rest in Peace.

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2 Samuel 7: 18-19, 29.

TABLE OF CONTENTS

CONTENT

PAGE

DECLARATION	ii
ABSTRACT	iii
DIDICATION	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	viii
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
LIST OF PLATES	xxi
LIST OF SYMBOLS AND ABBREVIATIONS	xxii

CHAPTER I: INTRODUCTION	1
1.1. Aim of the project	1
1.2. Background	2
1.2.1. Perennial tree component of agroforestry parkland systems	2
1.2.2. Annual crop component of agroforestry parkland systems	4
1.2.3. Crown pruning as a tree management tool in agroforestry	
parkland systems	5
1.2.4. Application of pruned material as mulch	7
1.3. Summary and objectives	9
1.4. Study area	12
1.5. Tree selection and pruning treatments	15

CHAPTER II: LITERATURE REVIEW	18
2.1. Description of agroforestry parkland systems	18
2.2. Traditional tree pruning practices in agroforestry parkland systems	19
2.3. Effects of crown pruning on resource capture and utilisation	
in agroforestry parkland systems	22

2.3.1. Effect of crown pruning on light transmission	22
2.3.2. Effect of crown pruning on water uptake and use of trees	24
2.3.2.1. Relative humidity	27
2.3.2.2. Temperature	28
2.3.3. Effect of crown pruning on soil physical and chemical	
properties	28
2.4. Effect of crown pruning on tree architecture and productivity	29
2.4.1. Effect on tree architecture	29
2.4.2. Leaf and wood biomass yield from pruning	31
2.4.3. Effect of crown pruning on tree fruit production	31
2.5. Effects of crown pruning on associated crop yield	34
2.6. Influence of crown pruning on roots	35
2.6.1. Characteristics of roots	35
2.6.2. Distribution patterns of fine roots	36
2.6.3. Effects of pruning on roots	37
2.7. Mulching practices using pruned material for improved production of	
agroforestry parkland systems	38
2.7.1. Mulching effects on soil physical properties and crop yield	39
2.7.2. Mulching effects on soil chemical properties and crop nutrition	39
2.7.3. Effects of mulch on weed and crop yield	41
2.7.4. Decomposition of mulch material	41
2.7.4.1. Factors influencing decomposition	42
2.7.4.2. Probable reasons for conflicting results in organic matter	
decomposition process	44
2.7.4.3. Decomposition models	45
2.8. Conclusions	45

CHAPTER III: THE EFFECTS OF CROWN PRUNING OF VITELLARIA	
PARADOXA AND PARKIA BIGLOBOSA ON THE PERFORMANCE	
OF THE PRUNED TREES AND ASSOCIATED CROPS	47
3.1. Introduction	47
3.2. Material and methods	48

3.2.1. Experimental design and layout	48
3.2.2. Assessment of biomass from pruning and recovery of crown	
size	49
3.2.2.1. Assessment of leaf and wood biomass from pruning	49
3.2.2.2. Assessment of recovery of crown size	50
3.2.3. Phenological studies	50
3.2.3.1. Leafing	50
3.2.3.2. Flowering	51
3.2.3.3. Fruiting	51
3.2.3.3.1. Random branch sampling (RBS) method	51
3.2.3.3.2. Direct harvest (DH) methods	53
3.2.4. Assessment of crops yield	53
3.2.5. Measurement of environmental factors	55
3.2.5.1. Light interception and transmission	55
3.2.5.2. Transpiration	55
3.2.5.3. Soil physical and chemical properties	57
3.2.5.3.1. Soil physical properties	57
3.2.5.3.2. Soil chemical properties	57
3.2.6. Data analysis	58
3.3. Results	59
3.3.1. Biomass from pruning and recovery of crown size	59
3.3.1.1. Leaf and wood biomass from pruning	59
3.3.1.2. Recovery of crown size	60
3.3.2. Tree phenology	60
3.3.2.1. Phenology patterns	60
3.3.2.2. Tree fruit production	64
3.3.2.2.1. Effects of pruning on fruit production of karité	
and néré	64
3.3.2.2.2. Comparative study of Random Branch	
Sampling (RBS) and Direct Harvest (DH) methods for	
fruit production estimation	65
3.3.3. Crop performance	68
3.3.3.1. Millet performance	68
3.3.3.2. Sorghum performance	72

3.3.4. Environmental factors	77
3.3.4.1. Light transmission and its relationship with crop	
performance	77
3.3.4.2. Transpiration by trees and its relationship with crop	
performance	81
3.3.4.3. Soil properties under karité and néré influence zones	84
3.3.4.3.1. Soil physical properties and their relationship	
with crop performance	84
3.3.4.3.2. Soil nutrient status and its relationships with	
crop performance	85
3.4. Discussion	88
3.4.1. Biomass from pruning and recovery of crown size	88
3.4.2. Tree phenology and fruit production	89
3.4.3. Effect of pruning on crop performance	91
3.4.4. Agronomic impact of the present study	94

CHAPTER IV: THE EFFECT OF CROWN PRUNING OF VITELLARIA

PARADOXA AND PARKIA BIGLOBOSA ON FINE ROOT

DISTRIBUTION AND THE CONSEQUENCES FOR CROP

PRODUCTION	96
4.1. Introduction	96
4.2. Material and methods	98
4.2.1. Tree samples	98
4.2.2. Core sampling of tree and crop roots	98
4.2.3. Data analysis	99
4.3. Results	101
4.3.1. Fine roots of trees and millet during 1999 cropping season	101
4.3.1.1. Tree roots	101
4.3.1.2. Millet roots	105
4.3.2. Fine roots of trees and millet in 2000: one year after pruning	109
4.3.2.1. Tree roots	109
4.3.2.2. Millet roots	115
4.3.3. Fine roots of trees and sorghum in 2001: two years after pruning	118

4.3.3.1. Tree roots	118
4.3.3.2. Sorghum roots	122
4.3.4. Correlations between root length density and root weight	
density	125
4.3.5. Relationship between fine roots and crop performance	126
4.4. Discussion	130
4.4.1. Effect of pruning on root length density and the consequence for	
crop production	130
4.4.2. Pattern of fine root distribution with soil depth	131
4.4.3. Pattern of fine root distribution in relation to distance from trees	131
4.4.4. Effect of pruning on fine root weight density and its relationship	
with fine root length density	133

CHAPTER V: USE OF PRUNED MATERIAL OF VITELLARIA

PARADOXA AND PARKIA BIGLOBOSA AS MULCH FOR

IMPROVED SOIL PROPERTIES AND CROP PRODUCTION	134
5.1. Introduction	134
5.2. Material and Methods	136
5.2.1. Decomposition experiment	136
5.2.1.1. Experimental design	136
5.2.1.2. Laboratory analyses of leaf chemical composition	138
5.2.2. Field mulching experiment	140
5.2.2.1. Experimental design	140
5.2.2.2. Data collection in the field mulching experiment	143
5.2.2.2.1. Soil physical properties	143
5.2.2.2.2. Soil chemical properties	145
5.2.2.3. Millet performance	145
5.2.3. Allelopathy experiment	145
5.2.4. Data analysis	146
5.3. Results	147
5.3.1. Decomposition of karité and néré leaf litter	147
5.3.1.1. Initial characteristics of leaves	147
5.3.1.2. Decomposition and release of nutrients	147

5.3.2. Soil properties and millet performance as influenced by leaf	
litter mulch	154
5.3.2.1. Soil physical properties in relation to the quantity of	
mulch applied	154
5.3.2.2. Soil chemical properties in relation to the quantity of	
mulch applied	156
5.3.2.3. Millet performance as influenced by the quantity of	
mulch applied	157
5.3.3. Inhibition of crop development due to allelopathy	160
5.4. Discussion	161
5.4.1. Decomposition and nutrient release patterns of pruned leaves	
of karité and néré	161
5.4.2. Mulching effect on soil properties	163
5.4.3. Mulching effect on millet production	165
5.4.4. Allelopathy	166

CHAPTER VI: GENERAL DISCUSSION, CONCLUSIONS AND

RECOMMENDATIONS	168
6.1. Introduction	168
6.2. The response of karité, néré and associated crops to crown pruning	169
6.3. Decomposition and nutrient release of pruned materials and their	
mulching effects on soil and crop	173
6.4. Limits of the approach used in the present study	175
6.5. General conclusions and recommendations	175
6.6. Specific recommendations for further investigation	177
REFERENCES	180
Appendices	208

LIST OF TABLES

TABLE	PAGE			
Table 1.1: List of woody species encountered in the study area, Saponé,				
Burkina Faso				
Table 1.2: Characteristics of parkland tree population in the study area in				
Saponé, Burkina Faso	15			
Table 1.3. Characteristics of the tree samples selected for the study in				
agroforestry parkland system in Saponé, Burkina Faso	15			
Table 2.1: Fruit production (kg tree-1 year-1) of Parkia biglobosa	33			
Table 2.2: Nutrient release from tree leaves in 120 days	40			
Table 2.3: Content of factors influencing decomposition	43			
Table 3.1. Recovery of crown size in total-pruned trees of karité				
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland				
agroforestry system in Saponé, Burkina Faso	60			
Table 3.2: Effect of pruning on fruit production of karité (Vitellaria				
paradoxa) and néré (Parkia biglobosa) trees in a parkland				
agroforestry system in Saponé, Burkina Faso (kg±SE tree-1)	65			
Table 3.3: Average fruit number estimated by RBS method and by DH				
methods for karité (Vitellaria paradoxa) and néré (Parkia biglobosa)				
trees in a parkland agroforestry system in Saponé, Burkina Faso	67			
Table 3.4: Soil bulk density and porosity (%) according to tree species				
and distance from the trunk in topsoil (0-5 cm) under karité				
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland				
agroforestry system in Saponé, Burkina Faso	84			
Table 3.5. Soil chemical properties according to tree species and distance				
from the trunk in topsoil (0-10 cm) under karité (Vitellaria				
paradoxa) and néré (Parkia biglobosa) in a parkland agroforestry				
system in Saponé, Burkina Faso	86			
Table 3.6. Pearson correlation analysis between millet production and				
soil chemical properties under karité (Vitellaria paradoxa) and				
néré (Parkia biglobosa) in a parkland agroforestry system in				
Saponé, Burkina Faso	87			

Table 3.7. Pearson correlation analysis between sorghum production and	
soil chemical properties under karité (Vitellaria paradoxa) and	
néré (Parkia biglobosa) in a parkland agroforestry system in	
Saponé, Burkina Faso	88
Table 4.1: Mean root length density (cm cm ⁻³ ±SE) of differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, over	
three years	102
Table 4.2: Mean root weight density (mg cm ⁻³ ±SE) of differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, over	
three years	102
Table 4.3: Root weight density (mg cm-3) of differentially pruned karité	
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland	
agroforestry system in Saponé, Burkina Faso, during the	
cropping season of 1999	105
Table 4.4: Mean root length density (cm cm ⁻³ ±SE) of millet and sorghum	
under differentially pruned karité (Vitellaria paradoxa) and néré	
(Parkia biglobosa) in a parkland agroforestry system in Saponé,	
Burkina Faso, over three years	106
Table 4.5: Mean root weight density (mg cm ⁻¹ ±SE) of millet and	
sorghum under differentially pruned karité (Vitellaria paradoxa)	
and néré (Parkia biglobosa) in a parkland agroforestry system in	
Saponé, Burkina Faso, over three years	106
Table 4.6: Root weight density (mg cm ⁻³) of millet under differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, during	
the cropping season of 1999	109
Table 4.7: Root weight density (mg cm ⁻³) of differentially pruned karité	
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland	
agroforestry system in Saponé, Burkina Faso, during the	
cropping season 2000	114

Table 4.8: Root weight density (mg cm ⁻³) of millet under differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, during	
the cropping season 2000	118
Table 4.9: Root weight density (mg cm-3) of differentially pruned karité	
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland	
agroforestry system in Saponé, Burkina Faso, during the	
cropping season of 2001	121
Table 4.10: Root weight density (mg cm ⁻³) of sorghum under	
differentially pruned karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) in a parkland agroforestry system in Saponé, Burkina	
Faso, during the cropping season of 2001	125
Table 5.1: Quantities of leaf litter and their N equivalents (kg ha-1)	
applied in the field mulching experiments in 1999 and 2000 in	
Saponé, Burkina Faso	142
Table 5.2: Initial nutrient, ash, lignin, cellulose and polyphenols	
concentrations (%±SE) in leaves of karité and néré from Saponé,	
Burkina Faso	147
Table 5.3: Decomposition and nutrient release constants, k, for leaves of	
karité (Vitellaria paradoxa) and néré (Parkia biglobosa) as	
determined from litter tube experiment in Saponé, Burkina Faso	152
Table 5.4: Soil physical properties (mean \pm SE) according to tree species,	
treatments and light zones in topsoil (0-5 cm) in Saponé, Burkina	
Faso	155
Table 5.5: Soil chemical properties (mean \pm SE) according to tree species,	
treatments and light zones in topsoil (0-10 cm) in Saponé,	
Burkina Faso	156
Table 5.6: Effects of leaf leachates on number of seeds of sorghum	
germinated (mean \pm SE) and radicle length (mean \pm SE) after 10	
-	

LIST OF FIGURES

FIGURE	PAGE		
Figure 1.1: Map of Burkina Faso showing Saponé the study site			
Figure 1.2: Rainfall in Saponé during three consecutive years, Burkina			
Faso	12		
Figure 3.1: Branching system of tree and the selection probabilities at			
each fork	52		
Figure 3.2: Leafing pattern of differentially pruned karité (Vitellaria			
paradoxa) trees in a parkland agroforestry system in Saponé,			
Burkina Faso	61		
Figure 3.3: Leafing pattern of differentially pruned néré (Parkia biglobosa)			
trees in a parkland agroforestry system in Saponé, Burkina Faso	62		
Figure 3.4: Pattern of flowering of differentially pruned karité (Vitellaria			
paradoxa) and néré (Parkia biglobosa) trées in a parkland			
agroforestry system in Saponé, Burkina Faso	63		
Figure 3.5: Pattern of fruiting of differentially pruned karité (Vitellaria			
paradoxa) and néré (Parkia biglobosa) trees in a parkland			
agroforestry system in Saponé, Burkina Faso	64		
Figure 3.6: Aboveground dry matter production and grain yield of pearl			
millet under differentially pruned karité (Vitellaria paradoxa) and			
néré (Parkia biglobosa) trees in a parkland agroforestry system in			
Saponé, Burkina Faso	70		
Figure 3.7: Aboveground dry matter production and grain yield of pearl			
millet in relation to tree pruning intensity and distance from the			
trunk under karité (Vitellaria paradoxa) trees in a parkland			
agroforestry system in Saponé, Burkina Faso	71		
Figure 3.8: Aboveground dry matter production and grain yield of pearl			
millet in relation to tree pruning intensity and distance from the			
trunk under néré (Parkia biglobosa) trees in a parkland			
agroforestry system in Saponé, Burkina Faso	72		

Figure 3.9: Aboveground dry matter production and grain yield of	
sorghum under differentially pruned karité (Vitellaria paradoxa)	
and néré (Parkia biglobosa) trees in a parkland agroforestry system	
in Saponé, Burkina Faso	73
Figure 3.10: Aboveground dry matter production and grain yield of	
sorghum in relation to tree pruning intensity and distance from	
the trunk under karité (Vitellaria paradoxa) trees in a parkland	
agroforestry system in Saponé, Burkina Faso	74
Figure 3.11: Aboveground dry matter production and grain yield of	
sorghum in relation to tree pruning intensity and distance from	
the trunk under néré (Parkia biglobosa) trees in a parkland	
agroforestry system in Saponé, Burkina Faso	75
Figure 3.12. Pattern of pearl millet performance in relation to light	
intensity under karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) trees in a parkland agroforestry system in Saponé,	
Burkina Faso	78
Figure 3.13: Pattern of sorghum performance in relation to light intensity	
under karité (Vitellaria paradoxa) and néré (Parkia biglobosa) trees	
in a parkland agroforestry system in Saponé, Burkina Faso	80
Figure 3.14: Transpiration rates from pruned trees of karité (Vitellaria	
paradoxa) and néré (Parkia biglobosa) in a parkland agroforestry	
system in Saponé in 1999, Burkina Faso	82
Figure 3.15: Transpiration rates from pruned trees of karité (Vitellaria	
paradoxa) and néré (Parkia biglobosa) in a parkland agroforestry	
system in Saponé in 2001, Burkina Faso	83
Figure 4.1: Root length density (cm cm-3) of differentially pruned karité	
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland	
agroforestry system in Saponé, Burkina Faso, during the	
cropping season of 1999	104
Figure 4.2: Root length density (cm cm ⁻³) of millet under differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, during	
the cropping season of 1999	108

Figure 4.3: Pruning effect on root length density (cm cm ⁻³) of	
differentially pruned karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) in parkland agroforestry system in Saponé, Burkina	
Faso, during the cropping season of 2000	111
Figure 4.4: Effect of distance from tree trunk on root length density (cm	
cm-3) of differentially pruned karité (Vitellaria paradoxa) and néré	
(Parkia biglobosa) in parkland agroforestry system in Saponé,	
Burkina Faso, during the cropping season of 2000	114
Figure 4.5: Root length density (cm cm ⁻³) of millet under differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, during	
the cropping season of 2000	117
Figure 4.6: Root length density (cm cm-3) of differentially pruned karité	
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland	
agroforestry system in Saponé, Burkina Faso, during the	
cropping season of 2001	121
Figure 4.7: Root length density (cm cm ⁻³) of sorghum under differentially	
pruned karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé, Burkina Faso, during	
the cropping season of 2001	124
Figure 4.8: Pattern of millet performance in relation to RLD of millet,	
karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé in 1999, Burkina Faso	127
Figure 4.9: Pattern of millet performance in relation to RLD of millet,	
karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in a	
parkland agroforestry system in Saponé in 2000, Burkina Faso	128
Figure 4.10: Pattern of sorghum performance in relation to RLD of	
sorghum, karité (Vitellaria paradoxa) and néré (Parkia biglobosa) in	
a parkland agroforestry system in Saponé in 2001, Burkina Faso	129
Figure 5.1: Design and layout of the mulching experiment in Saponé,	
Burkina Faso	142
Figure 5.2: Effects of treatments on the percent of original leaf mass	
remaining with time for decomposing leaves of karité (Vitellaria	
paradoxa) and néré (Parkia biglobosa) in Saponé, Burkina Faso	148

Figure 5.3: Percent of original leaf nitrogen remaining with time in	
decomposing leaves of karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) in Saponé, Burkina Faso	152
Figure 5.4: Percent of original leaf phosphorus remaining with time in	
decomposing leaves of karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) in Saponé, Burkina Faso	153
Figure 5.5: Percent of original leaf potassium remaining with time in	
decomposing leaves of karité (Vitellaria paradoxa) and néré (Parkia	
biglobosa) in Saponé, Burkina Faso	153
Figure 5.6. Millet grain yield (kg ha ⁻¹ \pm SE) and dry matter production	
(kg ha ⁻¹ \pm SE) over two growing seasons (1999-2000) according to	
the type and the quantity of mulch applied in Saponé, Burkina	
Faso.	158
Figure 5.7. Millet grain yield (kg $ha^{-1} \pm SE$) and dry matter production	
(kg ha ⁻¹ \pm SE) over two growing seasons (1999-2000) according to	
the type of mulch and light zones in Saponé, Burkina Faso	159

LIST OF PLATES

PLATE		
Plate 1.1: Pruned trees and products of pruning	17	
Plate 3.1: Apparatus for light and transpiration measurement	54	
Plate 3.2: Karité fruit in a parkland system in Saponé, Burkina Faso	66	
Plate 3.3: Millet development under differentially pruned karité		
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland		
system in Saponé, Burkina Faso	69	
Plate 3.4: Sorghum development under differentially pruned karité		
(Vitellaria paradoxa) and néré (Parkia biglobosa) in a parkland		
system in Saponé, Burkina Faso	76	
Plate 4.1: Fine root processing	100	
Plate 5.1: Plots of mulching experiment in Saponé, Burkina Faso	139	

LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	Analysis of Variance
C/N	Carbon/Nitrogen ratio
CEC	Cation Exchange Capacity
CI	Confidence Interval
CNRST	Centre National de Recherche Scientifique et Technologique
DBH	Diameter at Breast Height
DH	Direct Harvest
FAO	Food and Agriculture Organisation of the United Nations
GLM	General Linear Model
IAEA	International Atomic Energy Agency of the United Nations
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
INERA	INstitut de l'Environnement et de Recherches Agricoles
IRBET	Institut de Recherches en Biologie et Ecologie Tropicale
OM	Organic Matter
PAR	Photosynthetically Active Radiation
RBS	Random Branch Sampling
RLD	Root length Density
RWD	Root Weight Density
SAFS	School of Agricultural and Forest Sciences
SALWA	Semi-Arid Low Lands of West Africa
SE	Standard Error
TDM	Total Dry Matter
TSP	Triple Super Phosphate
VPD	Vapour Pressure Deficit

CHAPTER I

INTRODUCTION

1.1. Aim of the project

Despite the considerable potential benefits of complementarity in agroforestry systems, few quantitative attempts have been made to analyse the productivity of components of the system in terms of resource capture and use (Kessler and Breman, 1991; Ong and Black, 1994; Ong *et al.*, 1996). A good example is the agroforestry parkland systems of sub-Saharan Africa for which there is dearth of information. This situation stems from the fact that separate quantification of resource capture and use by the components of mixed systems is physically, technically and intellectually extremely challenging. A fundamental understanding of how agroforestry systems utilise available resources is nevertheless crucial for establishing species combination, planting arrangements, tree densities and management strategies suitable for different locations (Ong *et al.*, 1996).

There are very few and recent quantitative research results emerging in the literature on the productivity of agroforestry parkland systems of West Africa particularly based on the two major tree species of these parklands: *Vitellaria paradoxa* C.F. Gaertn and *Parkia biglobosa* (Jacq.) Benth. However this information is fragmented and extremely localised (Kessler, 1992; Kater *et al.*, 1992; Ouédraogo, 1995b; Boffa, 1995; Timmer *et al.*, 1996; Tomlinson *et al.*, 1998; Wilson *et al.*, 1998; Jonsson *et al.*, 1999; Teklehaimanot *et al.*, 2000). Although these studies have contributed a great deal to understanding of the two species and their functions in the systems, quantitative data on productivity in terms of resource capture and use is still lacking for agroforestry parkland systems where *Vitellaria paradoxa* and *Parkia biglobosa* constitute the dominant tree species.

It has been reported that sorghum and millet yields are generally substantially (30-60%) reduced under *Vitellaria paradoxa* and *Parkia biglobosa* when compared with the open field (Kessler, 1992; Kater *et al.*, 1992; Boffa, 1995). The reduction in crop yield is attributed to competition for light, nutrients and water between the trees and the crop and light was found to be the most important factor in yield reduction according to Kessler (1992) and Kater *et al.* (1992). According to their findings the most significant effect is due to the dense spreading crowns of *Vitellaria paradoxa* and *Parkia biglobosa*, which effectively reduce light intensity reaching the canopy of associated crops.

One method of reducing light interception by these trees and enhance associated crop production may be by crown pruning. Crown pruning has been reported to have effect on root distribution of other tree species and thus substantially reducing belowground competitive effect of trees on associated crops (Jones *et al.*, 1998). Thus, crown pruning of *Vitellaria paradoxa* and *Parkia biglobosa* may have the potential of enhancing productivity of the system by reducing competition for light, nutrient and water as a result of reduction of the crown area of the trees. However, no work has so far been reported on the effect of crown pruning of *Vitellaria paradoxa* and *Parkia biglobosa* on the trees themselves and on the yield of associated crops. In addition, the pruned material from the trees can be added to the soil to enhance its fertility as a result of which the productivity of the pruned trees as well as the yield of associated crops may also be increased.

The main aim of the present research reported in this thesis was, therefore, to assess the effects of crown pruning and the application of the pruned material as mulch on the performance of the pruned trees and the yield of associated crops.

1.2. Background

1.2.1. Perennial tree component of agroforestry parkland systems

In sub-Saharan Africa, trees are preserved on farm fields because of the numerous benefits derived from them (food, wood, fodder, medicine, climatic amelioration, boundary markers) (Gijsbers *et al.*, 1994; Boffa, 1995; Tomlinson *et al.*, 1995; Lamien *et al.*, 1996; Jonsson *et al.*, 1999). Farmlands with such scattered trees, which form an open permanent overstorey of associated annual crops are called agroforestry parkland systems (Pullan, 1974; Raison, 1988; Nair, 1993).

In West Africa, the dominant tree species of agroforestry parkland systems are *Vitellaria paradoxa* and *Parkia biglobosa*. *Vitellaria paradoxa*, (known as karité in French and shea butter tree in English), was previously known as *Butyrospermum paradoxum*. The tree gives a variety of useful products including kernel, medicine and fuelwood. It is the source of vegetable fat which, in Africa, is second in importance only to palm oil (Hall *et al.*, 1996). The species grows within a belt of 500-750 km wide and a length of 5000 km running from West to East Africa (Bonkoungou, 1987a; Hall *et al.*, 1996). The southernmost occurrences (*e.g.* Tiryniri, Uganda: 1°00'N to 34°35'E) are near the eastern end of the range and the northernmost occurrences (Sakoné, Sénégal: 13°53'N, 16°21'W) occur near the western end. Karité belongs to Sapotaceae family. It can grow up to 15 m high with leaves as large as 12-25 cm. In general, the density of karité individuals \geq 10 cm dbh in farm fields was more than 10 ha⁻¹ (Gijsbers *et al.*, 1994; Boffa, 1995; Schreckenberg, 1996; Hall *et al.*, 1996; Bayala and Lamien, 1997).

Parkia biglobosa (known as néré in French and locust bean in English) is found in savannah zones with a natural range extending from 5°N to 15°N and 16°W to 32°E (Hopkins and White, 1984). It is a large tree, up to 20 m high, with a wide-spreading crown. *Parkia biglobosa* belongs to family Mimosaceae, with small leaflets; 0.8-3.0 x 0.2-0.8 cm (Maydell, 1983) but it doesn't fix atmospheric nitrogen (Dommergues, 1987; Tomlinson *et al.*, 1998). The tree yields a condiment locally called *'soumbala'* (type of cheese made from seeds), food (pulp), medicine and fuelwood (Bonkoungou, 1987b; Ki, 1994; Hall *et al.*, 1997; Teklehaimanot, 1997). The density of néré individuals ≥10 dbh is lower in farm fields compared to karité being less than 5 ha⁻¹ (Kessler, 1992; Bayala and Lamien, 1995; Ouédraogo, 1995a; Bernard *et al.*, 1995; Schreckenberg, 1996; Hall *et al.*, 1997).

Even though the above two tree species dominate agroforestry parkland systems, the system is reported to be extremely diverse in species composition depending on the original vegetation from which it is derived, the needs of farmers and the uses of species known by the locality's ethnic group. For instance, Gijsbers *et al.* (1994) and Boffa (1995) recorded 43 and 74 tree species, respectively in parklands of north and south of Burkina Faso. Bayala and Lamien (1995, 1997) recorded 54 species in Yasso

village in the West of Burkina and 48 species in Dimolo village in the South of Burkina.

The structure of parklands and the distribution and pattern of the tree population are intimately related to human influences (Kessler, 1992; Ouédraogo, 1994). Parklands, which are close to settlements tend to have low tree densities. Parklands on more fertile soils, usually found in lower parts of slopes or valleys, remain for many years under cultivation, so they bear well developed trees (Kessler and Boni, 1991, Ouédraogo, 1994; Bayala and Lamien, 1995).

1.2.2. Annual crop component of agroforestry parkland systems

Negative impacts of karité and néré on associated crops have been reported by Maïga (1987), Kessler (1992), Kater *et al.* (1992), and Boffa (1995). Maïga (1987) in Burkina Faso and Kapp (1987) in Mali found a reduction of millet production of 35% and 50%, respectively under karité. Kessler (1992) found a reduction of light (PAR) from 100% to only 20% near the stem of néré trees and 40-50% for karité trees. The reduction of crop yields associated with light transmission was 70% for sorghum according to Kessler (1992). Kater *et al.* (1992) found 65% and 2% for cotton, 66% and 60% for sorghum and 60% and 44% for millet, under néré and karité, respectively. Boffa recorded 15% of sorghum decrease under karité. The main reasons given by the authors to explain this reduction were: competition for light, nutrients, soil moisture, fungal attacks associated with humidity, weeds, and birds resting on trees. However, researchers in Nigeria (Sabiitti and Cobbina, 1992a) have observed that crops gave higher yields under *Parkia biglobosa*. These may be due to positive effects trees have on soil fertility as proven by Tomlinson *et al.* (1995) and micro-climate parameters such as soil temperature reduction by Jonsson *et al.* (1999).

The modification of micro-climate (light, temperature) may have both negative and positive influences on yield of associated crops. For example, a reduction in temperature delayed the flowering of millet by 2-3 days (Corlett *et al.*, 1992). Similar observations have been made by Kessler (1992) for sorghum. Such a delay is beneficial for crop growth if moisture is not limiting but would be a disadvantage if water stress exists because C_4 species, with much greater light-saturated

photosynthetic rates, with even minimal shading is likely to reduce assimilation (Ong et al., 1996). Thus, some authors have found that shading is the main factor of associated crop yield reduction in parklands (Kessler, 1992; Kater et al., 1992; Yelemou, 1993). However, these conclusions have been drawn based on one or two environmental parameters studied in isolation and not based on comparative studies where all environmental parameters are considered. It is well known that environmental factors are intimately linked and in order to understand and assess the performance of tree-crop mixtures simultaneous studies of the processes of capture and utilisation of important environmental resources by components of the system are implicit. For instance, studies on changes in water use and soil nutrients in agroforestry parkland systems in relation with tree management have not been undertaken yet, but significant changes in these parameters have potentially the most crucial contribution to the sustainability of agroforestry parkland systems in sub-Saharan Africa. Competition for water is a major constraint to productivity in multi-species agriculture such as agroforestry parkland systems where this resource is a limiting factor. In the process of understanding resources sharing, a focus must be put on the limiting factors. In semi-arid areas such as Burkina Faso, apart from nutrients, water supply is a real concern both in time and space. In this kind of situation, understanding how trees share water with annual crops in agroforestry parkland systems is of paramount importance.

Trees can be managed in order to control water loss by employing techniques such as crown pruning. The apparatus of transpiration are stomata borne by leaves. Pruning by removing, reducing and modifying leaf structure will necessarily induce a shift in transpiration process in terms of the quantity of water lost.

1.2.3. Crown pruning as a tree management tool in agroforestry parkland systems

The study of Ki (1994) may be cited as one of the few studies that report traditional tree management practices in agroforestry parkland systems in sub-Saharan Africa. In her inventory of management techniques for néré, she found that néré are pruned and thinned by the local people in Burkina Faso. Timmer *et al.* (1996) made an inventory of current pruning practices on néré in Burkina Faso. According to farmers interviewed in this study the motives to prune néré trees were: rejuvenation,

increasing fruit production, sanitary pruning, reducing the danger of falling branches, reducing the shade impact on crops under the canopy, correcting a lopsided tree to prevent it from falling, removing low branches that hamper passage, enabling fruits high up in the tree to be harvested, exploitation for firewood and construction wood. Karité and néré branches are also usually lopped by farmers and fed to livestock especially in the dry season when good quality feed is scarce (Sabiiti and Cobbina, 1992b; Bayala *et al.*, 2000).

Even though scattered trees are rarely subjected to formal management (Hall *et al.*, 1997) and despite laws against pruning and cutting of this species (Nikiéma, 1993), pruning practice is widespread in all ethnic groups in Burkina Faso. However, the frequency of this practice is low, for instance 10-30% of néré were found pruned in central Burkina Faso by Timmer *et al.* (1996). In their study of parkland characterisation in western Burkina Faso, Bayala and Lamien (1995), and Bayala *et al.* (2000) noted that 20% of néré and 13% of karité were pruned in Yasso.

Less attention is given to karité than néré apart from natural regeneration and pruning with the aim to remove dead or branches parasitised by Tapinanthus the African mistletoe (Agbahungba and Depommier, 1989; Boussim et al., 1993b; Schreckenberg, 1996). Karité leaves are used as fodder in Yasso, Burkina Faso just before the rainy season when this resource becomes scarce (Bayala and Lamien, 1995). Many authors stated that Karité doesn't support pruning (Kessler, 1992; Kater et al., 1992; de Saint Sauveur, 1999). Pruning seems to be less applied to karité, presumably because karité does not cast a heavy shade, despite its dense crown. This species bears branches, which usually have an upright habit (Bonkoungou, 1987a; Hall et al., 1996). According to some farmers, karité pruning induces no improvement of fruit production (farmers in west Burkina) or reduction of fruit production (in Mali) (de saint Sauveur, 1999). However pruning may be a useful tool to combat parasites. Boussim et al. (1993a) found that about 95% of karité were found parasitised by Tapinanthus, the African mistletoe, in Burkina Faso. This parasite has been considered as one of the principal causes of karité mortality (Maïga, 1987; Boussim et al., 1993b). Even though this parasite seems to prefer karité (Boussim et al., 1993b), it attacks other species such as néré as well. Taking into account the damage this parasite causes to karité and the potential hazard it represents for other

local hardwood trees, application of pruning to parasitised branches may help reduce the infestation by *Tapinanthus* and consequently enhance the productivity of karité and associated crop (Kessler, 1992; Boussim *et al.*, 1993b).

Pruning as a management tool to reduce interspecific competition has been recommended in agroforestry parkland systems for both néré and karité by several authors (Bonkoungou, 1987b; Agbahungba and Depommier, 1989; Kessler, 1992; Savenije, 1993; Timmer *et al.*, 1996; Wilson *et al.*, 1998). However, there is very limited information in the literature that reports the benefit of tree pruning on crop yield (Kessler, 1992; Kater *et al.*, 1992; Savenije, 1993; Timmer *et al.*, 1992; Savenije, 1993; Timmer *et al.*, 1996). The only actual work reported in the literature on the effect of pruning on crop yield in agroforestry parkland systems is by Kessler (1992). However, his study is based on a comparison between one single pruned néré tree against several unpruned trees and yet he reported that reduced shading by the pruned néré led to better crop production under the tree.

As transpiration is linked with leaf area and leaf area with crown dimension, modification of crown size by pruning is likely to reduce water uptake by tree. If less water is used by trees, this water is assumed to be available for the associated crop. Water use efficiency of component crop is equally as important as water availability under water-limiting conditions as the quantity of dry matter produced depends on the quantity of water captured and the efficiency with which it is used in dry matter production (Ong *et al.*, 1996). However, no work has been reported in the literature on the effect of crown pruning on the productivity of both tree and crop component in agroforestry parkland systems in terms of resource capture and use.

1.2.4. Application of pruned material as mulch

Mulching is widely used in the tropics for conserving soil water and reducing soil erosion (Stigter, 1984). An additional beneficial effect of mulching is through increased activity of soil fauna, further improving the soil structure (Young, 1989; Lavelle *et al.*, 1992; Wallace, 1996). The addition of tree leaves and branches as mulches to soils has also been shown to improve site micro-environmental conditions (Budelman, 1989; Schroth *et al.*, 1992) and increase the productivity of

agricultural crops (Duguma et al., 1988; Yamoah and Burleigh, 1990; Rippin et al., 1994; Muller-Samman and Kotschi, 1994). In general, the benefits of the application of mulches to the soil surface include the reduction of erosion, improved infiltration of rain water and less evaporation, lower soil temperature, supply of organic matter and nutrients, higher biological activity and better root growth (Webster and Wilson, 1980; Schroth et al., 1992). Schroth et al. (1992) noticed a strong increase of surface porosity, accompanied by the concentration of large numbers of plant roots, worms and other invertebrates in the protected area directly under the mulch. Application of 24 t ha-1 of Chromolaena odorata mulch increased cassava yield by 140% (Hulugalle et al., 1990). According to Lal (1975) cited by Muller-Samman and Kotschi (1994) at mulching rate of 2 t ha⁻¹, surface runoff was decreased by 60% and soil erosion by an average of 90% and soil bulk density from 1.54-1.70 to 1.40-1.42. Application of about 2.5 t ha-1 mulch of Gliricidia sepium released 95 N kg ha-1 compared with the 132 N kg ha-1 needed by maize (Yamoah et al., 1986b). Well managed mulching can also lead to an increase in exchangeable calcium, magnesium, potassium, a decrease in base saturation by 195%, 43%, 50% and 14%, respectively. These effects combined with a better infiltration led to an increase in cassava yield by 140% as shown by Hulugalle et al. (1990).

Weeds are estimated to account for up to 50% of the loss in crop production in the tropics, 10% world-wide, 50% of the total farm labour and 40% of the production cost (Rippin *et al.*, 1994). The supply of organic matter from mulching can play an important role both for soil fertility and weed control as well. The extent to which weed suppression is achieved depends mostly on the tree species, the rate of decomposition of pruned tree residues. A reduction of up to 90% in weed biomass was observed by Jama *et al.* (1991) under *Leuceana leucocephala* alley cropping where tree prunings were applied at a rate of 14 t ha⁻¹ year⁻¹. Rippin *et al.* (1994) obtained a reduction of weeds by 52% under mulching of *Erythrina poeppigiana* at a rate of 10 t ha⁻¹ leading to an increase by 90% of maize yield.

Thus, if crown pruning is recommended as a tool to reduce interspecific competition in agroforestry parkland systems for both néré and karité, good use could be made of the pruned leaves and branches by either incorporating them directly into soil or as mulch (Sabiitti and Cobbina, 1992a; Tilander, 1996; Namirembe, 1999). From pruning two components can be produced: leaves and wood. The leaves can be used for mulching to provide all the benefits of mulching described above and the wood for either fuelwood or other domestic uses. Thus, it is important to be able to estimate the quantity of material that can be produced from pruning. If leaves are used as mulch, it is also essential to know how much is needed to apply on the soil to influence soil fertility and enhance crop production.

1.3. Summary and objectives

In order to assess the productivity of agroforestry parkland systems, the complementarity or competitiveness of the major components of the system has to be studied in detail. Complementary or competitive interactions between the tree species and the associated crop depend on their ability to capture and use the most limiting essential growth resources effectively (Monteith, 1981). Capture of the limiting resources (e.g. light, water and nutrients) depends on the number, surface area, distribution and effectiveness of the individual elements within the canopy, the root system of the species or mixture involved. The use of the acquired resources depends on the conversion coefficient of the species involved and environmental influences such as temperature extremes or drought. Biomass production over a time period thus can be expressed in terms of resource capture and utilisation (Ong *et al.*, 1996).

In the past, for example, the roles of water and nutrients have been largely studied in isolation, yet it is known that they are intimately linked. Thus, it is not possible to understand and predict the performance of tree-crop mixtures unless recognition is given to this fact. Again in the past scientists have tended to study above and belowground processes separately. Plants have to balance the aboveground demands for evaporation with the belowground supply of water. In mixed communities plants rarely compete for light without simultaneously competing for water and nutrients and our understanding of how mixed species systems grow and utilise resources will remain restricted unless experiments are designed which explicitly recognise this (Wallace, 1996). The present research was, therefore, designed to study the effect of crown pruning and the application of the pruned

leaves as mulch on the productivity of agroforestry parkland systems in terms of resource capture and utilisation with the following three specific objectives:

- To assess the effect of crown pruning on the performance of the pruned trees and yield of associated crops in terms of resources capture and use;
- To assess the effect of crown pruning on fine roots distribution and their relationship with crop yield, and;
- To assess the effect of using pruned material as mulch on soil properties and crop production.

The experiments reported in the present thesis were, therefore, carried out to test the following hypotheses:

- crown pruning enhances crop production due to increased light transmission, reduced water and nutrients use by pruned trees;
- a reduction of crown volume is associated with a reduction of nutrient and water demand and therefore a decrease of root length density;
- pruning effects decrease with increased distance from the base of crownpruned trees;
- the use of pruned material as mulch improves soil physical and chemical properties and consequently increases crop yield.

This thesis has six chapters. Chapter 1 comprises this introduction and the description of the study site, and tree selection and pruning treatments. Chapter 2 consists of review of literature on parkland systems, their management practices, resource capture and utilisation and the principles of mulching. Chapter 3 consists of four subchapters. Subchapter 3.1 is an introduction to the effects of crown pruning to tree and crop performance. In Subchapter 3.2 the methodologies used in the study of tree and crop performance, resource capture and use by the components and their relationship with the performance of tree and crop components; in Subchapter 3.3 and Subchapter 3.4 the results and discussion are presented, respectively. Chapter 4 consists of four subchapters. Subchapter 4.1 consists of an introduction to tree and crop root distribution in relation to crown pruning. In Subchapters 4.2, 4.3 and 4.4 the methodology, results and discussion are presented, respectively. Chapter 5, which is concerned with the study of mulching, is also divided into four

subchapters. Subchapters 5.1 is concerned with an introduction to mulching. In the subsequent three subchapters, the methodology, results and discussion are presented. In Chapter 6, a general discussion, which integrates all the results of the present research and general conclusions and recommendations drawn from them are presented.



Figure 1.1: Map of Burkina Faso showing Saponé the study site

1.4. Study area

The study was carried out in the parklands of Saponé, a village located 30 km south of the city of Ouagadougou, Burkina Faso, West Africa (12°03' latitude north and 1°43' longitude west) and at an altitude of 200 m.a.s.l (Figure 1.1). The parklands of Saponé are dominated by the two major tree species of Sub-Saharan African parklands: karité (*Vitellaria paradoxa* C.F. Gaertn.f.) and néré (*Parkia biglobosa* (Jacq.) Benth). The rainfall is uni-modal with a mean annual rainfall of about 721 mm. The rainfall for 1999 rainy season was 805 mm, 680 mm in 2000 and 931 mm in 2001 (Figure 1.2). The soils are sandy loamy Regosols (Pallo, 2001), with very low nutrient content (N=0.03%, extractable P=1.05 ppm and exchangeable bases<2.5 cMol_c kg⁻¹) (Jonsson *et al.*, 1999).



Figure 1.2: Rainfall in Saponé during three consecutive years, Burkina Faso.

The population of the village amounts to 13,988 persons, belonging mainly to Mossi tribe (Census, 1998). The main livelihood of the villagers is based on crop farming, livestock and crafting. Millet, sorghum (red and white), peanut and beans are the major crops. Livestock is composed of mainly cattle, sheep and goats.

The study area covers approximately 59 ha of cultivated fields. The tree species composition and tree population status of the study area was assessed in 1999. Using one corner of the study area as reference point, all trees ≥ 1 cm dbh were enumerated. Height, diameter at breast height and crown diameter in East-West and North-South directions were measured for trees ≥ 10 cm dbh. Tree density, frequency and tree population structure were assessed as shown in Table 1.1 and 1.2, respectively.

Table 1.1 indicates that a total of 35 species from 27 genera and 17 families were encountered in the study area. Six of the 35 species were exotic (*Azadirachta indica*, *Citrus sp., Eucalyptus camaldulensis, Mangifera indica, Psidium guayava,* and *Senna seamea*).

The dominant species was karité with relative frequency of 58% and density of 9.05 individuals per hectare followed by néré 8% frequency and 1.22 individuals per hectare (Table 1.2). Other species occurring with relative frequency of higher than 1% were: *Mangifera indica* (4.2%), *Ficus gnaphalocarpa* (3.3%), *Sclerocarya birrea* (3.2%), *Lannea microcarpa* (2.5%), *Terminalia laxiflora* (1.9%), and *Psidium guayava* (1.2%).

The total number of individuals enumerated on 59 ha of cultivated fields in Saponé were 910 with a total basal area of 904.16 m² ha⁻¹ and the overall density of trees was 15.5 trees per hectare (Tables 1.1 and 1.2).

Table 1.1: List of woody species encountered in the study area, Saponé, Burkina Faso.

Family	Species	Frequency	Relative	Density
7. 	-		Frequency (%)	(Nb ha-1)
Mimosaceae	Acacia dudgeoni	3	0.3	0.05
Mimosaceae	Acacia nilotica	6	0.7	0.10
Mimosaceae	Acacia seyal	1	0.1	0.02
Mimosaceae	Acacia sieberiana	1	0.1	0.02
Bombaceae	Adansonia digitata	5	0.5	0.08
Combretaceae	Anogeissus leiocarpus	4	0.4	0.07
Meliaceae	Azadirachta indica	74	8.1	1.25
Bombaceae	Bombax costatum	9	1.0	0.15
Rutaceae	Citrus sp	5	0.5	0.08
Ebenaceae	Diospyros mespiliformis	6	0.7	0.10
Myrtaceae	Eucalyptus camaldulensis	4	0.4	0.07
Mimosaceae	Faidherbia albida	4	0.4	0.07
Moraceae	Ficus gnaphalocarpa	30	3.3	0.51
Rubiaceae	Gardenia ternifolia	1	0.1	0.02
Meliaceae	Khaya senegalensis	6	0.7	0.10
Anacardiaceae	Lannea acida	3	0.3	0.05
Anacardiaceae	Lannea microcarpa	23	2.5	0.39
Anacardiaceae	Mangifera indica	38	4.2	0.64
Mimosaceae	Parkia biglobosa	42	7.9	1.22
Myrtaceae	Psidium guayava	11	1.2	0.19
Papilionaceae	Pterocarpus erinaceus	2	0.2	0.03
Anacardiaceae	Sclerocarya birrea	29	3.2	0.49
Caesalpiniaceae	Senna seamea	1	0.1	0.02
Bignoniaceae	Stereospermum kunthianum	2	0.2	0.03
Loganiaceae	Strychnos spinosa	1	0.1	0.02
Caesalpinaceae	Tamarindus indica	6	0.7	0.10
Combretaceae	Terminalia avicennoides	5	0.5	0.08
Combretaceae	Terminalia laxiflora	17	1.9	0.29
Combretaceae	Terminalia macroptera	3	0.4	0.07
Sapotaceae	Vitellaria paradoxa	504	58.5	9.05
Verbenaceae	Vitex doniana	2	0.2	0.03
Rhamnaceae	Ziziphus mauritiana	4	0.4	0.07
	Total	910	100	15.47
Variables	Total population	Karité population	Néré population	
--------------------------------	---------------------	----------------------	--------------------	
Density (number of trees ha-1)	15.5	9.1	1.2	
Relative frequency (%)	100	58.5	7.9	
Basal area (m² ha-1)	904.2	388.3	301.7	
Mean Dbh (cm)	30.8	28.8	65.2	
Dbh of largest tree	160	102	160	
Dbh of smallest tree	1	2	3	

Table 1.2: Characteristics of parkland tree population in the study area in Saponé, Burkina Faso

1.5. Tree selection and pruning treatments

With the help of an informant from the village, 30 mature trees, which were \geq 30 cm in diameter and bearing fruit, each of karité and néré (total 60 trees) were randomly selected in January 1999. Discussions were held with the farmers, who are the owners of trees and those who cultivate crop by borrowing land from the owners of the trees, to obtain their agreement to carry out the research. Prior to this, an agreement with the chief of the village was also acquired. Tree height and diameter and crown diameter were measured on all sixty selected trees (Table 1.3).

Table 1.3. Characteristics of t	he tree samples selected	for the study in	agroforestry
parkland system in Saponé, B	Burkina Faso.		

		Height (m)	Trunk height (m)	DBH (cm)	Crown diameter (m)	Crown area (m²)
Karité	Average	11.67	2.1	49.76	10.56	87.54
	St. Dev.	2.39	0.48	13.71	1.87	2.76
	Max	17	3.3	102	14.5	165.05
	Min	7.5	1.2	30	7.15	40.13
Néré	Average	15.38	2.21	89.06	20.98	345.58
	St. Dev.	2.35	0.39	27.40	3.76	11.13
	Max	19.5	3.2	160	27.75	604.5
	Min	12	1.7	45	12.1	114.93

According to Timmer *et al.* (1996), traditionally farmers apply six methods of tree pruning that can be grouped into two categories: partial and total pruning. Taking this into account, the following treatments were applied to the sample trees in May-June 1999 by agreement with the farmers: 20 unpruned (control), 20 half-pruned (50% of the crown removed) and 20 total-pruned (100% of the crown removed). These intensities of pruning were also based in the following criteria "tree age", crown size, level of fruit production and sanitary status. The removal of 100% of the crown was achieved by reducing all of the secondary branches to one metre from their bases and the removal of 50% of the crown involved similar reduction but applied only to half of the secondary branches (Plate 1.1). After pruning the mean crown diameter of total-pruned néré trees was 11.6 ± 1.1 m and karité 3.4 ± 0.7 m. However, pruning 50% of the crown of both species did not modify crown diameter. Plate 1.1: Pruned trees and products of pruning



Half-pruned karité



Total-pruned karité





17

CHAPTER II

LITERATURE REVIEW

2.1. Description of agroforestry parkland systems

Scattered trees are characteristics of landscapes of a large part of sub-Saharan Africa. These landscapes are generally called parklands. When they are farmed or recently fallowed they are referred to as agroforestry parkland systems or practices (Pullan, 1974; Raison, 1988; Sinclair, 1999). The trees are deliberately selected and left standing when converting a natural woodland to farmland. The trees are selected because they are valued for their multipurpose uses (Gijsbers *et al.*, 1994; Boffa, 1995; Tomlinson *et al.*, 1995; Lamien *et al.*, 1996; Jonsson *et al.*, 1999).

Agroforestry parkland systems may be classified into two types based on their origin and the dominant species found in them:

1- Selected parklands - those which contain trees selected and preserved from the original vegetation; and

2- Constructed parklands - those, which include preserved as well as planted trees (Raison, 1988; Kessler and Boni, 1991; Ouédraogo, 1995b).

Selected parklands are spatially distributed around homesteads in three strata: house fields, village fields and bush fields. This spatial arrangement is a product of long-term land cultivation. Farmed parkland is initially established around a settlement or homestead given what is called house fields. Progressively, the village and bush fields are created as the space cultivated expands further from the settlement toward the bush (Raison, 1988; Ouédraogo, 1995b; Bayala and Lamien, 1995; 1997). At the time of clearing woodland, farmers remove most of the vegetation leaving only selected multipurpose trees. As a result parklands are dominated by few tree species (Ouédraogo, 1995b; Boffa, 1995). The reduction in tree density followed by cultivation results in good growth for the retained trees (Kessler and Boni, 1991; Ouédraogo, 1994; Boffa, 1995; Oni, 1997). Thus, well-developed parklands are those that are found on farm fields, which have been cultivated over a long period of time.

Constructed parklands are also spatially arranged around homesteads. They are established in areas where local people have access to extension services and seedlings of trees. The species planted are those that are valued for their unique products preferred by the local farmers and suitability of the areas for growing them. In drier areas, where wood is scarce, farmers prefer to plant eucalyptus and neem, which are adapted to dry conditions. In areas, where climatic conditions are favourable, an emphasis is placed on planting fruit tree species like mangoes and citrus (Ouédraogo, 1995b).

Even though parklands are dominated by few tree species, they also contain a wide range of other species depending on the original vegetation, the level of vegetation degradation, the needs of farmers and knowledge of the local ethnic group of the uses of the species (Gijsbers *et al.*, 1994; Boffa, 1995; Bayala and Lamien 1995, 1997).

In agroforestry parkland systems where *Vitellaria paradoxa* and *Parkia biglobosa* constitute the dominant tree species, a variety of crop species are grown under the canopy of these trees. Sorghum, millet and cotton are the major crop species grown. Results of research carried out so far to assess the performance of these crops under the canopy of *Vitellaria paradoxa* and *Parkia biglobosa* indicate that crop yield is depressed due to shading by the dense and spreading crowns of these two tree species (Maïga, 1987; Kapp, 1987; Kessler, 1992; Kater *et al.*, 1992; Boffa, 1995). The reduction in crop yield is attributed to competition for light, nutrients and soil moisture between the trees and the crop component. One method of reducing light interception by these trees and enhance associated crop production may be by crown pruning (Bayala *et al.*, 2002). Farmers in some communities already practice crown pruning for several motives in addition to reducing shading of crop by trees.

2.2. Traditional tree pruning practices in agroforestry parkland systems

The most intensive study on indigenous tree management practices in the literature is the review made by Savenije (1993). A total of 320 references were used for semiarid region in general, and for Sahel region in particular. Relatively few specific references were found on traditional tree management techniques. The reason, according to the author, is because the development of appropriate management systems of trees has received relatively little scientific attention, probably because of underestimation of their importance in the past. Another reason stems from storage problems and difficulties for tropical products to access the world market. But with the growing pressure on agroforestry parklands, the need for more systematic and intensified technical management has emerged. However, from the few reports that document traditional tree management techniques, it appears that such techniques have not been systematically studied in the Sahel zone. It is rarely described how and with what intention these practices are carried out, at what scale, with what kind of effect and how useful they are under the present conditions (Savenije, 1993). Although deliberate tree manipulation practices are reported for various population groups, it seems that these are usually less intensive (Timmer *et al.*, 1996).

Ki (1994), in an inventory of management techniques for néré in Burkina Faso, found that néré are well protected against animals (fences), fire (clearing of herbs, early fire, green belt) and theft. These protections are implemented in farm fields and very rarely (except Bobo ethnic group) for trees located in the bush. According to the same author, other silvicultural techniques used by local people are pruning, thinning, bark removal, incision, and micro-catchments around trees for retaining water. All these techniques are implemented at the beginning of the rainy season. *Parkia* branches are usually lopped by farmers and fed to livestock especially in the dry season when good quality feed is scarce (Sabiiti and Cobbina, 1992b).

Six different pruning types have been distinguished by Timmer et al. (1996) for néré:

- removing each main branch near the trunk;
- removing each main branch, including the axis, at some distance from the trunk;
- removing each main branch, except the axis, at some distance from the trunk;
- removing one or more branches, except the axis, near the trunk;
- removing several main branches, except the axis, at some distance from the trunk;
- removing one or several branches from the second ramification.

Of all the farmers who practised pruning with the motives to improve tree productivity and survival, 58% applied intensive pruning types (the first three mentioned above). Contrary to their expectation, intensive pruning did not reduce crown size. Fifty-seven percent of trees were pruned in April and May in order to enable trees to benefit from the wet season similarly to the findings of Ki (1994). Trees pruned in October and November were usually not intensively pruned (93%), with motives for exploitation mainly for construction wood (69%). The youngest pruned néré recorded was 17 year-old and 94% of the pruned trees were older than 30 years (72% with an average crown area of more than 168 m²).

There is no detailed study on pruning of karité as much as néré. Despite the belief that karité doesn't support pruning (Kessler, 1992; Kater *et al.*, 1992; de Saint Sauveur, 1999), pruning has been reported to be applied by farmers to combat parasites. Boussim *et al.* (1993a) and Sallé and Boussim (2001) in their studies on karité parasite identified three species of *Tapinanthus*, the African mistletoe, in Burkina Faso: *Agelanthus dodoneifolius, Tapinanthus globiferus, Tapinanthus ophiodes*. About 95% of karité were found parasitised by *Tapinanthus* in Burkina Faso. Pruning is applied by farmers only on old karité trees with the aim to remove branches infected with *Tapinanthus* or dead branches (Agbahungba and Depommier, 1989; Boffa, 1995; Hall *et al.*, 1996). Pruning is also applied by some farmers to improve the next season's production (fruit and crops) (Kater *et al.*, 1992; Timmer *et al.*, 1996). Some branches of this species are also lopped by farmers and fed to livestock in the dry season when good quality feed is scarce (Bayala and Lamien, 1995; Bayala *et al.*, 2000).

The difference in the application of pruning to karité and néré by farmers may be due to the different characteristics of the species. Néré belongs to the *Fabaceae*, which is known as a family with relatively strong re-sprouting powers (Oldman ex Kater *et al.*, 1992). Re-sprouting of karité after pruning or lopping is less certain as stated by some farmers (de Saint Sauveur, 1999).

The effect of pruning on aboveground architecture, tree root density and distribution, tree fruit production and production of associated crops are areas of research required to assess the potential of crown pruning as a management tool to enhance productivity of agroforestry parkland systems. The influence of pruning on both above- and belowground processes is mediated through the environment (light,

water, nutrients). Therefore, understanding the influence of crown pruning on light, water and nutrients, which in turn influence plant production is essential.

2.3. Effects of crown pruning on resource capture and utilisation in agroforestry parkland systems

2.3.1. Effect of crown pruning on light transmission

Leaf is the main component of the canopy by which light is modified in quantity and quality (Jones, 1992; Kessler, 1992; Boffa, 1995; Hall *et al.*, 1996, 1997; Jonsson *et al.*, 1999). The wavelengths of radiation that are of primarily concern in plant production lie between about 400 nm and 700 nm, the photosynthetically active radiation (PAR). PAR is measured either as photon or as energy flux density. The photosynthetic photon flux density (PPFD) is the incident photon flux density of PAR or the number of photons (400-700 nm) incident per unit time on a unit surface area of plant (mol m⁻²s⁻¹). The Photosynthetic irradiance (PI) is the radiant energy flux density of PAR or radiant energy (400-700 nm) incident per unit of time on a unit of surface area of plant (W m⁻²) (Jones, 1992).

One of the major environmental resources, which has been reported to have significant influence on productivity in agroforestry parkland systems, is light. Kessler (1992) and Bayala *et al.* (2002) found that reduced shading as a result of pruning néré and karité led to better crop yield under the tree canopy. Thus, crown modification by pruning of the tree component is likely to have significant effect on light capture and utilisation and consequently on the productivity of the crop component of agroforestry parkland systems. If less light is intercepted by tree crown due to reduced crown size as a result of pruning, more light will be transmitted to the understorey that may result in increased crop production. However for increased production to take place, light use efficiency of the component crop is as important as the quantity and quality of light transmitted.

Dry matter production of the components in agroforestry systems is often linearly related to the quantity of radiation absorbed by their canopies, in the absence of other limiting factors. The slope of this relation provides measure of the light conversion coefficient (e), which is usually expressed as the quantity of aboveground dry matter produced per unit of intercepted light (g MJ⁻¹) (Monteith, 1981). When water is freely available, light interception is related to leaf area index (L) of a sole crop by the expression:

$$f = 1 - \exp(-kL) \tag{2.1}$$

where k is an extinction coefficient for the canopy, which is dependent on leaf angle and distribution, and L is leaf area. Light interception increases as k and L increase (Ong *et al.*, 1996).

For example, light interception by alley-cropped millet was found to be 14-40% of that in sole millet. Conversion coefficient (e) value for the alley-cropped millet was 1.6 g MJ⁻¹, which was 32% greater than in the sole crop, possibly because the reduced light-saturating photon flux density for photosynthesis associated with drought was attained less frequently under condition of partial shade. However, the overall conversion coefficient for the alley system was only 9% greater than in sole millet (Ong *ct al.*, 1996; Ong and Leakey, 1999).

In general, C₄ species should have lower quantum efficiency than C₃ species because of the greater energy costs of the additional carboxylation steps and intercellular transfers of intermediate metabolites (Osmond *et al.*, 1982). However, the quantum efficiencies of C₃ species are adversely affected by photorespiration, to an extent dependent on temperature, $CO_2:O_2$ ratio and drought. Quantum efficiencies are therefore similar in C₃ and C₄ species at 20-25°C, but are greater in C₃ at lower temperatures. Thus, the photosynthetic temperature response curves of C₃ and C₄ species differ greatly, with the latter usually declining sharply at temperatures below 15-20°C. Photosynthesis increases with increasing atmospheric CO₂ concentration within a range 0-800 ppm but is consistently higher in C₄ species. Thus, C₄ species have been reported to have higher light conversion coefficient than C₃ species (Ong *et al.*, 1996; Ong and Leakey, 1999).

It is evident from the above that light transmission or interception depends on the composition of tree species and the density and the crown size of the tree species in

agroforestry parkland systems. The amount of light intercepted by the tree canopy and the amount of light that is transmitted to the lower storey determines the productivity of the tree and the associated crop, respectively. Thus, biomass production and fruit yield by the tree or crop yield by the associated crop (B) over a time period (t) may be expressed as:

$$B = c.e.t \tag{2.2}$$

where B has units of g m-² of land area; c is the amount of light absorbed by the component crop and e is the conversion coefficient, the mean value of c and e have units of MJ m-² and g MJ-¹ m-²; t has dimensions of days (Ong *et al.*, 1996).

The major advantage of expressing productivity in this term is that the equation derived can be used to predict production under similar species and conditions elsewhere. Thus, detailed measurements of PAR interception and transmission are essential for a full understanding of the influence of the tree pruning on the light use, growth and productivity of the components in agroforestry parkland systems.

2.3.2. Effect of crown pruning on water uptake and use of trees

Water transpired by tree comes mainly from the soil. In an agroforestry system like parkland it is expected that the components use water from separate soil layers as shown by Howard *et al.* (1995). These authors, analysing the transpiration of young *Grevillea sp.* trees, found that at least 80% of transpired water may be drawn from below crop rooting zone. In such a situation, the overall production of the system may be maximised depending on the quantity of available water, which, in turn, is linked to the depth of the soil.

Conservation of surface water is of paramount importance for crop growth in agroforestry parkland systems. As a result of shading by tree canopy, temperature of soil is lowered and therefore, the loss of water from the soil surface due to surface evaporation will also be lower and this will allow better crop growth beneath and adjacent to the tree (Bhatt, 1990; Droppelmann *et al.*, 2000; Miller and Pallardy, 2001). As the population of trees reduces, sole cropping systems in semi-arid regions often

use less than half the rainfall input since there can be substantial losses of water via soil evaporation, runoff and drainage. In the semi-arid region of the Middle East and West Africa 30-60% of rainfall is directly evaporated (Cooper *et al.*, 1983). Study from Indian plateau shows that the best cropping systems use only 40% of the annual rainfall, while the rest is lost as runoff (26%), and deep percolation (33%) (Ong *et al.*, 1991). These causes of water losses in the water balance can be modified by the presence of trees, since trees can utilise water outside the rooting zone of annual crops and also outside the crop growing season. For example, works at ICRISAT centre in India showed that substantial quantities of available water were left in the 45-90 cm horizons when short-duration sole sorghum was harvested in October. This available water remained even after the longer duration sole pigeon pea was harvested some three months later (Ong *et al.*, 1992). Therefore the water balance in an agroforestry system is more efficient than in monoculture.

In order to get benefit from the agroforestry systems in relation to water balance, the components of the system need to be managed to minimise soil evaporation, runoff and drainage. Eastham *et al.* (1988) evaluating the effect of tree density (82, 304, 2150 trees ha⁻¹) on water use by silvopastoral systems in Queensland Australia, found that cumulative transpiration exceeded rainfall by over 300 mm at the high tree density during two years (1986, 1987), and also at the intermediate density during one year (1986). These results suggest that these densities may be unsustainable. However, the results obtained demonstrate that manipulation of tree density in agroforestry may be used to modify biomass production by the component species and control interspecific and intraspecific competition for available water (Ong *et al.*, 1996; Droppelmann *et al.*, 2000). Another means of management by which water loss may be controlled may be by pruning (Bayala *et al.*, 2002).

Transpiration, which is an expression of water use, is controlled by stomatal frequency, and size (Stomatal resistance) (Schulze *et al.*, 1985; Granier, 1987; Machado and Tyree, 1994; Zimmermann *et al.*, 1994). Since stomatal pores constitute the main means of gaseous exchange between plants and their environment, changes in their dimensions would be expected to affect transpiration rates to a considerable extent. Stomatal frequency and size vary markedly between plant species and within a species between different trunk sizes (Knight, 1967; Cohen *et al.*, 1981). It also

depends upon what is called the boundary layer, which is an undisturbed layer of air around each leaf (boundary layer resistance) or the canopy aerodynamic structure (aerodynamic resistance) (McNaughton and Jarvis, 1983). Both boundary and stomatal resistances depend on environmental conditions (e.g. relative humidity, soil moisture) and physiological processes (e.g. respiration for stomatal resistance) because of the link between transpiration and photosynthesis (Fitter and Hay, 1993).

Thus, a lot of variation in the rate of transpiration is expected between karité and néré as well as between pruned and unpruned trees and between different sizes of trees within each species in agroforestry parkland systems. However, no work has been carried out so far to quantify the effect of pruning on transpiration rate as well as the influence of environmental factors on transpiration rate in agroforestry parkland systems. Studies so far on water use of parkland species have been done using seedlings only. Stomatal conductance, transpiration and xylem pressure potential of *Parkia biglobosa* have been assessed by Osonubi and Fusehun (1987) and Teklehaimanot *et al.* (1998). These authors found that transpiration of *Parkia biglobosa* is under a high degree of stomatal control. They concluded that a lack of linear relationship between transpiration rate and xylem water potential indicates high tissue capacitance and internally stored water, which can be used during periods of rapid transpiration.

In agroforestry parkland systems where trees are pruned to favour associated crop production, it would be extremely useful to quantify production in terms of water use as water is the most important environmental resource in semi-arid region where such practices occur. Because of the strong link between transpiration and photosynthesis, plant production is expressed as a function of transpiration as follows:

$$B = E.e_w.t \tag{2.3}$$

where B has units of g m⁻² of land area; E is cumulative transpiration by the component crop; t has dimensions of days; e_w is the conversion coefficient for water and is dependent on atmospheric saturation deficit (D) such that e_w is proportional to 1/D, where D has units of kPa. Conservative values for e_w of around 4 kg mm⁻¹ kPa⁻¹

for C₃ species and 8 kg mm⁻¹ kPa⁻¹ for C₄ species have been reported (Squire, 1990; Ong *et al.*, 1996).

It is also important that all environmental factors which influence transpiration are analysed and their relationship with transpiration established in order to fully understand the effect of pruning on transpiration and hence the influence of transpiration on plant production. The two major environmental factors that influence transpiration are relative solar radiation, wind speed, relative humidity and temperature.

2.3.2.1. Relative humidity

The rate of transpiration increases slowly with the increasing solar radiation at low vapour pressure deficit (VPD) where it increases rapidly when VPD is high (Morikawa *et al.*, 1986). For the intact leaves, the humidity response was distinguished from a water stress response, in that transpiration may decrease at increasing vapour pressure deficit, and that water content may increase at reduced transpiration. Generally, the drier the situation, the greater is the number of stomata per unit area (Knight, 1967). The stomata in many species close in response to increased leaf-to-air vapour pressure differences. The magnitude of this response is dependent on species, growing conditions and particularly plant water status, the response being smaller at high temperature or in stressed plants (Jones, 1992).

When a vegetation canopy is dry, evaporation comes under the physiological control of the plants, since it has to pass through the stomata or cuticle of the leaves. The rate of cuticular transpiration is usually very low, since the resistance to water vapour transfer across the cuticle is at least an order of magnitude greater than when the stomata are opened (Rutter, 1975). Transpiration rate therefore depends on the bulk stomatal resistance of the entire canopy or simply the 'surface resistance' (Wallace, 1996).

2.3.2.2. Temperature

In general stomata tend to open as temperature increases over the normally encountered range, though an optimum is sometimes reached (Hall *et al.*, 1976). The magnitude of the temperature response does, however, depend on the vapour pressure (Jones, 1992). Concentration of water vapour of saturated air within the leaf is determined by leaf temperature and transpiration plays a regulatory role in leaf temperature.

Leaves exposed to bright sunshine absorb radiation and may become several degrees warmer than the air around them. Transpiration energy is required to supply the latent heat vaporisation. In the absence of a supply of energy (heat) the leaf would be rapidly cooled by transpiration and the concentration of water vapour of saturated air within the leaf would fall until it becomes equal to relative humidity of surrounding air. For transpiration plant leaves need energy to maintain leaf temperature. In nature, when the whole surface of the land is covered with transpiring vegetation, the temperature of leaves and air would fall rapidly in the absence of any external source of energy and plants in nature obtain most of their energy for transpiration by absorbing solar radiation (Rutter, 1972).

2.3.3. Effect of crown pruning on soil physical and chemical properties

It has been shown that trees have some impacts on soil physical and chemical properties. Previous studies on the effect of both karité and néré on soil dealt essentially with chemical properties (Kessler, 1992; Kater *et al.*, 1992; Tomlinson *et al.*, 1995). However, improvement of trees on physical properties of soil might be important in semi-arid areas as good physical properties are required for a better water holding capacity and an efficient use of nutrients supplied. Physical properties have been studied for other species. For instance, Samba (1997) found that soil bulk density, soil structure and soil moisture were not improved by *Cordyla pinnata*. However, Belsky *et al.* (1993) have shown that soil bulk density was lower under *Adansonia digitata* and *Acacia tortilis* compared with the open area for the upper 0-5 cm layer. That was ascribed to the higher soil organic matter content under trees. This difference was not observed deeper at 10-15 cm layer. Similarly, Pandey *et al.*

(2000) found a decrease by 10% and 9% for sand particles whereas clay particles increased by 14% and 10% under mid canopy and edge canopy, respectively, compared to that under canopy gap of *Acacia nilotica*.

The impact of trees is beneficial on soil fertility in semi-arid zones in terms of organic matter and nitrogen contents. Thus, nutrient concentrations increasing with proximity to the trunk under both karité and néré were found by previous workers (Kessler, 1992; Kater *et al.*, 1992; Tomlinson *et al.*, 1995; Jonsson *et al.*, 1999; Bayala *et al.*, 2002). These concentrations are largely due to increased input of organic matter by trees from aboveground and belowground parts.

Cation Exchange Capacity (CEC) is influenced by soil carbon content indicating the importance of increasing organic matter in the soil. Thus, fertiliser effect can be limited by inefficiency of use caused by erosion, volatilisation and leaching due to a low CEC. The value of CEC required for an economic use of fertilisers is 4 to 5 meq. per 100 g soil according to Pieri (1989) whereas Kater *et al.* (1992) found a value of 3.4 to 3.6 meq. per 100 g soil in conditions similar to those prevailing in semi-arid areas in Burkina Faso. Pieri (1989) and Kater *et al.* (1992) predicted that continuous cultivation in semi-arid areas will eventually lead to organic carbon values in the topsoil close to 0.33% and concomitant low values of the CEC. That shows that trees have to be retained in the fields and managed properly to maintain and enhance their contribution to soil organic matter. However, no work is reported so far to show the effect of pruning on soils.

2.4. Effect of crown pruning on tree architecture and productivity

2.4.1. Effect on tree architecture

The crown shape of mature *Vitellaria paradoxa* has been described as variable (round, spindle, umbrella), but the architecture has been reported by Hallé *et al.* (1978 ex-Hall *et al.*, 1996) to conform to Aubréville's model. In this model, the stem and the main branches show a rhythmic growth, the branches being modular and plagiotropic by apposition. The bole is short and stout, and the main branches large, gnarled and wide spreading. Lower secondary branches may droop to the ground. Delolme (1947

ex-Hall *et al.*, 1996) distinguished three stem and branch growth patterns. The first pattern, rapid apical growth, is typical of very young trees. The second, starting at 5-6 year old, is represented by the development of axillary branches extending 15-20 cm year-¹. Such growth occurs only once a year, except in young and particularly vigorous plants, where it may occur two or three times. The third type of growth occurs in old trees or under difficult growing conditions and is very slow, approximately 2-3 cm year-¹; apical buds elongate, forming two characteristic barrel-shaped internodes per year. The first internode forms just after leaf fall as the tip of the branch swells and bears the flowers and leaves of the subsequent season. The second is produced during vegetative growth, after flowering.

Néré tree architecture has been reported to conform to Champagnat's model (Binnekamp, 1992; Ouédraogo, 1995a). In this model, the trunk is formed by progressive superposition of renewal shoots. Plants have spiral phyllotaxy and an underlying radial shoot symmetry. In *Parkia biglobosa*, each superposed axis is orthotropic but, as the length increases, becomes pendulous distally under its own weight. A renewal shoot developing from a lateral bud on the upper surface of the curve behind the shoot apex then continues vertical growth for further cycles (Binnekamp, 1992; Ouédraogo, 1995a; Hall *et al.*, 1997). Binnekamp (1992) and Ouédraogo (1995a) distinguished four elementary structural units for néré tree species: vegetative module, linear series of modules, sympode and, architectural unit.

As the size of crown is a determining factor affecting crop growth, farmers prune crown of trees to reduce shading (Kessler, 1992; Kater *et al.*, 1992; Binnekamp, 1992; Ki, 1994; Timmer *et al.*, 1996). As the size of crown increases with age, it is generally the older trees that are pruned in order to manipulate their architecture for the benefit of understorey crops. Farmers also prune trees for several other motives (Ki, 1994; Timmer *et al.*, 1996; Bayala *et al.*, 2000).

From the above architectural description of both tree species, they have distinctive shapes but it is not know what happens to these if the crown is pruned. Trees may be pruned to produce wood and the resulting architecture may hinder fruit production and vice versa. No study on the dynamics of architectural elements of wild fruit trees such as néré and karité after pruning has been reported in the literature. Studying the dynamics of the architecture is important in understanding the phenomena that occur after pruning including the development of different parts of a plant (branch, stem, leaf, flower, fruit, etc.) (De Reffye *et al.*, 1995; Bouchon *et al.*, 1997).

2.4.2. Leaf and wood biomass yield from pruning

Some of the motives of pruning by farmers as described above are to harvest wood for construction, fuel wood and fodder for livestock. Again few work has been done to quantify the biomass of wood and leaves produced from pruning.

Sabiiti and Cobbina (1992b), based on their study on the use of néré leaves for animal feeding from 7 year old trees, found that néré has a high coppice shoot regrowth potential, in terms of both total numbers of shoots formed and shoot length. Fully established 7 year old *Parkia* trees coppice successfully one week after being cut back and the foliage becomes dense after 3 months. High quality fodder can be repeatedly obtained at 16 weeks and 24 weeks cutting intervals without much change in leaf nutritional quality (Sabiiti and Cobbina, 1992b). However, they have not reported how much fodder could be produced at these cutting intervals for older trees in farmed parklands. In a tree management experiment in a parkland system in Sénégal, Samba (1997) found a production of leaf biomass of 82 kg tree⁻¹ for trees of *Cordyla pinnata*, which was equivalent to 337 kg ha⁻¹. Thus, few work has been reported in the literature on biomass production and use. Quantification of the biomass of leaf and wood produced by pruning is essential for managing trees for either fodder or mulching.

2.4.3. Effect of crown pruning on tree fruit production

The primary traditional role of karité is derived from the oil present in the kernels. It is a very important export commodity and contributes significantly to the generation of revenues to many countries in West Africa. Karité nut was the third export product of Burkina Faso in the 1980's (World Bank, 1989). There is also a new growing interest for this product in the chocolate and cosmetic industries worldwide. The time at which karité begins to produce fruit has been debatable. According to Baumer (1994) karité begins fruit production only after 20 years, with full production at about 40 or 50 years of age. However, Hall *et al.* (1996) reports that fruit production starts after 10 years of age. It seems that the flowers at early stage are sterile. In 1999, fruits were observed on karité trees planted in 1987 by IRBET (Institut de Recherches en Biologie et Ecologie Tropicale) in Saponé 30 km from Ouagadougou, Burkina Faso (West Africa) (pers. obs.). The person in charge of the plantation stated that this was the third year of production, which means planted karité trees can bear fruit at 9 years old.

According to Hall *et al.* (1996) the productivity, both in terms of the quantity of fruit and the quality of the kernels, is marked by its enormous variability. At the level of individual tree, extremes of 0 to 500 kg of fresh fruit per year have been reported under average conditions. However, 15-30 kg fresh fruit per tree per year is more realistic, reaching sometimes 50 kg (Agbahungba & Depommier, 1989). Length of production is debated but one year in three is a commonly accepted estimate. Agbahungba & Depommier (1989) suggested that whilst production can be reduced to a third or a half one year to the next, one year in four or five will see a drop of 90% or more. For instance, Boffa (1995) found nut production four times higher in 1994 than in 1993 in the South of Burkina Faso (West Africa). Boffa (1995) and Schreckenberg (1996) found a correlation between tree size and fruit production regardless of the location either in cultivated or in bush land.

Even though, néré products have only a local use and are only sold in local and regional markets, they have very high demand and generate higher household income than karité products (Lamien *et al.*, 1996; Teklehaimanot, 1997). Néré tree was found starting to produce fruit at 6 years old. The full fruit production is reached at 10 years of age (Hall *et al.*, 1997) and Bonkoungou (1987a) suggests that trees reach maturity at 30-50 years of age. According to Hall *et al.* (1997), fruit production of néré varies from year to year in relation to rainfall. Farmers state that production is higher in fields than in fallows, as a result of protection from fire and silvicultural practices performed on trees in cultivated fields (Ouédraogo, 1994; Ki, 1994; Schreckenberg, 1996; Timmer *et al.*, 1996).

At individual tree scale, production appears very variable (Table 2.1). Estimating the production of an individual tree is difficult, as the pods on one tree are not always harvested at the same time and, because of the value of the pods, there may be thefts (Ki, 1994). Bagnoud *et al.* (1995) suggest that production may vary according to a two years cycle.

Yield (kg)	Country	Reference		
15-20*	Southern Mali	Bagnoud et al. (1995)		
25	Burkina Faso	Kessler (1992)		
25-100	-	Busson (1965)		
39-130	Gambia	Tattersall (1978)		
41.25-125	Burkina Faso	Ki (1994)***		
76	Bassila, Benin	Schreckenberg (1996)		
90-120**	Southern Mali	Bagnoud <i>et al.</i> (1995)		

Table 2.1: Fruit production (kg tree-1 year-1) of Parkia biglobosa.

Source: Hall et al (1997)

* Poor year; ** Good year; *** Using a transformation rate of 5 kg fruit = 1 kg seed (Somé *et al.*, 1990).

Timmer *et al.* (1996) noted that 10-30% of néré are pruned in Burkina Faso with the aim to improve fruit production. Some authors stated that karité doesn't support pruning (Kessler, 1992; Kater *et al.*, 1992; de Saint Sauveur, 1999). However, karité trees have been found pruned by farmers for motives other than increasing fruit yield (Bayala and Lamien, 1995). According to some farmers pruning does neither induce (Burkina Faso) nor reduce fruit production (Mali) (de Saint Sauveur, 1999). Binnekamp (1992) noticed that when fruit production of néré decreases, farmers prune parts of the crown. From this traumatism, reiterated complexes develop. These proleptic reiterations behave like young plants and as a result the pruned tree bears fruit only three years after the pruning (Binnekamp, 1992; Ki, 1994).

Reports in the literature on evaluation of pruning impact on fruit production for other species show that fruit production varies, both with age and pruning intensity. For example, pod production in *Faidherbia albida* has been shown to decline after pruning evolving from 50 to 150 kg tree⁻¹ year⁻¹ for unpruned tree and 10 to 20 kg for pruned trees (Le Houerou, 1980).

Although some farmers claim that crown pruning induces fruit production (Binnekamp, 1992; Ki, 1994; de Saint Sauveur, 1999), there is no report in the literature on the quantity of fruit production achieved as a result of pruning of néré and karité. Thus, there is a need to quantify fruit production from these trees to be able to ascertain induction of fruit productivity affected by pruning.

2.5. Effects of crown pruning on associated crop yield

There are very few data available in the literature on the benefits of tree pruning on crop yield (Kessler, 1992; Yelemou, 1993; Samba, 1997; Lehmann et al., 1998b; 1999; Namirembe, 1999; Droppelmann et al., 2000). Yelemou (1993) evaluated the effects of pruning of neem (Azadirachta indica) on sorghum production in Burkina Faso and concluded that interception of light by trees was the major factor for the reduction of yield even though soil fertility was high. Samba (1997) in Sénégal arrived at similar conclusion in his study under crown pruned trees of Cordyla pinnata. He ascribed increase in crop production to increased quantity of light reaching underneath trees. Three effects of pruning appear to be obvious from previous studies: it allows more light to reach crops underneath and increases temperature. More light appeared to be the beneficial effect of pruning leading to an increase in crop vield (Kessler, 1992). In fact C4 species like cereals are very sensitive to shade. A conscious pruning should aim at obtaining a tree structure that allows either morning or afternoon sunshine to reach the crops under the canopy. On the other hand, high temperature, during very low rainy season, may lead to bad establishment of crop seedlings. The reduction of temperature by unpruned tree canopy has been found to have a positive beneficial effect during low rainv season by Jonsson et al. (1999). Tree pruning can also lead to a reduction in tree water uptake. For example, Lehmann et al. (1998b) found that tree root biomass reduction because of pruning induced a reduction in water uptake by trees, which led to an improvement in associated crop production. However, the extent to which associated crop benefits from the untapped water depends on environmental conditions and tree species. For instance, Namirembe (1999) found that pruned trees of Senna spectabilis, displaying a root dieback and reduction in root length density, continued to depress maize because of insufficient soil water in the system.

2.6. Influence of crown pruning on roots

2.6.1. Characteristics of roots

Roots of plants serve for anchorage, uptake of water and nutrients from the soil, production of cytokinins, gibberellins and other growth regulators and storage of carbohydrates (van Noordwijk et al., 1996; Akinnifesi et al., 1999; Hopmans and Bristow, 2002). For both annual and perennial components of agroforestry systems, roots constitute a substantial proportion of net primary production occurring belowground. This proportion varies with vegetation type, developmental stage, soil conditions and cultural practices. Shoot:root ratios on dry matter basis are typically between 5:1 and 10:1 for annual crops at maximum standing biomass (van Noordwijk, 1993). For perennial plants, root biomass was found ranging from 27% (Leucaena Leucocephala) to 72% (Eucalyptus tereticornis) of the total biomass for trees of five species of 2 years age (Dhyani *et al.*, 1990). The range of this biomass is variable depending on species, environment, management practices, etc. Perennial plant root biomass is essentially constituted of coarse roots with fine roots representing less than 1% of the total biomass of mature trees (Grier et al., 1981; Mortimer, 1992). In spite of that fine roots are capable of providing two-thirds of the annual biomass production (Grier et al., 1981; Ares and Penemann, 1992). This important production is due to the decay of aged fine roots and their replacement by new ones.

In terms of root extension, Rao *et al.* (1993) reported a lateral root extension of 9 m for 4-5-year-old *Senna siemea* trees. In a stand of 9-year-old *Prosopis cineraria, Albizia lebbek, Dalbergia sissoo* roots extended 4-6 m (Singh, 1994). Root extension of 30 m or more have been observed for other tree species, including the tropical genera *Acacia, Adansonia* and *Bombax* (Kessler and Breman, 1991; Stone and Kalisz, 1991). Tomlinson *et al.* (1998) showed that néré tree root extended to at least 10 m from the trunk and can cover an area eight times that of the crown. Jonsson (1995) found large roots of karité and néré 60 m away from the trunk. When mature, trees of these two species have a tap root with length depending on the soil type and tending to disappear as

the trees become aged. The tap roots can even be replaced by holes (Bamba, 1985). When aged the individuals of these two species have many long, superficial and lateral roots. The more difficult the environmental conditions the longer are these lateral roots (Boffa, 1999).

2.6.2. Distribution patterns of fine roots

The information on root distribution of tree species is mostly concentrated on the total root mass. However, it is the finest part of the root systems (i.e. fine roots) that are most dynamic and most actively involved in water and nutrient uptake, hence of great interest in agroforestry (Dhyani *et al.*, 1990; van Noordwijk, 1993; Schroth, 1995; van Noordwijk *et al.*, 1996). Thus, root uptake dynamics is usually related to measured distributions of root-length density and root surface area (Bohm, 1979; van Noordwijk, 1993), even if this ignores the fact that uptake is also controlled by root age and other mechanisms in the rhizosphere (van Noordwijk *et al.*, 1996; Hinsinger, 1998; Hopmans and Bristow, 2002).

Studies done on fine root distribution showed that root mass decreases with distance from the trunk according to Singh (1994) and Tomlinson et al. (1998) while Ares and Penemann (1992) and Jones et al. (1998) did not observe such trend. The reasons of these variable results are the use of different methods (wall profile, core sampling, etc.), the distance within which the assessments have been done and site quality (Ares and Penemann, 1992). Bedemeau and Auclair (1989) found a mean value of 108 g m⁻³ of roots of which 90% were in the upper 50 cm. In Ares and Penemann's (1992) study, fine root density in the stands diminished with greater depth and increasing site quality, so roots were more concentrated in the upper 20 cm (85-90%) in stony soils and soils with a clay horizon. Heilman et al. (1993) found a root density of fine roots of 2.4-6.3 cm cm⁻³ within the layer 0-18 cm, 0.02-0.6 cm cm⁻³ between 1-3.17 m of depth. Singh (1994) found fine root biomass concentrated within the 0-15 cm upper layer for A. lebbek (47%), D. sissoo (35.5%), and within 30-60 cm layer for P. Cineraria (38%). The same author found in the 0-15 cm upper layer 65.2%, 71.4%, 78.7% of total fine roots in the stands of 2x2 m, 4x4 m, 6x6 m plantation of Populus deltoides, respectively. Tomlinson et al. (1998) showed that 60% of the roots of néré tree were present in the upper 20 cm of soil.

To reduce competition of trees with crop for belowground resources, the ideal tree for agroforestry should have a deep root system and little root proliferation near the top of the profile (Schroth, 1995). However, as shown above in many studies, root distribution of most of the trees appear to coincide with the upper soil layers occupied by annual plants (Schroth, 1995; Smith *et al.*, 1999). This property of accumulating maximum fine root in upper soil profile gives the plant an easy access to moisture and nutrients from topsoil while the primary root growing deeper helps in extracting more moisture (Dhyani *et al.*, 1990).

Beside the property to colonise primarily the top layer of soil, trees tend to develop fine roots in microenvironment where there is high level of fertility. Thus trees growing in nutrient-poor environment partition a larger proportion of biomass to fine or absorbing root systems than those growing in nutrient-rich environment (Friend *et al.*, 1990). It can be assumed that species with the ability to accumulate a high concentration of fine roots in the upper layer are likely to induce a high level of competition when associated with annual crops. Root distribution is also influenced by tree density as shown by Singh (1994). This author found that root depth increased significantly with greater spacing, from 54 cm in the stand of 2x2 m plantation to 130 cm in the stand of 6x6 m plantation of *Prosopis cineraria*, *Dalbergia sissoo* and *Albizia lebbek*.

2.6.3. Effects of pruning on roots

Agroforestry technologies are based on the idea that trees can recycle nutrients, which will have leached beyond the reach of crop roots and this is known as the safety-net hypothesis (Schroth, 1995; van Noordwijk *et al.*, 1996). However, as shown in the previous section, the idea of selecting species and provenances according to root-related criteria with deeper roots for agroforestry systems (Schroth, 1995) appears to be rarely met (Smith *et al.*, 1999; Rowe *et al.*, 1999). Only few researchers found separate niches for tree and crop absorptive root systems (Ruhigwa *et al.*, 1992; Singh, 1994; Howard *et al.*, 1997; Rowe *et al.*, 1999, Akinnifesi *et al.*, 1999). A better option is therefore to manipulate tree root systems to maximize benefit and minimize competition (Schroth, 1995; Namirembe, 1999). This implies reducing niche overlap

by disabling tree roots in the crop rooting zone (Namirembe, 1999). One option is to prune tree roots but that is a tedious work and not desirable for carbon sequestration and nutrient cycling (Schroth, 1995; Smith *et al.*, 1999). Another possibility is to manipulate tree crown because, roots do not act as simple pumps, since their activity is regulated by conditions in the aboveground parts of the plant (Jeschke and Hartung, 2000). Water uptake is determined by a combination of water availability in the soil and potential transpiration by the canopy (Hoad *et al.*, 2001).

Pruning has been shown to reduce root biomass by Schroth and Zec (1995a), Jones *et al.* (1998) and Hoad *et al.* (2001). This was ascribed to translocation of carbohydrates from roots to shoots to maintain their growth (Govindarajan *et al.*, 1996; Namirembe, 1999; Hoad *et al.*, 2001). Nevertheless, the impact of pruning is variable and depends on species (Schroth and Lehmann, 1995; Jones *et al.*, 1998; Akinnifesi *et al.*, 1999; Odhiambo *et al.*, 2001), management practices (Govindarajan *et al.*, 1996; Namirembe, 1999) and environmental conditions (Vogt *et al.*, 1998; Vanlauwe *et al.*, 2002). Distribution of plant roots within soil layers is also a dynamic process. Thus, contrary to Jones *et al.* (1998) and Smith *et al.* (1999) who found that tree roots dominated agroforestry plots all the times, in the study of Odhiambo *et al.* (2001), tree roots were only the most numerous about half of the cropping time. In some circumstances, pruning induces no effect on roots and even increases root density (van Noordwijk and Purnomosidhi, 1995). In any case, the reducing effect on well-established trees is transient and roots will recover as crown regains its size (Namirembe, 1999; Odhiambo *et al.*, 2001).

2.7. Mulching practices using pruned material for improved production of agroforestry parkland systems

Mulching is a crop husbandry practice in which organic material is spread over the soil surface to influence the physical, chemical and biological properties of the soil and its micro-climate with the aim of improving the productivity of a site (Muller-Samann and Kotschi, 1994). Thus, key features of mulching are changes of soil physical and chemical properties, weed control and as a consequence improved or sustained crop production.

2.7.1. Mulching effects on soil physical properties and crop yield

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The addition of tree leaves and branches as mulch to soils has been shown to improve site micro-environmental conditions (Budelman, 1989; Schroth et al., 1992) and to increase the productivity of agricultural crops (Duguma et al., 1988; Yamoah and Burleigh, 1990; Rippin et al., 1994; Muller-Samman and Kotschi, 1994). The main reasons of these improvements are due to changes in soil texture and structure, and soil water dynamics. In semi-arid areas mulching with millet straw at the rate of 2000 kg ha⁻¹ has been reported to reduce sand flux by 25-50% during the rainy season and by 67% during the dry season (Buerkert and Lamers, 1999). They also reported that, in mulched plots, between 160 and 200 t ha-1 of soil was deposited as a result of which there was an increase in the finer soil particles, which led to an increase in soil water holding capacity. Mulching was also found to decrease soil bulk density through increased soil organic matter, soil fauna biomass and activity (Mando and Stroosnijder, 1999; Wardle et al., 1999). Even without improvement in soil bulk density, mulch has been reported to improve water infiltration because of runoff reduction, soil protection from high intensity of rainfall, and hence prevention of formation of "surface seals" (Hulugalle et al., 1990; Lal, 1998). All these physical changes reported by previous workers were associated with higher production of crop due to increased availability and efficient use of soil water (Michels et al., 1998; Lal, 1998; Burkert and Lamners, 1999; Buerkert et al., 2000). However, mulching has also been reported to decrease crop production in humid areas depending on the species (Nvakatawa, 1997; Buerkert et al., 2000). In semi-arid areas, however, physical effects of mulch once triggered by soil fauna are more important than chemical effects commonly expected (Kater et al., 1992; Yamoah et al., 1986b; Mando and Stroosnijder, 1999).

2.7.2. Mulching effects on soil chemical properties and crop nutrition

To find technologies that sustain production using low external inputs and soil conservation techniques for arid areas is a challenge for both researchers and extension workers. In this respect, mulching constitutes a promising technology because it improves nutrient cycling in the upper layer of the soils for these areas (Rippin *et al.*, 1994; Yamoah *et al.*, 1986b) (Table 2.2.).

04%	3.17%	2.57%
)0%	73%	85%
<u>;%</u>	58%	46%
.%	26%	77%
1	1%	1% 26%

Table 2.2: Nutrient release from tree leaves in 120 c	lay	15
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Source Yamoah et al, 1986b

According to Yamoah *et al.* (1986a), *Gliricidia sp.* can release all of its N in prunings for crop's use while *Cassia* sp. releases only half of its N in 120 days. Thus, a combination of slow rate decomposition material of *Cassia* sp. and fast rate decomposition material of *Gliricidia* sp. could be better used to improve N and organic matter content in soil. Mulching can lead to an increase of exchangeable calcium, magnesium, potassium, a decrease of acid saturation and an increase of cassava yield as shown by Hulugalle *et al.* (1990). However, not all the quantity of nutrient released is taken up by plants. Even in fertilisation based system, 50% of applied fertiliser N is taken up by the plants, 25% is lost by different mechanisms and 25% remains in soil in more or less stable forms (Azam *et al.*, 1985). Haggar *et al.* (1993) found that only 10% of N released by *Gliricidia* and *Erythrina* mulches was taken up by the associated maize crop.

The potential contribution of mulch becomes important when nutrients are made available to arable crops at the time when the nutrients are most needed (Yamoah *et al.,* 1986a; Palm and Sanchez, 1991). Thus, mulch with large nutrient stores that are released after the food crop is harvested will be of little value to that crop in terms of nutrient supply. This means for a given mulch material, information pertaining not only to nutrient but also the rate of decomposition and release of nutrients is important.

2.7.3. Effects of mulch on weed and crop yield

In the search for socio-economically, and ecologically stable low-external input agricultural production system, it was found that supply of organic matter from mulch can play an important role both for soil fertility and weed control. However, the extent to which weed suppression is achieved depends mostly on the tree species and the rate of decomposition of pruned tree residues. Weed control is more effective when mulch material has a slow rate of decomposition such as the mulch of Cassia sp. as reported by Yamoah et al. (1986b). A reduction of up to 52-90% in weed biomass using tree prunings was reported by Jama et al. (1991) and Rippin et al. (1994). This effect depends also on farming systems and climatic conditions. In semi-arid areas, mulching has been reported to be associated with rehabilitation of degraded vegetation and extensive weed development (Buerkert and Lamers, 1999; Mando et Stroosnijder, 1999). Buerkert and Lamers (1999) found that mulching with millet straw at the rate of 2000 kg ha⁻¹ led to consistently larger weed growth throughout the growing season reaching 167% in 1993 and nine-fold higher in 1994. Despite this, total dry matter of millet at harvest was increased by 108% in 1993 and 283% in 1994 (Buerkert and Lamers, 1999). According to Buerkert et al. (2000) the increasing trend of crop production improvement between 1993 and 1994 shows the cumulative effects of mulch application with time and also that the improvements of soil properties can outweigh weed effects.

2.7.4. Decomposition of mulch material

Decomposition is a complex process governed by decomposers (fauna and microorganisms), physical environmental factors (particularly temperature and moisture) and resource quality (defined here by lignin, nitrogen, condensed and soluble polyphenol concentrations) (Meentemeyer, 1978; Swift *et al.*, 1979; Melillo *et al.*, 1982; Cadisch and Giller, 1997). As decomposition progresses, soluble and particulate materials from litter, organism tissues and products of microbial metabolism are separated from the original resources by leaching, physical fragmentation and animal feeding activities. These products are then transported by wind, water and gravity to soil microhabitats that have different set of conditions regulating decomposition to those of the parent material (Anderson and Ingram, 1993).

2.7.4.1. Factors influencing decomposition

The nutrient content (especially N and P), lignin and polyphenol concentrations of litter strongly influence its rate of decomposition and nutrient release to the soil (Palm and Sanchez, 1990; Szott et al., 1991). There is a general consensus that net N mineralisation occurs if the N concentration is above 2% and immobilisation occurs below that concentration (Palm and Sanchez, 1990, 1991; Fox et al., 1990). Thus according to some authors (Meentemeyer, 1978; Gupta and Singh, 1981; Constantinides and Fownes, 1994, Handavauto et al., 1995), nitrogen predominantly controls litter decay rates followed by lignin (Meentemeyer, 1978). As a consequence, under most circumstances the C:N ratio or the N content alone provides better predictions of mass loss rates than does the lignin: N ratio (Taylor et al., 1989). Nevertheless, Fox et al. (1990) and Palm and Sanchez (1991) found in their studies that N mineralised was not correlated to the N concentration or their lignin concentration. Other researchers (Mellilo et al., 1982; Palm and Sanchez, 1990; Thomas and Asakawa, 1993) reported that lignin concentration of the substrate is an excellent index to use for prediction of the rate of disappearance and weight loss. Similarly, litter which breaks down slowly may have large C:N ratio. P+Ca, lignin + tannin, carbohydrates including cellulose have significant correlation with decomposition rates (Table 2.3). The advantage of using lignin content as a predictor of N release is that it is fairly consistent for a particular species within a region even though it may vary from year to year (Meentemever, 1978).

In general, the greater the N content, the lower the lignin content (Table 2.3). Litter with high carbon content strongly tends to be low in both N and P and high in lignin (Table 2.3). A more complex effect of these elements on N release is the fact that their contents become dynamic along the decomposition process. As lignin content progressively decreases, the degree of lignin control over decomposition rate will decrease, while the control by nutrients or the other chemical fractions will proportionally increase. As decomposition proceeds, the proportion of lignin increases as microbes preferentially metabolise other chemical fractions. Lignin control of mass loss rate becomes stronger through the time. According to Palm and Sanchez (1990), that is the case for non-leguminous plants. These authors found that

Erythrina sp. (1.04% of polyphenol) decomposed twice as fast as *Inga sp.* (3.43%) and *Cajanus sp.* (3.34%).

	N	С	Lignin	Lignin:	Poly-	Sources
				1	phenois	
Leuceana	3.94 (1)		8.1. (2)	1.3 (1)	1.02(1)	1.Palm and Sanchez, 1991
leucocephala						2. Kachaka et al., 1993
11				1.4		Fox <i>et al.</i> , 1990
11				1.9		Kachaka et al., 1993
Desmodim sp	2.37				3.61	Palm and Sanchez, 1991
Rice straw	1.13				0.69	Palm and Sanchez, 1991
Inga edulis	3.18		16.3		3.43	Palm and Sanchez, 1990
Cajanus cajan	3.48		10.2		9.7	Palm and Sanchez, 1991
Erythrina sp	3.52		9.7		1.04	Palm and Sanchez, 1991

Table 2.3: Content of factors influencing decomposition (%)

If lignin:N ratio is a good predictor of decay rate for some classes of litter, the C:N ratio appears to be the best predictor for substrates low in lignin (Melillo *et al.*, 1982; Kachaka *et al.*, 1993; Thomas and Asakawa, 1993). Lignin importance in decomposition process comes from the fact that it is an interfering factor in the enzymatic degradation of cellulose and other carbohydrates, as well as proteins (Melillo *et al.*, 1982). High initial levels of lignin may thus slow decomposition rates. The higher the initial lignin content, the greater the amount of nitrogen "immobilised" per unit of carbon respired. This phenomenon may be the result of the formation of meta-stable nitrogen, "lignin-derivative" complexes (i.e. humus) during decomposition (Melillo *et al.*, 1982). This phenomenon occurs also with polyphenolics (nitrosation) according to Palm and Sanchez (1991) and can lead sometimes to the inhibition of enzyme action (Palm and Sanchez, 1990).

Apart from resource quality, the state and the nature of organic matter play an important role in decomposition process as well. Thus, the younger the organic material, the more rapidly it decomposes. Since the percentage of nitrogen in the plant diminishes with the advance in growth, its rate of decomposition also diminishes (Oglesby and Fownes, 1992; Vanlauwe *et al.*, 2001). Since legumes contain more nitrogen than non-legumes, they decompose more rapidly. Drying of green plants was found to retard their decomposition; the assumption was, that as a result

of drying, soluble hemicellulose changes into less soluble forms (Lehmann *et al.* 1995).

Another category of factors influencing N release is the climatic conditions. According to Stanford *et al.* (1972), soil nitrogen mineralisation rate is influenced profoundly by temperature within the range normally encountered under field conditions. Since mineralisation practically ceases near the freezing point, the temperature of greatest interest in soil biology, generally occur in the range of 0 to 35°C (in temperate conditions). Over a considerable range of temperature above 35°C, ammonification continues but nitrification essentially ceases at 45°C. In mineralisation of soil organic nitrogen, the rate-limiting step is ammonification, and, over much of the range from 0 to 35°C, almost complete conversion of NH₄-N to NO₃ normally occurs in aerated soils. Sundhu and Ambasht (1990) found that relative loss rate was correlated with temperature for root decomposition. A lack of net nitrogen immobilisation has been found in some studies in the tropics, even for non-leguminous leaves (Vogt *et al.*, 1986; Palm and Sanchez, 1990; Thomas and Asakawa, 1993).

Finally decomposition is under the control of decomposers and agricultural practices as the latter influence soil fauna community (Tian *et al.*, 1997; Wardle and Lavelle, 1997; Wardle *et al.*, 1999).

2.7.4.2. Probable reasons for conflicting results in organic matter decomposition process

The workers on mulching can be roughly grouped into two. One group of authors using green leaf material of tropical legumes, have found that neither the content of nitrogen nor lignin:N ratio were good indicators of decomposition or N release. Nevertheless, they found a significant negative exponential relationship between polyphenols and N release (Palm and Sanchez, 1990, 1991). Another group (Fox *et al.*, 1990; Thomas and Asakawa, 1993) reported that percentage of nitrogen, lignin:N or polyphenol:N ratios were not particularly well correlated with the amount of N released from the tropical legumes but rather the (lignin+polyphenol):N ratio was a better predictor of N release. Those differences come from the use of different types

of mulch: legumes Vs non-legumes; perennial Vs annual; litter Vs green manure, young material Vs mature material, temperate Vs tropical. Differences can also come from the limitation in the current methodology used for estimated polyphenol, which extracts only some 30-95% of the total polyphenol in plant tissue (Swain, 1979; Thomas and Asakawa, 1993). Another problem with polyphenol analysis is that the tannic acid used as a reference standard is a mixture of polyphenols and varies from sample to sample (Mcleod, 1974; Fox *et al.*, 1990).

2.7.4.3. Decomposition models

In modelling decomposition phenomena, expressions are desired that are realistic in terms of both mathematical and biological behaviour (Wieder and Lang, 1982). Especially, the mathematical expressions should meet the following requirements: the proportion of initial mass remaining should change as a function of time, i.e., X = f(t); the expression should be monotonically decreasing and continuous; the expression should be bounded by X = 1 and X = 0; the absolute decomposition rate should progressively decline; and the relative decay rate should be a constant or tend toward a constant in the limit. Of all the types of model used by workers (linear, exponential, quadratic, power), only exponential (3 variants) models meet all those requirements, whereas the linear, quadratic and power models each fail to meet at least one of the requirements. The most realistic, in terms of both mathematical and biological behaviour, are the exponential models (double exponential model).

2.8. Conclusions

Analysis of the literature reviewed influenced the form and the scope of the present study in a number of ways. It appears that pruning has not been systematically studied in the Sahel zone showing the need to gather information on this technique based on local knowledge to support extension work and the sustainability of the system. According Timmer *et al.* (1996) farmers in Burkina Faso apply six methods of pruning but for practical reasons, these methods were grouped into two categories (partial and total pruning). Complementarity of the major components of the system in terms of resources sharing appeared to be a condition of the sustainability of the system. The two tree species of the present study being associated with annual crops and based on the factors involved in tree-crop-soil interactions, the research was orientated towards assessing the impact of pruning on above- and belowground interactions between the two components of the system. Fruit and crop yields are the major productive outputs and these are largely influenced by the capture and use of the limiting resources (light, water and nutrients). Recycling of the biomass from pruning is also an important factor. For all these reasons, the present study focused on light, water and nutrients capture and use in the system as well as on yields of the major products of the system.

CHAPTER III

THE EFFECTS OF CROWN PRUNING OF VITELLARIA PARADOXA AND PARKIA BIGLOBOSA ON THE PERFORMANCE OF THE PRUNED TREES AND ASSOCIATED CROPS

3.1. Introduction

In sub-Saharan Africa, farmers grow annual crops in agroforestry parkland systems where scattered trees form an open permanent upperstorey (Nair, 1993). The trees are selected wild multipurpose trees that are left standing after the original savannah woodland has been cleared (Gijsbers *et al.*, 1994). These trees are retained on farmlands primarily because of the benefits derived from their fruits. Karité nuts are an important local and export product, which are processed into butter for cooking, cosmetics, medicine and as a cocoa butter replacement (Hall *et al.*, 1996; Boffa *et al.*, 2000). The seeds of néré are fermented to produce a condiment used throughout West Africa in the preparation of local dishes (Tomlinson *et al.*, 1995; Hall *et al.*, 1997). It is sometimes described as a meat or cheese substitute because of its savoury taste and high protein content (Booth and Wickens, 1988).

Apart from the products obtained from parkland species, they play an important ecological role in terms of erosion control through reduction of runoff and deposit of finer particles, and soil fertility improvement through litter fall and decay of roots (Tomlinson *et al.*, 1995; Samba, 1997; Jonsson *et al.*, 1999). This ecological impact is essential in maintaining favourable conditions for the production of associated crops even though the immediate effects are not always beneficial to crops underneath.

The major crops grown in association with néré and karité are pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) (Boffa *et al.*, 2000). Recent studies on the effect of néré and karité on sorghum and millet production showed that excessive shading substantially reduced cereal crop production under the crowns of these trees compared with crops in the open (Kessler, 1992; Kater *et al.*, 1992, Wilson *et al.*, 1998; Boffa *et al.*, 2000). In contrast, Jonsson *et al.* (1999), during a year of exceptionally high rainfall, found no significant difference in millet yield

between crop in the shade and in the open. However, under normal low rainfall conditions in the savannah regions of West Africa, Maïga (1987) reported a reduction in millet production of 35% under karité in Burkina Faso. These negative effects may be due to either shading or water use by the tree, which are the main effects of pruning as both of them are related to crown size.

Crown pruning may be one way to reduce the shading effect of néré and karité. Mann and Saxena (1980) reported a six fold increase in mung bean when it was grown under 12-year-old pruned Acacia tortilis compared with unpruned Acacia tortilis. Kessler (1992) found that reduced shading as a result of pruning néré led to better sorghum crop yield under the tree crown. Crown pruning has been reported to have an effect on root distribution of other tree species and to substantially reduce the belowground competitive effect of trees on associated crops (Jones et al., 1998). However, crown pruning may also reduce crop production as a result of increased crop temperature. Mobbs et al. (1998) reported that parkland trees improve millet production due to reduction in crop temperature that may be supra-optimal without trees. Hence, crown pruning may enhance crop production at least in the short term due the net effects of increased light transmission to the understorey crop, reduced water and nutrient use by trees and increased crop temperature as a result of reduced crown area. The effects of these may decrease with increased distance from the base of crown-pruned trees. Therefore the present research was designed and conducted to study the effect of crown pruning of nere and karite on the production of associated crops.

3.2. Material and methods

3.2.1. Experimental design and layout

Measurements of crop performance, light, water and soil properties were made under three randomly selected trees per pruning treatment (half-pruned, totalpruned and unpruned) and tree species, i.e. a total of 18 trees from both species were sampled. The study site and the trees used in this study are described in Chapter 1. The area around each of the 18 sampled trees was subdivided into four concentric zones, which were laid out before the trees were pruned:

Zone A - from the trunk of each tree up to 2 m away; Zone B - from 2 m from the tree trunk to half of the radius of the tree crown; Zone C - from half of the radius of the tree crown up to the edge of the crown; Zone D - from the edge of the tree crown up to 2 m away; and A control plot for crop only treatment for each sample tree (a total of 18 control plots) - an area of 4 x 4 m situated at least 40 m away from the edge of the crown of the sample tree but unshaded by any of the surrounding trees at any time of the day throughout the cropping season.

Even though cardinal direction does not usually result in significant variation of the overall production, it was better to avoid its occasional occurrence. For this reason concentric zones were preferred to directional transects. This kind of design can reduce directional biases related to leaf and rain fall, and micro-variability of soil fertility (Boffa, 1999). The fact that this research was carried out directly in farmers fields rendered more difficult any attempt to use empirical approaches that control component effect because the system is inherently opened to the influences of many sources (humans, animals, etc.).

Observations on tree phenological events were made on all the 60 sample trees.

3.2.2. Assessment of biomass from pruning and recovery of crown size

3.2.2.1. Assessment of leaf and wood biomass from pruning

Leaf and wood biomass production by pruning was investigated using data from the 100% pruned trees of karité and néré species. From each 100% pruned tree, all the leaves and wood were collected and their fresh weight was measured separately (Plate 1.1). For wood power saw was used to cut the branches into small pieces. A

small sample was taken from the pruned material (leaf and wood as separate samples) of each tree and this was weighed and dried under shade for one month. Their dry weight was measured. The dry weight of the samples was used to extrapolate the total weight of biomass per tree. A sub-sample from each dried sample of leaves was kept for chemical analysis.

3.2.2.2. Assessment of recovery of crown size

Crown diameter was assessed at each year's cropping season. The measurement of crown diameter for the 2000 cropping season, that is, one year after pruning, was made in June 2000. For 2001 cropping season, that is, two years after pruning, crown diameter was measured in July 2001. For 2002 cropping season, that is, three years after pruning, crown diameter was measured in May 2002. For the estimation of crown diameter of the 20 total-pruned trees (both karité and néré) - maximum and minimum crown length on each tree at north, south, east and west directions were recorded and later combined to derive the average crown diameter.

3.2.3. Phenological studies

Observations of phenological changes on all the 30 sample trees of each species were recorded at fortnightly intervals from April 2000 to December 2001: leafing, flowering and fruiting events. Unfortunately same dates were missed. The same ordinal scales as described by Ouédraogo (1995a) were used to describe the different phenology events.

3.2.3.1. Leafing

The following scales were used for leafing: Le1 = swelling buds (no leaf development); Le2 = leaf buds open (10 to 50% of these organs in each individual); Le3 = leaves are open (over 50% of these organs in each individual); Le4 = 10 to 50% of the leaves changing colour from green to yellow or dried; Le5 = over 50% of the leaves are yellow or dried; Le6 = leafless tree (bearing no bud).
3.2.3.2. Flowering

The following scales were used for flowering: Fl1 = floral buds only; Fl2 = 10 to 50% opened flowers; Fl3 = over 50% opened flowers; Fl4 = 10 to 50% withered flowers; Fl5 = over 50% withered flowers:

3.2.3.3. Fruiting

The following scales were used for fruiting:

Fr1 = fruit setting;

Fr2 = 10 to 50% normal sized green fruits;

Fr3 = over 50% normal sized green fruits;

Fr4 = 10 to 50% matured fruits (harvested or fallen for karité);

Fr5 = over 50% matured fruits (harvested or fallen for karité).

The data were summarized into frequencies in respective phenophases. Peak flowering and peak fruiting refer to periods on which a maximum number of individuals of each species and each pruning treatment were active.

Besides these qualitative observations, fruit production was estimated using two methods: Random Branch Sampling method (RBS) and Direct Harvest method (DH). Fruit assessment was done every year in May-June for néré and June to August for karité for the direct harvest method in 1999, 2000 and 2001. The Jessen method was applied at the same periods as for direct harvest method but only in 1999 and 2000.

3.2.3.3.1. Random branch sampling (RBS) method

In the present study, Jessen (1955) method of Random Branch Sampling (RBS) was tested to determine fruit yield. In this method, the starting point is the first forking at the trunk. If there are two branches at the first fork, they are numbered as Branch 1 and Branch 2. One of the two branches is selected on the basis of random numbers. A similar fashion is repeated until a terminal branch segment is reached (Figure 3.1). The fruits are then counted in this branch and this process is repeated five times for each main branch beginning at the second level of ramification. The estimated total number of fruits from each branch is determined by the following formula:

Number of fruits / Probability of branch



Figure 3.1: Branching system of tree and the selection probabilities at each fork (Adopted from: Jessen, 1955)

- underlined figures are branch numbers at each fork

- arrows are indicating selection probabilities at each fork

- figure in box is the number of fruits on that branch

As can be seen from figure 3.1, selection probabilities (which are equal) at each forking are 0.5, 0.5 and 0.33 and the selected branch has 5 fruits. The estimated total fruit number for this branch is:

$$\frac{5}{0.5 \times 0.5 \times 0.33} = 61 \text{ fruits}$$
(3.2)

The estimates from the 5 branches are averaged to provide the final estimate. According to Jessen (1955) an average of 5 replicates was sufficient to estimate the

(3.1)

number of fruits of citrus trees. During the first year, i.e. 1999, only 5 branches were selected in néré as well as karité. The outcome of the first year results suggested that an increase in the number of replicates for the huge canopies of karité and néré might bring some improvements. Thus, 15 replicates were taken for each tree during the second year.

3.2.3.3.2. Direct harvest (DH) methods

For the first year, counting was made on 100% pruned karité trees (10 trees). After pruning, all the fruits of karité trees were collected and counted (Plate 3.2). For néré species in the first year the trees were pruned after the fruits were harvested. Thus, there was an opportunity to weigh all the fruit production from each néré tree. A sample was taken from the fruit harvested from each tree that was weighed and the number of fruits in the weighed sample was counted. The number obtained from this counting was used to extrapolate the number of fruits per tree. Thus, for néré trees there were more data than for karité but less than 30 because of theft of fruit from some trees (totally or partially). For the subsequent years, contracts were made with the farmers who owned the trees to harvest and store all the fruits produced on each sample tree. Thereafter, a technician weighed the fruit production separately for each sample tree.

3.2.4. Assessment of crops yield

Pearl millet (*Pennisetum glaucum* L.) with about 130-day duration and *Sorghum bicolor* (L.) Moench with about 105-day were used for the study because they are the common crops grown in Saponé. Millet was grown and assessed over two years (1999-2000) and sorghum only for one year (2001). During the three cropping years, millet and sorghum were sown in the second week of June at the spacing of 0.8 x 0.4 m under the 18 trees studied and in the crop only control plot by the farmers who owned the trees. All crop plants in each concentric zone and the control plot were assessed at harvest (130 and 105 days after planting for millet and sorghum, respectively). Crop parameters measured were: (1) total dry matter and (2) grain yield per unit area.



Plate 3.1: Apparatus for light and transpiration measurement

3.2.5. Measurement of environmental factors

Light transmission and transpiration by trees, and soil properties were measured only under 18 sample trees similarly to crop production. These measurements began after total-pruned trees had a chance to re-grow for two months.

3.2.5.1. Light interception and transmission

Quantum sensors, type DRP-1B (Didcot Instrument Co. Ltd, UK), were used for the measurement of photosynthetically active radiation or PAR (Plate 3.1). The measurements were made at one minute intervals and 10-minute mean values stored on a DL2e data logger (Delta-T Devices Ltd, UK). The measurement of PAR under each tree of the 18 selected sample trees were made at three random positions, in the first three concentric zones (A, B and C) and a fourth sensor was positioned in an area outside the influence of the surrounding trees as a control. Due to shortage of PAR sensors no measurement was made in Zone D. Subdividing the area into 16 smaller sections around each tree and selecting one section by means of random numbers determined the random position of a sensor in each concentric zone. The measurement under each tree lasted for 48 hours. After two days of monitoring, the equipment was moved to another tree. This was continued until one set of three trees, one from each treatment, was measured for one tree species. Then, the equipment was shifted to the other species to measure one set of three trees, one from each treatment. The measurement of PAR under all 18 trees was carried out twice. The first measurement was done between 1st August and 21st September 1999 when millet was grown, and the second between 6th June and 4th September in 2001 when sorghum was grown.

3.2.5.2. Transpiration

Tree transpiration rate, which is an expression of water use by the tree, was estimated from sap velocity measured using Thermal Dissipation Probes (TDP) type SV1 (Delta-T Devices Ltd, UK) (Plate 3.1). Sap velocity data was collected at the same time as PAR measurement. Measurements were made every 1-minute and 10-minute mean values stored on a DL2e data logger (Delta-T Devices Ltd, UK). Data was collected on 18 sample trees. On each tree, three sets of probes were used and these were installed at 120 degree intervals around the stem at 1.5 m above ground. Each probe consisted of a pair of thermocouple needles of 1.1 mm diameter, each of which was inserted 8 cm into the sapwood of the tree bole with 4 cm vertical distance between them (Granier, 1987). The probe needles measure the temperature difference (dT) between the heated needle above and the sapwood ambient temperature measured by the reference needle below. The dT variable and the maximum dTm at zero flow provide a direct and calibrated conversion to sap velocity (Granier, 1987). Each TDP set on the tree stem was insulated against solar radiation, wind and rain by covering it with aluminium foil (Plate 3.1). The measurement on each tree lasted for 48 hours before the equipment was moved along with the other instruments (the PAR sensors and the data logger) to another tree. The mean sap flux density *u* along a radius (m s⁻¹) was calculated using the following equations established by Granier (1985):

$$K = 0.0206u^{0.8124} \tag{3.3}$$

in which

 $K = (T_{M} - T) / (T - T_{-})$ (3.4)

is a dimensionless value depends on T: T_M , the temperature of the heated probe, obtained when u = 0; T, the temperature of the heated probe when u>0; and T_{∞} , the reference temperature of non-heated probe.

As both thermocouples connected in opposition give the temperature difference between the two probes directly, we can use another expression of K:

$$K = (dTm - dT)/dT$$
(3.5)

where dTm and dT are the temperature differences between the two probes, for no flow and positive xylem flow (u>0) conditions, respectively. Solving for u and from (3.6);

$u = 1119 \times 10^{-6} K^{1.231}$

(3.6)

Total sap flow (cm³ s⁻¹) was calculated as:

$$\mathbf{F} = u\mathbf{S}_{\mathbf{A}} \tag{3.7}$$

where S_A is the cross-sectional area of the sapwood at the heating probe (cm²). Mean sapwood cross sectional area per tree was obtained by taking wood cores with an increment borer at two opposite positions in the trunk of each sample tree.

Sap velocities were adjusted to account for natural thermal flux in the Sahel region of Africa, which was estimated to cause an overestimation of transpiration rate by average of about 120% (Douglas and Munro, 1999). Douglas and his colleagues made this estimation in the same region and using similar type SV1 sap flow gauges as in the present experiment. Then transpiration rate per tree was calculated from the adjusted sap velocity and sapwood cross sectional area of each tree.

3.2.5.3. Soil physical and chemical properties

3.2.5.3.1. Soil physical properties

In December 2000, two undisturbed soil samples of 100 cm³ were taken from the 0-5 cm horizon of each concentric zone as well as from the control plot to determine soil bulk density and porosity. They were oven-dried at 105°C for 24 hours to obtain their dry weight, from which bulk density was determined. Soil porosity was calculated using the following formula:

Porosity (%) = $(1-(d_b/d_p))^*100$ (3.8)

Where d_b is the dry bulk density and d_p is soil particle density, which was considered to equal 2.6 g cm⁻³ (Carter and Ball, 1993)

3.2.5.3.2. Soil chemical properties

Soil samples under trees were taken at two points in each concentric zone. Each soil sample was taken in the upper 0-10 cm layer. The two samples from each concentric

zone were bulked and mixed thoroughly to make a total of four samples per tree and a total of 72 for the 18 trees for the two species. The samples were air dried for chemical analyses. Soil organic carbon was determined using potassium di-chromate, acid sulphuric and Mohr's salt (Anderson and Ingram, 1993). Total nitrogen was analysed using a Kjeldahl digestion. For total phosphorus and total potassium the soil was mineralised using sulphuric acid and determined by colorimetry and flame photometry, respectively. Available phosphorus was extracted using ammonium molybdate and ascorbic acid and determined by colorimetry whereas available potassium was extracted using ammonium acetate at pH 7 and determined by flame photometry (Walinga *et al.* 1989).

3.2.6. Data analysis

Data were analysed using Minitab Release 12 Statistical Package. In order to avoid a further use of DH method in the estimation of fruit production in subsequent years, fruit data were subjected to regression analysis at 5% significance level. Allometric relationships were established between tree parameters (tree height, crown height, tree diameter, crown diameter, crown area, crown volume) and fruit numbers directly counted by Direct Harvest (DH) method as well as estimated using Random Branch Sampling (RBS) method developed by Jessen (1955). Since the DH method is the most accurate, comparison was also made between the values estimated by RBS method and DH method to test the suitability of RBS method.

The difference between treatments in all the above parameters including crop and tree performance, soil properties, transmitted light and transpiration was analysed using ANOVA General Linear Model (GLM). Crop yield data were analysed as a multifactorial design with three factors (species, pruning and zone) and including all possible two-way interactions between these factors and the three-way interaction (Appendix 1). Regression and correlation analyses were also used to establish relationships between crop performance and the environmental parameters.

3.3. Results

3.3.1. Biomass from pruning and recovery of crown size

3.3.1.1. Leaf and wood biomass from pruning

Karité produced less dry matter of leaf biomass (68.2±4.9 kg tree⁻¹) than néré (138.6±22.9 kg tree⁻¹). Assuming a density of 15 trees ha⁻¹ and taking into account the diameter of trees pruned and the density of the two species, leaf biomass per tree was equivalent to 275 kg ha⁻¹ and 124 kg ha⁻¹ for karité and néré, respectively. Allometric relationships between leaves dry matter and tree dimension parameters were explored using regression analysis. Karité leaves dry matter did not show significant relationship with any of tree dimension parameters (Equation 3.9) whereas néré dry matter was significantly correlated to diameter at breast height (DBH) (Equation 3.10).

Leaves dry matter of karité =
$$87.5 - 2.25^*$$
(Crown height) (3.9)
[$r^2 = 9\%$; P >0.05]

Leaves dry matter of néré =
$$-81.8 + 2.5^{*}(DBH)$$
 (3.10)
[$r^{2} = 52\%$; P <0.05]

Similar to leaf biomass, néré tree produced more wood than karité with 1915.1±334.9 and 433.0±74.5 kg dry matter tree⁻¹), corresponding to respectively to 1687 kg and 1769 kg ha⁻¹ dry wood. The most significant regressions between wood biomass data and tree dimension parameters showed that karité wood biomass had strong relation with tree diameter at breast height while néré wood biomass was strongly related to crown diameter (Equations 3.11, 3.12).

Wood dry matter of karité =
$$29.2 + 0.032^{*}(DBH)$$
 (3.11)
[$r^{2} = 81\%$; P < 0.01]

Wood dry matter of néré = $15.7 + 0.003^{*}$ (crown diameter) (3.12) [$r^{2} = 74^{\circ}$; P < 0.01]

3.3.1.2. Recovery of crown size

The crowns of total-pruned trees of karité recovered at the rate of 1 m and néré by 1.6 m per year in diameter (Table 3.1). The rate of crown size recovery appeared to decline with time for both species.

Table 3.1. Recovery of crown size in total-pruned trees of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso.

Species	Karité			Néré		
Year	2000	2001	2002	2000	2001	2002
Crown diameter (m±SE)	4.7±0.6	5.8±0.5	6.3±0.3	13.8±1.0	15.7±1.3	16.3±0.7

3.3.2. Tree phenology

3.3.2.1. Phenology patterns

Figure 3.2. shows that the maximum leaf fall (Le4) for karité took place between the second half of October to the first half of March in 2000. The maximum of leaf flashing (Le3) started during the second half of May in 2000 and 2001. Unpruned and half-pruned trees of both species showed similar patterns in leafing. Leaves tended to persist on new shoots of total-pruned trees during leaf fall period.

Maximum leaf fall (Le4) lasted for three months starting in the second half of December 2000 for both unpruned and half-pruned néré (Figure 3.3). For total pruned trees however it lasted only for two months. In all cases, maximum leaf flushing (Le3) took place toward the end of May (Figure 3.3).



Figure 3.2: Leafing pattern of differentially pruned karité (*Vitellaria paradoxa*) trees in a parkland agroforestry system in Saponé, Burkina Faso.

Unpruned





Karité flowering started in November with an asynchrony of two weeks for totalpruned trees compared with both unpruned and half-pruned trees (Figure 3.4). Fruiting began in January for unpruned and half-pruned trees with again a discrepancy for total pruned trees. In both cases fruiting lasted up to the end of August (Figure 3.5). Néré flowering started in December for unpruned and half-pruned trees and in January for total pruned trees (Figure 3.4). The fruiting lasted from February to May regardless of pruning intensity (Figure 3.5).



Figure 3.4: Pattern of flowering of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso.



Figure 3.5: Pattern of fruiting of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso.

3.3.2.2. Tree fruit production

3.3.2.2.1. Effects of pruning on fruit production of karité and néré

Data of two years fruit production measured by Random Branch Sampling (RBS) and Direct Harvest (DH) are given in table 3.2. One year after pruning only one tree of total-pruned néré produced fruit while none of the total-pruned trees of karité produced fruit (Table 3.3). However, two years after pruning, 70% of total-pruned trees of néré and 30% of total-pruned trees of karité produced fruit (Plate 3.2). There was no significant difference in fruit production between unpruned and half-pruned trees of both karité and néré. However, total-pruned trees of néré produced only about 4% of fruit produced by both unpruned and half-pruned trees of néré, one year after pruning. In the second year, however, fruit production in total-pruned trees of néré increased five-fold more than the first year but it was still only about 10% of fruit production in both unpruned and half-pruned trees of néré. In the case of total-pruned karité, fruit production was only about 4% of fruit production in both unpruned and half-pruned trees of karité, two years after pruning (Plate 3.2).

Table 3.2: Effect of pruning on fruit production of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (kg \pm SE tree⁻¹).

	Pruni	ng intensities	Pruning intensities of néré			
Year	0%pruned	50%pruned	100%pruned	0%pruned	50%pruned	100%pruned
2000	$43.8 \pm 7.4a$	51.3±5.9a	$0.0 \pm 0.0 b$	53.4±14.5a	$68.1 \pm 12.7a$	0.2±0.2b
2001	15.0±2.6a	15.6±2.2a	0.5±0.3b	70.2±9.4a	67.8±10.2a	7.6±2.2b

Data on the same rows with the same letter are not statistically different at P<0.05

3.3.2.2.2. Comparative study of Random Branch Sampling (RBS) and Direct Harvest (DH) methods for fruit production estimation

Relationships were established between tree parameters and fruit numbers counted by RBS method using regression analysis. Although significant relations were established with data of 2000 for karité (Equations 3.13, 3.14), and with data of 1999 for néré (Equation 3.15), the equations don't explain an important part of the variability in fruit production data (Equations 3.13, 3.14, 3.15) as shown by the low r² values.

Estimated number = $141119 - 53526^{*}(trunk height)$ (3.13) [$r^{2} = 34\%$; P < 0.01]

Estimated number = $192185 + 2023^{*}(height) - 54457^{*}(trunk height)$ - $1025^{*}(DBH) - 1755^{*}(crown diameter)$ (3.14) $[r^{2} = 46\%; P < 0.05]$

Estimated number = $78053 - 2342^{*}(\text{height}) - 13147^{*}(\text{trunk height})$ (3.15) [$r^{2} = 23\%$; P < 0.05]



Plate 3.2: Karité fruit in a parkland system in Saponé, Burkina Faso



Table 3.3: Average fruit number estimated by RBS method and by DH methods for karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso.

			Fruit estim	ation methods		
		RBS		DH		
		1999	2000	1999	2000	
Karité	Average	53850	19684	2463 (20.0)	4642 (47.6)	
	Max	437313	189551	5770 (46.7)	18511 (93.0)	
	Min	3420	529	127 (1.0)	437 (4.4)	
Néré	Average	13319	31944	5584 (70.1)	2943 (61.0)	
A. 65 F	Max	78497	157681	10519 (144.0)	10253 (130.0)	
	Min	691	9689	1800 (25.0)	1105 (15.0)	

NB: () = weight kg tree⁻¹

Relationships between tree parameters and fruit numbers estimated by DH method were also established. Although the equation for 1999 of karité fruit production showed a high value of r², the relationship was not significant (Equation 3.16) whereas it was significant for 2000 data (Equation 3.17). The data of two years of néré fruit production did not show any significant relations with tree parameters.

Direct harvest number = -
$$1671 + 651^{*}$$
(height) + 345^{*} (trunk height) +
 110^{*} (DBH) - 850^{*} (crown diameter) (3.16)
 $[r^{2} = 71\%; P > 0.05]$

Direct harvest number = $-5927 + 1108^*$ (crown diameter) (3.17) [$r^2 = 32\%$; P < 0.01]

The suitability of RBS method for fruit yield estimation was tested by regressing the data obtained using this method against those obtained with DH method. No significant relation was found for both species and during the two seasons of monitoring.

3.3.3. Crop performance

3.3.3.1. Millet performance

Millet total dry matter production and grain yield are given in Figures 3.6, 3.7 and 3.8, according to tree species and pruning treatments and according to pruning treatments and tree influence zones, respectively (Plate 3.3).

There was significant difference between tree species in both grain yield (P<0.001) and dry matter production (P<0.001) (Figure 3.6). The highest grain yield and total dry matter production were achieved under karité (466±55 kg ha⁻¹ year⁻¹ and 1533±134 kg ha⁻¹ year⁻¹, respectively).

Pruning had no significant effect on both millet grain yield and dry matter production under karité (Figure 3.6) whereas it had significant effect on both millet grain yield (P<0.001) and dry matter production under néré (P<0.001). The highest values were obtained under total-pruned néré trees (507±49 kg ha⁻¹ year⁻¹ and 2033±236 kg ha⁻¹ year⁻¹ for grain yield and dry matter, respectively). There was, however, no significant difference between unpruned, half-pruned and the open (control) in either dry matter production or grain yield under néré.

There was significant interaction between species and pruning for total dry matter (P<0.01) with total-pruned néré giving the highest value (2276 ± 405 kg ha⁻¹ year⁻¹).

There was significant difference between millet crops in the four tree influence zones and those in the open in dry matter production (P<0.001) with Zone B under total-pruned trees giving the greatest biomass under karité (2320±388 kg ha⁻¹ year⁻¹). There was, however, no significant difference between crops in the four tree influence zones and those in the open in millet grain yield under karité (Figures 3.7). No significant difference was found between zones under néré (Figure 3.8).

Plate 3.3: Millet development under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland system in Saponé, Burkina Faso





(c) Total-pruned karité (c) Total-pruned néré



Figure 3.6: Aboveground dry matter production and grain yield of pearl millet under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 1999 and 2000 kg \pm SE ha⁻¹).



Figure 3.7: Aboveground dry matter production and grain yield of pearl millet in relation to tree pruning intensity and distance from the trunk under karité (*Vitellaria paradoxa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 1999 and 2000 kg \pm SE ha⁻¹).



Figure 3.8: Aboveground dry matter production and grain yield of pearl millet in relation to tree pruning intensity and distance from the trunk under néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 1999 and 2000 kg \pm SE ha⁻¹).

3.3.3.2. Sorghum performance

A significant difference was found between tree species in grain yield (P<0.05) but not in dry matter production (Figure 3.9, Plate 3.4). The highest grain yield and total dry matter production were achieved under karité (810±125 kg ha⁻¹ year⁻¹ and 3659±647 kg ha⁻¹ year⁻¹, respectively).

Pruning induced significant difference in both sorghum grain yield (P<0.05) and dry matter production under karité (P<0.05). The highest values were obtained under

total-pruned trees (grain yield 1092±290 kg ha⁻¹ year⁻¹ and dry matter 5218±1715 kg ha⁻¹ year⁻¹). Under néré no significant difference was found between pruning treatments.

Zone B was significantly higher than the rest of the influence zones (P<0.05) both in sorghum grain yield and total dry matter production under karité (Figure 3.10). This zone produced a grain yield of 1568 ± 290 kg ha⁻¹ year⁻¹ and dry matter of 7171 ± 1628 kg ha⁻¹ year⁻¹ under karité. It is interesting to note that whilst there was no significant difference between zones A, C, D and the control, zone B yields increased significantly with increased intensity of pruning. Under néré, zones A, B and the control zone gave the highest productions and these were significantly greater than the productions registered in zones C and D (Figure 3.11).



Figure 3.9: Aboveground dry matter production and grain yield of sorghum under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 2001 kg ± SE ha-1).



Figure 3.10: Aboveground dry matter production and grain yield of sorghum in relation to tree pruning intensity and distance from the trunk under karité (*Vitellaria paradoxa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 2001 kg \pm SE ha⁻¹).



Figure 3.11: Aboveground dry matter production and grain yield of sorghum in relation to tree pruning intensity and distance from the trunk under néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso (mean of 2001 kg±SE ha⁻¹).

Plate 3.4: Sorghum development under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland system in Saponé, Burkina Faso







3.3.4. Environmental factors

3.3.4.1. Light transmission and its relationship with crop performance

Mean PAR reaching the soil surface in the open (control) was $79.8\pm2.9 \text{ mol m}^{-2} \text{ day}^{-1}$ during the cropping season of 1999. The amount of PAR transmitted under the crowns of unpruned karité and néré were 36.2 ± 6.1 and $31.3\pm8.1 \text{ mol m}^{-2} \text{ day}^{-1}$, respectively. Thus, PAR was reduced to 47% (95% C.I. for difference = 40.3 ± 15.2) and 38% (95% C.I. for difference = 50.9 ± 20.2) of the incident PAR under karité and néré, respectively. Under half-pruned karité and néré PAR was reduced to 37% (95% C.I. for difference = 47.9 ± 15.7) and 50% (95% C.I. for difference = 41.3 ± 15.1) of the incident PAR, respectively, whereas under total-pruned karité and néré it was reduced to 70% (95% C.I. for difference = 22.8 ± 10.1) and 62% (95% C.I. for difference = 31.8 ± 24.1) of the incident PAR, respectively.

There was a consistent pattern of PAR increase from the base of trees to the outside. Under Zone A, the amount of PAR received was only 29% (95% C.I. for difference = 56.7 ± 10.9) of the incident PAR whereas under Zone B it was 52% (95% C.I. for difference = 38.3 ± 9.1) and Zone C 70% (95% C.I. for difference = 24.3 ± 9.3) of the incident PAR.

Figure 3.12 shows the patterns of light intensity, grain yield and dry matter production of pearl millet at the three tree influence zones and the controls. With the exception of Zone A and half-pruned néré, there was a consistent pattern of millet performance and light intensity. Millet performance decreased as light intensity increased from Zone B to outside crown.



Figure 3.12. Pattern of pearl millet performance in relation to light intensity under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso

During the rainy season of 2001, mean PAR reaching the soil surface in the open (control) was $66.7\pm8.0 \text{ mol m}^{-2} \text{ day}^{-1}$. The amount of PAR transmitted under the crowns of unpruned karité and néré were 34.2 ± 6.8 and $19.8\pm4.7 \text{ mol m}^{-2} \text{ day}^{-1}$, respectively. Thus, PAR was reduced to 51% (95% C.I. for difference = 39.9 ± 14.9) and 30% (95% C.I. for difference = 39.5 ± 7.1) of the incident PAR under karité and néré, respectively. Under half-pruned karité and néré PAR was reduced to 45.61% (95% C.I. for difference = 20.7 ± 14.9) and 48.2% (95% C.I. for difference = 21.9 ± 7.1) of the incident PAR, respectively, whereas under total-pruned karité and néré it was reduced to 80.1% (95% C.I. for difference = 28.2 ± 15.3) and 62.5% (95% C.I. for difference = 27.2 ± 7.1) of the incident PAR, respectively.

There was again a consistent pattern of PAR increase from the base of trees to the outside. Under Zone A, the amount of PAR received was 35.8% (95% C.I. for difference = 42.8 ± 7.6) of the incident PAR whereas under Zone B it was 48.2% (95% C.I. for difference = 34.6 ± 7.7) and Zone C 85.2% (95% C.I. for difference = 9.9 ± 7.6) of the incident PAR.

Figure 3.13 shows the patterns of light intensity, grain yield and dry matter production of sorghum at the three tree influence zones and the control plots. With the exception of Zone A, there was a consistent pattern of sorghum performance and light intensity under karité. Sorghum production decreased as light intensity increased from zone B to outside. Sorghum performance decreased from zone A to zone C and thereafter increased while light intensity increased from the trunk to outside under néré, except for total-pruned treatment.



Figure 3.13: Pattern of sorghum performance in relation to light intensity under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso

3.3.4.2. Transpiration by trees and its relationship with crop performance

Mean sapwood cross sectional area was $638\pm75 \text{ cm}^2$ and $1891\pm236 \text{ cm}^2$ for karité and néré, respectively. Using the data of sap velocity and sapwood cross sectional area, mean hourly transpiration rates were calculated. In 1999, mean transpiration rates in karité were found to significantly decrease (P<0.001) with increasing pruning intensity (Figure 3.14). For néré, however, although pruned trees transpired significantly less than unpruned trees (P<0.001), total-pruned trees transpired more than half-pruned trees, but the difference was not significant. Néré overall transpired significantly (P<0.05) more than karité. Regression analysis revealed that there was no strong relationship between pearl millet performance and transpiration rate in both néré and karité in 1999. However, the unpruned trees of néré, which gave significantly the least millet production (both dry matter and grain yield), gave significantly the highest mean transpiration rate of 146 l hr⁻¹, which was eight times higher than unpruned trees of karité (18 l hr⁻¹). Assuming that the water transpired is from the influence zone of tree (i.e. crown projection area), these values correspond to 10 mm day⁻¹ and 5 mm day⁻¹ for néré and karité, respectively.

In 2001, mean transpiration rates in karité were significantly different (P<0.05) with half-pruned trees giving the highest rate followed by unpruned trees and total-pruned trees (Figure 2.15). For néré, there was no significant difference between pruning intensities for transpiration rate, however total-pruned trees transpired more than half-pruned trees. Néré overall transpired significantly (P<0.05) more than karité (Figure 2.13). Regression analysis revealed that there was no relationship between sorghum performance and transpiration rate in both néré and karité in 2001. However, the unpruned trees of néré, which gave significantly the least sorghum production (both dry matter and grain yield), gave significantly the highest mean transpiration rate of 79 l hr⁻¹, which was nine times higher than unpruned trees of karité (9 l hr⁻¹). Assuming that the water transpired is from the influence zone of tree (i.e. crown projection area), these values correspond to 5.5 mm day⁻¹ and 2.5 mm day⁻¹ for néré and karité, respectively. Overall, trees transpired less in 2001 compared with the rates obtained in 1999 (Figures 3.14 and 3.15).



Figure 3.14: Transpiration rates from pruned trees of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé in 1999, Burkina Faso.



Figure 3.15: Transpiration rates from pruned trees of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé in 2001, Burkina Faso.

3.3.4.3. Soil properties under karité and néré influence zones

3.3.4.3.1. Soil physical properties and their relationship with crop performance

Pruning did not show any significant effect on soil bulk density and soil porosity. The influence zones (A, B, C) of néré gave statistically lower bulk density and higher porosity than control plots (P<0.05) which, showed no significant difference with the influence zone of karité (Table 3.4). Soil bulk density was significantly lower in zone B than those obtained in zones D and in the control plots under néré (P<0.05). Thus, soil porosity was higher in zone B than in zone D and in the control plots. Similar trend was observed under karité but the difference was not significant between zones.

According to Pearson's correlation analyses, only millet grain yield showed significant negative relationships with soil bulk density under karité (correlation coefficient = -0.33 at P<0.05), yet the relations with grain yield of sorghum, total dry matter of millet and sorghum were negative even not significant. There were significant correlations between grain yield and total dry matter of both millet and sorghum and soil bulk density under neré (P<0.05). The coefficients of correlation were -0.39, -0.36, -0.38, -0.53 for grain yield of millet, total dry matter of millet, grain yield of sorghum and total dry matter of sorghum, respectively.

Table	3.4:	Soil b	ulk	density	and	porc	sity (%) accord	ding to tree	species and	d dist	ance
from	the	trunk	in	topsoil	(0-5	cm)	under	karité	(Vitellaria	paradoxa)	and	néré
(Park	ia bi	iglobos	5a) i	n a park	land	l agro	oforestr	y syste	m in Sapor	ié, Burkina	Faso	1

				Zone		
	Species	A	В	С	D	Control
Density	Karité	1.60±0.02	1.58±0.02	1.59±0.01	1.61±0.02	1.63±0.01
-	Néré	1.57±0.02	1.53±0.02	1.60 ± 0.01	1.63±0.01	1.61±0.01
	Average	1.58±0.02	1.55 ± 0.02	1.59 ± 0.01	1.62 ± 0.02	1.62 ± 0.01
Porosity	Karité	38.57±0.58	39.23±0.66	38.930.47	38.21±0.64	37.44±0.43
	Néré	39.60±0.92	41.32±0.65	38.62±0.37	37.27±0.55	38.00±0.42
	Average	39.09±0.77	40.34±0.71	38.77±0.42	37.74±0.60	37.72±0.42

3.3.4.3.2. Soil nutrient status and its relationships with crop performance

The difference in soil nutrient status in the upper 0-10 cm depth between the two tree species was not significant (Table 3.5). Yet, the concentrations of C, OM, total N and available P were greater under néré than under karité whereas total P, total K and available K were higher under karité than néré. Pruning did not have significant effect on soil properties, with the exception of available K, which was significantly higher (P<0.05) under total-pruned trees (0.17 \pm 0.01). The difference in soil nutrient status among tree influence zones was also not significant, with the exception of available K, which was also significantly higher under Zone A (0.18 \pm 0.01) and decreased with increasing distance from trees. C and OM also increased, but not significantly, with proximity to trees. All soil nutrients with the exception of available P were higher under tree crowns than outside tree crowns (Table 3.5).

According to Pearson's correlation analyses, there were significant positive relationships between C and grain yield (P<0.05) and dry matter (P<0.01), between OM and grain yield (P<0.05) and dry matter (P<0.01) and between available K and grain yield (P<0.05) of millet although the correlation coefficients were low (Table 3.6). Among these chemical properties, only available P showed a significant (P<0.05) positive correlation with grain yield and total dry matter of sorghum (Table 3.7). However the correlation coefficient were low (0.29).

Table 3.5. Soil chemical properties according to tree species and distance from the trunk in topsoil (0-10 cm) under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso.

Karité		Zones around trees						
Variable	A	В	С	Control				
Carbon (g kg-1)	6.12±0.46	5.53 ± 0.40	5.28±0.57	5.05±0.32				
OM (%)	1.07 ± 0.08	0.95±0.08	0.90±0.09	0.88±0.06				
N-total (g kg ⁻¹)	0.45 ± 0.04	0.38±0.03	0.37±0.04	0.35±0.02				
P-available (mg kg ⁻¹)	3.62 ± 0.62	4.79±0.83	4.13±0.54	3.69±0.66				
P-total (mg kg ⁻¹)	110.97±7.66	96.70±13.80	91.80±11.70	85.03±8.01				
K-available (mg kg-1)	0.18 ± 0.01	0.16 ± 0.02	0.13±0.01	0.13±0.02				
K-total (mg kg-1)	654.50 ± 48.1	721.10±69.10	510.30±46.60	581.40±72.30				
Néré								
Carbon (g kg ⁻¹)	6.22±0.58	6.08±0.51	5.59±0.38	5.30 ± 0.22				
OM (%)	1.06 ± 0.10	1.04 ± 0.10	0.97±0.06	0.92 ± 0.04				
N-total (g kg-1)	0.42 ± 0.04	0.40±0.05	0.39±0.03	0.40±0.04				
P-available (mg kg ⁻¹)	3.77 ± 0.82	3.96 ± 0.56	4.07±0.64	5.16±0.45				
P-total (mg kg ⁻¹)	99.60±14.70	77.80±6.86	82.05±7.81	112.34±7.89				
K-available (mg kg-1)	0.18±0.03	0.12 ± 0.01	0.13±0.01	0.13±0.02				
K-total (mg kg-1)	607.60±75.6	680.70±34.30	566.80±69.20	565.10 ± 65.00				
Cell Contents: Correlation								
-------------------------------	--------	-----------	-------	-------	---------	-----------	---------	-----------
P-Value								
	Grain	Total dry	С	OM	N-total	P-	P-total	K-
	yield	matter				available		available
Total dry matter	0.887							
	0.001							
С	0.234	0.310						
	0.050	0.009						
OM	0.236	0.306	0.991					
	0.047	0.009	0.001					
N-total	0.064	0.142	0.587	0.567				
	0.598	0.238	0.001	0.001				0606
P-available	0.221	0.143	0.260	0.261	0.202			
	0.064	0.234	0.028	0.028	0.092			
P-total	-0.009	-0.029	0.271	0.270	0.463	0.250		
	0.942	0.810	0.022	0.023	0.001	0.035		
K-available	0.250	0.219	0.424	0.416	0.346	0.333	0.522	
	0.035	0.067	0.001	0.001	0.003	0.005	0.001	
K-total	0.011	-0.013	0.244	0.251	0.370	-().1.46	0.283	0.240
	ก จาก	() 912	0.040	0.035	0.001	0.224	0.017	0.044

Table 3.6. Pearson correlation analysis between millet production and soil chemical properties under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso.

					-U			
Cell contents: Correlation P-Value								
	Grain	Total	С	OM	N-	P_	P-total	K.,
	yield	dry	C	OM	total	available	1-10121	available
T-1-1-1	0.001	matter						
matter	0.921							
	0.000							
С	0.102	0.178						
	0.395	0.136						
OM	0.082	0.156	0.991					
	0.495	0.194	0.000					
N-total	-0.016	0.021	0.587	0.567				
	0.892	0.861	0.000	0.000				
P-available	0.294	0.288	0.260	0.261	0.202			
	0.013	0.015	0.028	0.028	0.092			
P-total	0.010	0.022	0.271	0.270	0.463	0.250		
	0.937	0.857	0.022	0.023	0.000	0.035		
K-available	0.132	0.139	0.424	0.416	0.346	0.333	0.522	
	0.271	0.248	0.000	0.000	0.003	0.005	0.000	
K-total	-0.044	-0.029	0.244	0.251	0.370	-0.146	0.283	0.240
	0.714	0.811	0.040	0.035	0.001	0.224	0.017	().().4.4

Table 3.7. Pearson correlation analysis between sorghum production and soil chemical properties under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso.

3.4. Discussion

3.4.1. Biomass from pruning and recovery of crown size

On an individual tree basis, néré produced more biomass of leaves and wood per tree because of its crown area that was four times larger than karité (Table 1.3). However, on a hectare basis, the contribution of these two species was of the same magnitude for wood but karité had a leaf production two-fold higher than néré. This was due to their different densities per hectare (9 karité against 1 néré ha⁻¹).

Based on litter basket collection under four karité trees (mean DBH 42 cm) in Thiougou, southern Burkina Faso, leaf production was estimated at 29 kg per tree (Bambara, 1993 cited by Boffa, 1999), which was twice lower than the value in the present study. The difference may be due to an underestimation by the baskets as some leaves may have been taken away from the trees by wind and also because of inappropriate sampling positions of the baskets.

Although the leaf biomass of néré in the present study was lower compared with those found by Sabiiti and Cobbina (1992b), the total biomass (leaves and wood) was within the range obtained by these authors.

Leaf biomass of karité did not show significant relationship with tree dimension parameter. At the period of pruning, karité was still bearing fruit at different stages whereas néré fruit were harvested. Because of resource allocation between leaf and fruit components, the fact trees of similar dimensions were at different developmental stages for these two components may explain the lack of strong and significant relationship between karité leaf biomass its dimensions.

3.4.2. Tree phenology and fruit production

No leafless state was observed on any sample tree of the present study. Trees showed an indistinguishable transition from old to new foliage. The major difference in leafing pattern was the fact that new leaves have been observed to resume and old leaves to persist on new shoots during leaf fall period. That was due to the fact that new shoots function as young plants in both species as reported by Binnekamp (1992) and Ouédraogo (1995a). Apart from a slight asynchrony in total-pruned trees, flowering and fruiting periods in both species conformed to what has been reported in the literature (Ouédraogo, 1995a; Hall et al., 1996; Hall et al., 1997; Guira, 1997). The asynchrony may be due to the tendency of pruned trees to allocate more resources to new shoots and leaves. Flowering in both species started during dry season and at the beginning of cold period (November and December for karité and néré, respectively). This phenophase followed the start of leaf fall but the two phenological events were not separated in time. Flower pick was in February for karité and in January for néré, showing that this phase lasted longer for karité than for néré. Fruiting pick was in March for both karité and néré. Vegetative and reproductive phenology of both species showed a seasonality as tropical species (Patel, 1997) and pruning did not change this seasonality sharply.

At individual tree level, there was a great variability in fruiting in both karité and néré due to probably variation in the age of the trees and farmer's management practices (length of cultivation phase, frequency of pruning). On average the yield was 28 kg tree⁻¹ year⁻¹ for karité. Karité trees showed a production of fruit at least two times higher in 2000 (excluding 100% pruned trees) compared with the mean yield of 1999 and 2001. This was in agreement with data from previous researchers (Agbahungba & Depommier, 1989; Boffa, 1995; Hall *et al.*, 1996; Guira, 1997). Annual average yield did not change sharply for néré during the three years of monitoring (70 kg tree⁻¹ year⁻¹ excluding 100% pruned trees). The range was between 15 and 144 kg tree⁻¹ year⁻¹, which was close to the range of 15-130 kg tree⁻¹ year⁻¹ found by Bagnoud *et al.*, (1995).

The significant allometric relationships found between fruit yield and the tree parameters for both species don't explain the data on fruit variability contrary to what was found by Boffa (1995) and Schreckenberg (1996). These authors found a correlation between karité tree size and fruit production regardless of the location either in cultivated or bush land.

A comparison of the results of the RBS estimates with DH methods over a period of two years revealed that the former method overestimated yield by at least a factor of 10 for karité and 5 for néré. No significant correlation was found between the two sets of data for both species. That indicates that RBS method doesn't appear to be appropriate to estimate fruit production in trees with huge crowns. However, Nguvulu (1997) found significant relationships for two wild species (*Uapaca*, *Strychnos*) in Zambia using RBS method. Although for the third species she didn't find significant relationship, she concluded that RBS method has potential for making estimates of fruit crops. Nevertheless, she faced the problem of tree size that rendered complication in the determination of the last branch sample. Jessen (1955) himself after trying three options concluded that the use of large branches did not appear to be generally as practicable as sampling using smaller branches.

The evaluation of pruning impact on fruit production revealed that half-pruned trees of the two species did not differ from the unpruned trees in terms of fruit production. The onset of fruiting after pruning can be one year for néré and two years for karité depending on individuals according to the findings of the present study. These findings and the fact that karité re-sprouts very well are not in accordance with findings of previous workers (Binnekamp, 1992; Kessler, 1992; Kater *et al.*, 1992; Ki, 1994; de Saint Sauveur, 1999). The capability of néré to start fruiting immediately after applying pruning but not in karité needs further work to establish whether this is due to genetic or to environmental factors. The results of the present study indicate that fruit production of total-pruned trees only partially recovered in both species, two years after pruning. It is not yet known how long it would take for these trees to fully recover and to produce as much fruit as unpruned and halfpruned trees.

3.4.3. Effect of pruning on crop performance

The results of the present study indicate that crown pruning had significant effect on millet and sorghum production under both karité and néré depending on the association and rainy season. This is due to the interaction between trees and crops, which is a balance of positive effects of trees on soil fertility, negative effects of competition for light, water and nutrients, respectively, a potentially positive effect via microclimate and uncertain effects via pests and diseases (Kho, 2000a&b; Mobbs *et al.*, 1998; Osman *et al.*, 1998; Ong and Leakey, 1999; Kho *et al.*, 2001; Miller and Pallardy, 2001).

The lack of significant difference in crop performance between unpruned trees of both tree species and in the open is in agreement with the findings of Jonsson *et al.* (1999). According to them, the negative effect of tree shade must have been compensated for by improvements in crop temperature and soil fertility. However, when pruning was applied, as in the present study, there was increased millet and sorghum production under total-pruned trees which indicates that excessive shading may still contribute to yield reduction under unpruned trees as reported by previous workers (Maïga, 1987; Kessler, 1992; Kater *et al.*, 1992; Wilson *et al.*, 1998; Boffa *et al.*, 2000; Miller and Pallardy, 2001). According to previous workers reduction of crop production was primarily attributed to reduced light intensity. Jonsson *et al.* (1999) reported a reduction of PAR to 24% of incident PAR under unpruned trees of karité and néré. Similarly, in the present study, under unpruned trees of karité and

néré PAR was reduced to 49% and 34% of the incident PAR, respectively, which were low enough to cause a substantial reduction in crop production.

The high rates of tree transpiration of unpruned trees may also contribute to reduction in crop performance (Droppelmann *et al.*, 2000). If it were inferred that high rates of tree transpiration would deplete soil moisture from an area occupied by the tree roots, then this would proportionally reduce crop production under unpruned trees compared with pruned trees where pruning may have affected the tree root distribution.

Maximum sap velocities of 82.4 cm h⁻¹ and 87.5 cm h⁻¹ recorded for unpruned trees, during the present study, for karité and néré, respectively, indicate that both species are capable of transpiring large quantities of water when compared with the typical midday values of 10 to 80 cm h-1 reported by Granier (1987). These transpiration figures are close to the values for evapotranspiration of 7-10 mm day-1 in this area (Roupsard, 1997). This shows the potential existence of competition for water but also that well established trees may withdraw large quantity of water from the water table at 5 to 15 m soil depth (pers. comm.), which can easily be reached by the roots of big trees as reported by Roupsard (1997). Unpruned nere transpired more than unpruned karité perhaps because of the large crown and sapwood cross-sectional area of néré, which was more than twice that of karité. The reason why total-pruned néré transpired more than half-pruned néré may be due to more new shoots emerging after pruning in total-pruned néré than in any of the pruned trees of both karité and néré as observed in 1999 in the field (personal observ.). Tschaplinski and Blake (1995) found that stomatal conductance in pruned hybrid poplar trees was 31% greater than that of the shoots of unpruned trees. Trees in general transpired less in 2001 because in this season the study site received more rains reducing the atmospheric demand. That is also corroborated by the lower PAR recordered in 2001 compared with the amount received in 1999.

Soil bulk density was lower under trees leading to higher soil porosity agreeing with Belsky *et al.* (1993). This means that water infiltration rate, water holding capacity of soil were better under trees than away from trees. The effects of trees on soil bulk density and porosity was greater under néré than under karité. The negative relationship between soil bulk density and crop performance shows the role of trees in increasing water storage in the soil as trees appeared to reduce this density. Nutrient concentrations increased with proximity to the trunk under both karité and néré as found by previous workers (Kessler, 1992; Kater et al., 1992; Tomlinson et al., 1995; Jonsson et al., 1999; Pandey et al., 2000). The strong correlation between C and N indicates that the main source of C and N may be the trees as crop residues are always removed from the land with harvest by farmers even though one may argue that trees might have grown on micro-sites of originally high fertility. Thus, the strong correlation between C and crop performance may indicate the positive effect of trees on soil amelioration. According to the results of the present study, soil was more fertile closer to the tree trunks than outside the tree crowns, which may explain why crop overall performed better under Zone B compared with the other tree influence zones. This production may also be partly explained by a better water supply because of a better water infiltration in this zone. Finally, the higher production of crop under Zone B than under Zone A may be due to low level of PAR and more intense competition between trees and crop for water under Zone A because of its proximity to tree trunks, where trees are known to grow more roots (Tomlinson et al., 1998). However, under half-pruned trees of néré, grain yield was higher under Zone A than under Zone B perhaps due to the low rate of transpiration by half-pruned trees of néré, which may have resulted in less competition for water.

From the analysis of the data carried out it was not possible to separate the effects of each of the environmental factors, that is, light, water and soil properties. This may be due to the fact that tree-crop-interaction depends on several factors of the environment, which have been reported to be confounding and difficult to separate (Ong, 1996; Kho, 2000a&b; Kho *et al.*, 2001).

The results of the present study provide evidence of the effects of crown pruning on light intensity and transpiration rates by trees and consequently on crop production. The statistically significant difference in crop production between crops under totalpruned trees and those in the open shows that the presence of trees is beneficial to crops due to improvement of soil fertility but detrimental to crops due to competition for water and nutrients unless the crown is pruned. Therefore, from the findings of the present study it is clear that the influence of crown pruning on crop production was due to the modifying effect of crown reduction on tree-crop-soil interactions. The evidence provided so far based on three seasons observation with different rainfall regimes and different crops implies that crops would benefit from crown pruning at least in the short term but long term effects may depend on the ability of the trees to maintain the amelioration of soil fertility and on how quickly the trees recover from pruning.

3.4.4. Agronomic implications of the present study

The main reason for maintaining woody species in the fields is the demand for food and traditional medicines for both humans and animals. Wood from farms is also becoming an important resource as the degradation of natural vegetation increases. The products of the two species under investigation are very important locally and as an export commodity (shea butter from karité). In the local market at Saponé, the prices fluctuated between 50 and 150 FCFA kg⁻¹ for the nuts of karité and 60 to 200 F CFA kg⁻¹ for the seeds of néré in 2002 (pers. observ.). These figures are higher than the 34 and 128 F CFA kg⁻¹ in western Burkina Faso as reported by Lamien *et al.* (1996) because of proximity of Saponé village to the capital of the country. At the same period the millet was sold at 150 to 200 F CFA kg⁻¹. Beside their nutritional importance, trees therefore constitute an important source of income as well as source of protein for livestock during the period of scarcity of quality fodder. The above figures show the potential of the products of these two species to generate incomes alleviating risks due to poor cropping season (100 F CFA = 0.15 Euro).

According to the inventory data (Table 1.2), the areas affected by trees represent 4% and 3% of the total area and this may appear negligible in terms of their agronomic impact. Such a conclusion does not take into account the fact that roots of these species can extend up to 60 m from the trunk increasing the affected area by 3 to 6 times (Jonsson, 1995). Another factor is the general trend of degradation, so parklands are becoming the only resource base to many farmers (Boffa, 1999). This trend shows the need to increase tree density in the fields because of the economic value of their products and this will be at the expense of the annual crop. For this reason and also because these species are fruit trees, they need to be managed in a

way to ensure a better and sustained crop production while providing good quality of tree products.

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CHAPTER IV

THE EFFECT OF CROWN PRUNING OF VITELLARIA PARADOXA AND PARKIA BIGLOBOSA ON FINE ROOT DISTRIBUTION AND THE CONSEQUENCES FOR CROP PRODUCTION

4.1. Introduction

Knowledge of root characteristics as influenced by management and site conditions is necessary for the optimisation of agroforestry systems (Schroth *et al.*, 1995; Ong and Leakey, 1999; Vanlauwe *et al.*, 2002). One of the tree management practices that can stop or reduce competition between trees and associated crops is crown pruning, which is known to modify the rooting pattern of trees (Schroth, 1995; Jones *et al.*, 1998; Namirembe, 1999). Under natural forest stands canopy gaps are reported to be associated with belowground gaps (Wilczynski and Pickett, 1993) because dynamic of fine root biomass, especially those near the soil surface, are most sensitive to changes in environment such as soil moisture and temperature.

Crown reduction by pruning is directly related to processes occurring belowground. A reduction of nutrient and water demand due to a reduction of crown volume should lead to a decrease in root biomass and an increase in soil fertility under tree due to dieback and decay of fine roots. The ability of trees to react to an increase in soil fertility by reducing root density offers a potential advantage when trees are pruned (Friend et al., 1990). Schroth and Zech (1995b), and Hoad et al. (2001) reported a reduction of root biomass of pruned trees that was ascribed to translocation of carbohydrates from roots to shoots to maintain the functional equilibrium. In field pot experiments with Inga edulis, Gupta and Singh (1981) observed increased mortality of fine roots beginning three to four days after shoot pruning, but regrowth of fine roots commenced again from primary and secondary laterals eight to ten days after shoot pruning. Jones et al. (1998) observed a marked reduction in tree root length density 60 days after pruning of Prosopis juliflora. This reduction was more pronounced in the upper layers. As a consequence, associated sorghum developed higher root density in pruned P. juliflora plots even though the difference was significant only at 10-20 cm depth.

Thus, pruning can be used as a management tool to create root niche differentiation for the benefit of associated crop. Although tree root biomass decline is thought to be beneficial for annual crops, it can in turn cause a reduction in the aboveground biomass of the tree itself. For example, Friend *et al.* (1990) found that a reduction of fine root dry weight by 36% induced a reduction by 72% of foliage dry weight of *Pseudotsuga menzienii*.

The effects of pruning on fine roots described above appear to be species and site specific (Namirembe, 1999). However, no study has been carried out so far on the effect of pruning of karité and néré on their roots. There are also no studies that have simultaneously measured crop and tree root distributions in agroforestry parkland systems when trees are pruned. Therefore, the present study was carried out to assess the impact of crown pruning on fine roots of these two tree species and their associated crop species in agroforestry parkland systems in Burkina Faso with the aim of testing the hypothesis that pruning may cause a decline in fine roots of trees in the upper soil layer separating the rooting zones of crop and tree components. The decrease of fine roots of trees in the upper soil layer and their increase in lower soil layers may reduce tree/crop competition and improve crop production, thus supporting the "safety-net" hypothesis described by Cadisch et al. (1997), Rowe et al. (1999) and Vanlauwe et al. (2002). This hypothesis postulates that deep rooting trees can utilize more efficiently leached nutrients beyond the range of crop roots when the demand for these nutrients is high (Cadisch et al., 1997; Lehmann et al., 1998a&b; Gathumbi et al., 2002; Suprayogo et al., 2002). This hypothesis is based on the assumption that fine roots are very sensitive to changes in soil temperature and soil moisture. A reduction or removal of tree crown will lead to an increase in soil temperature and also a reduction of soil water in the upper soil layers. Because root functioning is also under the control of above ground parts of the plant (Friend *et al.*, 1900; Steudle, 2000; Jeschke and Hartung, 2000; Hoad et al., 2001), crown reduction will also lead to a decrease in water and nutrient demand and consequently a reduction of fine roots. Water and to some extent nutrients are the most limiting factors in semi-arid areas. If, as a result of crown pruning, less water and nutrients are taken up by trees from the topsoil layer, this means greater availability of these resources for the associated crops at least in the short term. Consequently, this may

lead to more space for crop roots and thus higher crop root density and ultimately to better crop production under pruned trees.

4.2. Material and methods

4.2.1. Tree samples

The process of tree selection and the characteristics of the tree samples used in the present study have been described in Chapter 1. Root length density measurements were made on 3 trees of each of total-pruned (100% crown pruned), half-pruned (50% crown pruned) and unpruned (control) trees of both karité and néré. The sample trees were 11.7 ± 2.4 m in height with a diameter of 49.8 ± 13.7 cm for karité and 15.4 ± 2.4 m in height with a diameter of 89.1 ± 27.4 cm for néré. The mean crown diameter of unpruned néré (21.0 ± 3.8 m) was two times larger than that of unpruned karité (10.6 ± 1.9 m) (Table 1.3).

4.2.2. Core sampling of tree and crop roots

The area around of each tree was subdivided into four tree influence concentric zones before pruning in May 1999: 2 m around the trunk (zone A); from 2 m to half diameter of the crown (zone B), from half diameter to the edge of the crown (zone C), from the edge of the crown to 2 m outside of the crown (zone D).

Roots were sampled by soil coring to 50 cm depth using a 7 cm inner diameter corer. Root sampling was carried out annually during crop growing season for a period of three years (1999, 2000 and 2001). During each cropping season sampling was done in July/August, which is the active crop vegetative growth phase in Burkina Faso. In 1999 root sampling was done one month after crown pruning. Each year two sampling positions were chosen randomly within each tree influence zone and cores were taken from each sampling position at 10 cm intervals up to 50 cm soil depth: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm. This means 10 samples at the two positions for each zone, which were bulked for each soil layer to give 5 samples for each zone and a total of 20 samples for each tree. This gave a total of 180 core samples for each tree species per year. Roots were washed manually over three sieves of three mesh sizes (top = 2 mm, middle = 1 mm and bottom = 0.25 mm) in order to separate soil from roots (Plate 4.1). A sub-sample of 400 cm³ was used for root extraction.

Roots were sorted out into three categories: tree, crop and others (roots of other plants). Colour (purple for néré roots, pink for karité roots and white for crop roots) was used to distinguish roots of each category. For both crop and tree roots only fine roots ($\leq 2 \text{ mm}$) were retained for the purpose of the present study.

Root length of trees and crop was estimated using the line intercept method described by Tennant (1975). When samples were very small (less than 30 intercepts on a 1 cm grid), direct measurement of length was made using a ruler. Grid counts were calibrated by both direct measurement and counting the number of intercepts. After length measurement, root samples were dried in oven at 70°C for 48 hours and weighed. Root length was derived using the following formula (Tennant, 1975):

(-1.1)

 $L = \pi ND/4$

where N = number of counts; D (cm) = grid size; L (cm) = root length

Then root length density (RLD) was obtained by dividing root length by the volume of soil used for root extraction (400 cm³). Root weight density (RWD) was obtained by dividing root weight of each sample by its volume (400 cm³).

4.2.3. Data analysis

Root data were analysed using Minitab Release 12 Statistical Package. Root length density and root weight density were subjected to ANOVA General Linear Model (GLM) to test for the effect of pruning treatments. The effects of fertility, light and root trends were determined by using analysis of covariance with soil depth as covariate to compare the slopes of the different pruning treatments (Morgan and Carr, 1988) (Appendix 2). Relationships between root data, soil depth and crop production (grain yield and dry matter production) were explored through regression analysis.

Plate 4.1: Fine root processing



4.3. Results

4.3.1. Fine roots of trees and millet during 1999 cropping season

4.3.1.1. Tree roots

One month after crown pruning, root length density (RLD) of karité (0.16±0.01 cm cm⁻³) was significantly higher (P<0.05) than that of néré (0.13±0.01 cm cm⁻³). 59% and 69% of fine roots of karité and néré, respectively were found in the upper 20 cm depth of soil (Figure 4.1a, b). Crown pruning did not have significant influence on RLD of both karité and néré (Table 4.1). RLD of karité declined with distance from tree trunk but this was not significant except at the topsoil depth of 0-10 cm (P<0.05) (Figure 4.1.c). RLD of karité and néré decreased significantly with soil depth (P<0.01) with no significant difference in slope between the three pruning treatments (Equations 4.2, 4.3). RLD of néré also decreased significantly with distance from tree trunk in all soil layers (all P<0.01) (Figure 4.1.d). There was significant interaction between pruning treatment and zone of tree influence in RLD of neré, with the highest RLD recorded under half-pruned trees in Zone A (0.240 cm cm⁻¹). There was also significant interaction between zone and soil depth with the highest RLD (0.449 cm cm-³) recorded in Zone A and at 0-10 cm soil depth under néré.

Karité RLD = -0.00482^{*} (soil depth) + 0.284 $[r^2 = 79\%; P < 0.01]$ (4.2)Néré RLD = -0.00619^{*} (soil depth) + 0.284 $[r^2 = 66\%; P < 0.01]$

(4.3)

Table 4.1: Mean root length density (cm cm⁻³ \pm SE) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, over three years.

	Unpruned	Half-	Total	Mean	Significance
		pruned	pruned		-
Karité 1999	0.154±0.016	0.174±0.018	0.161±0.016	0.163±0.017	ns
Karité 2000	0.029±0.004	0.050±0.005	0.046±0.006	0.042±0.005	***
Karité 2001	0.169±0.016	0.191±0.012	0.172±0.013	0.177±0.014	ns
Significance	***	***	***	***	
Néré 1999	0.118±0.015	0.146±0.020	0.123±0.016	0.129±0.017	ns
Néré 2000	0.165±0.028	0.113±0.020	0.032±0.006	0.103±0.018	***
Néré 2001	0.315±0.033	0.313±0.041	0.250±0.031	0.293±0.035	ns
Significance	***	***	***	***	

Data in the same column or row are not statistically different at P>0.05 =ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

Table 4.2: Mean root weight density (mg cm⁻³ \pm SE) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, over three years.

			Total-		Significance
Species	Unprune	0			
Karité 1999	0.199±0.036	0.182±0.024	0.162±0.023	0.182±0.017	ns
Karité 2000	0.058±0.010	0.070±0.012	0.058±0.009	0.062±0.006	ns
Karité 2001	0.057±0.008	0.138±0.024	0.148±0.032	0.113±0.014	•
Significance	***	**	**	***	
Néré 1999	0.136±0.019	$0.1540.023 \pm$	0.125±0.019	0.138±0.011	ns
Néré 2000	0.174±0.024	0.173±0.026	0.043±0.010	0.130±0.011	***
Néré 2001	0.194±0.027	0.133±0.018	0.084±0.014	0.137±0.011	**
Significance	ns	ns	***	ns	

Data in the same column or row are not statistically different at P>0.05 =ns, significantly

different at P<0.05 = *, P<0.01 = **, P<0.001 = ***



b: Nere Root length density (cm cm-3) 0.05 0.25 0.00 0.10 0.15 0.20 0.30 035 0-10 00 10-20 Depth (cm) 20-30 30-40 40-50 .

103

a: Karite





d: Nere



Figure 4.1: Root length density (cm cm⁻³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 1999; (a-b) pruning effect; (c-d) effect of distance from tree trunk.

Similar to RLD, root weight density (RWD) of karité (0.18±0.02 mg cm⁻³) was significantly higher (P<0.01) than that of néré (0.14±0.01 mg cm⁻³) and there was also no significant difference between pruning treatments for both species (Table 4.2). RWD of karité did not differ with distance from tree trunk (4.3). However, there was

a significant (P<0.05) decrease with soil depth. RWD of néré declined significantly with distance from tree trunk as well as with soil depth (both P<0.05) (Table 4.3).

Table 4.3: Root weight density (mg cm-3) of differentially pruned karité (Vitellaria
paradoxa) and néré (Parkia biglobosa) in a parkland agroforestry system in Saponé,
Burkina Faso, during the cropping season of 1999.

Karité			D	epth		
Zone	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.342±0.066	0.311±0.115	0.214±0.089	0.132±0.040	0.178±0.093	0.235 ± 0.085
В	0.341±0.130	0.325±0.095	0.186±0.035	0.087±0.011	0.075±0.038	0.203 ± 0.083
С	0.249±0.067	0.340±0.078	0.087±0.021	0.034±0.009	0.046 ± 0.015	0.151 ± 0.061
D	0.213±0.077	0.162 ± 0.031	0.191±0.095	0.066 ± 0.016	0.064 ± 0.034	0.139 ± 0.060
Mean	0.285±0.083	0.283 ± 0.084	0.169 ± 0.068	0.079 ± 0.025	0.091 ± 0.054	0.182 ± 0.072
Signifi	ns	ns	ns	*	ns	ns
cance Néré						
A	0.461+0.065	0.265+0.065	0.197±0.047	0.141±0.038	0.053±0.020	0.224±0.066
В	0.322±0.052	0.233±0.036	0.145±0.037	0.072±0.024	0.01±0.004	0.156±0.050
С	0.218±0.035	0.161±0.047	0.036±0.013	0.046±0.024	0.022±0.019	0.097±0.039
D	0.159±0.033	0.146±0.043	0.043±0.016	0.028 ± 0.015	0.009 ± 0.006	0.077±0.033
Mean	0.290 ± 0.060	0.201±0.050	0.105±0.038	0.072 ± 0.029	0.024 ± 0.015	0.138 ± 0.052
Signifi cance	٠	ns	*	*	ns	***

Data in the same column are not statistically different at P>0.05 =ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.1.2. Millet roots

No significant difference was found in either RLD or RWD of millet with distance from tree trunk under both tree species (Figure 4.2, Table 4.6). However, under both tree species, a significant decline (P<0.001) in millet RLD was noted with soil profile depth (Figures 4.2). There was no significant difference between RLD of millet under karité (0.098 cm cm⁻³) and that under néré (0.102 cm cm⁻³) (Table 4.4.). Similarly, millet RWD under both karité and néré was almost equal (0.013 mg cm⁻³ and 0.014 mg cm⁻³, respectively) (Table 4.5). There was also no significant difference between pruning treatments in millet RLD under karité whereas there was significant higher RLD under total-pruned néré compared with unpruned néré (Table 4.4). However, RLD of millet decreased by 0.0081, 0.0061, and 0.0082 per cm soil depth with a significant difference in slope between unpruned, half-pruned and total-pruned karité, respectively. Similarly, RLD of millet decreased by 0.0056, 0.0067, and 0.0104 per cm soil depth with a significant difference in slope between unpruned, halfpruned and total-pruned néré, respectively. Furthermore, RLD of millet under totalpruned trees was higher than that of trees at the soil depth of 0-10 cm under both tree species: 0.32 cm cm⁻³ for millet Vs 0.27 cm cm⁻³ for karité and 0.33 cm cm⁻³ for millet Vs 0.28 cm cm⁻³ for néré.

Table 4.4: Mean root length density (cm cm⁻³ ±SE) of millet and sorghum under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, over three years.

	Unpruned	Half-pruned	Total-pruned	Mean	Signi-
			57		ficance
Millet under karité 1999	0.105±0.018	0.080±0.016	0.109±0.021	0.098 ± 0.018	ns
Millet under karité 2000	0.066±0.013	0.086±0.009	0.079±0.017	0.077±0.013	ns
Sorghum under karité 2001	0.123±0.022	0.157±0.027	0.091±0.025	0.124±0.025	ns
Significance	ns	*	ns	*	
Millet under néré 1999	0.069±0.015	0.085±0.020	0.151±0.016	0.102±0.017	*
Millet under néré 2000	0.024±0.004	0.025±0.005	0.050±0.007	0.033±0.005	***
Sorghum under néré 2001	0.147±0.038	0.152±0.025	0.408±0.064	0.236±0.042	***
Significance	**	***	***	***	

Data in the same column or row are not statistically different at P>0.05 =ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

Table 4.5: Mean root weight density (mg cm⁻¹±SE) of millet and sorghum under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, over three years.

		Half-	Total-		Significance
Species	Unpruned	lpruned	pruned	Mean	
Millet under karité 1999	0.006±0.001	0.003±0.001	0.008±0.003	0.006 ± 0.001	ns
Millet under karité 2000	0.008 ± 0.001	0.011 ± 0.001	0.011±0.002	0.010 ± 0.001	ns
Sorghum under karité 2001	0.012 ± 0.004	0.012 ± 0.002	0.017±0.004	0.013±0.002	ns
Significance	ns	***	ns	**	
Millet under néré 1999	0.003±0.001	0.006±0.002	0.008 ± 0.001	0.006±0.001	*
Millet under néré 2000	0.003±0.001	0.004±0.001	0.007±0.001	0.005±0.000	**
Sorghum under néré 2001	0.015±0.003	0.011±0.001	0.031±0.005	0.019±0.002	***
Significance	***	**	*	***	

Data in the same column or row are not statistically different at P>0.05 =ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***





b: Nere







d: Nere



Figure 4.2: Root length density (cm cm⁻³) of millet under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso during the cropping season of 1999; (a-b) pruning effect; (c-d) effect of distance from tree trunk.

Table 4.6: Root weight density (mg cm⁻³) of millet under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 1999.

Karité			D	Pepth		
Zone	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.052 ± 0.013	0.007 ± 0.002	0.004±0.003	0.001±0.001	0.000 ± 0.000	0.013±0.009
В	0.035±0.008	0.011 ± 0.004	0.007±0.005	0.001 ± 0.001	0.000 ± 0.000	0.011 ± 0.006
С	0.048 ± 0.008	0.062±0.005	0.006±0.003	0.001 ± 0.001	0.000 ± 0.000	0.023 ± 0.002
D	0.038±0.010	0.012 ± 0.004	0.005 ± 0.002	0.001 ± 0.001	0.000 ± 0.000	0.011 ± 0.007
Mean	0.043 ± 0.010	0.023±0.003	0.005 ± 0.003	0.001 ± 0.001	0.000 ± 0.000	0.015 ± 0.001
Signifi cance	ns	ns	ns	ns	ns	ns
Néré	Depth					
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
А	0.053 ± 0.011	0.017±0.003	0.007 ± 0.004	0.005 ± 0.002	0.003 ± 0.002	0.018 ± 0.008
В	0.034 ± 0.008	0.008 ± 0.002	0.003 ± 0.002	0.000 ± 0.000	0.000 ± 0.000	0.009 ± 0.006
С	0.039 ± 0.009	0.011 ± 0.005	0.029 ± 0.002	0.001 ± 0.001	0.000 ± 0.001	0.0160 ± 0.012
D	0.043 ± 0.010	0.014 ± 0.005	0.004 ± 0.002	0.001 ± 0.001	0.001 ± 0.001	0.013 ± 0.007
Mean	0.042 ± 0.009	0.012 ± 0.004	0.011 ± 0.001	0.002 ± 0.001	0.001 ± 0.001	0.014 ± 0.009
Signifi cance	ns	ns	ns	ns	ns	ns

Data in the same column are not statistically different at P>0.05 = ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.2. Fine roots of trees and millet in 2000: one year after pruning

4.3.2.1. Tree roots

One year after crown pruning, mean RLD of néré did not differ significantly from that of 1999 whereas for karité there was significant difference (P<0.001), with RLD in 2000 being four-fold lower than in 1999 (Table 4.1). Contrary to 1999, in 2000 RLD of néré was significantly higher (P<0.001) than that of karité. Similarly, RWD of karité was two times lower than that of néré (P<0.001) (Table 4.2). There was a significant difference (P<0.05) in RLD of karité between pruning treatments as well as in RLD of néré between pruning treatments (P<0.001) (Figures 4.3, Table 4.1).

One year after pruning the decreasing pattern of RLD with soil depth observed in 1999 changed in all pruning treatments of karité but in néré only under total-pruned treatment. There was less RLD in the topsoil (0 -10 cm) and reaching a maximum at

20-30 cm soil depth (Figure 4.4). Within each pruning treatment, there was no consistent pattern of root distribution with distance from tree trunk in both species although it was found that there were more roots under trees (Zone A, B and C) than outside (Zone D) (Figure 4.4). However, an analysis for all pruning treatments showed that RLD of karité increased from zone A to zone B and thereafter decreased significantly going to the open area (P<0.001) while RLD of néré decreased significantly with distance from tree trunk to the open area (P<0.01).

There was a significant difference in RWD between pruning treatments and with distance from tree trunk for néré and karité, respectively (Tables 4.2, 4.7). In turn, no significant difference was found in RWD between pruning treatments for karité and with distance from tree trunk for néré (Tables 4.2, 4.7).





Figure 4.3: Pruning effect on root length density (cm cm⁻³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2000.

0.06 0.07 0.01 0.02 0.03 0.04 0.05 0.00 0.10 F . 10-20 Depth (cm) 20-30 A 30-40 K В С D 40-50



Root length density (cm cm-3)

b: Unpruned nere

Root length density (cm cm-3)



c: Half-pruned karite



d: Half-pruned nere





f: Total-pruned nere



Figure 4.4: Effect of distance from tree trunk on root length density (cm cm⁻³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2000.

Table 4.7: Root weight density (mg cm³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season 2000.

Karitó			Der	oth		
Zone -	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.027±0.007	0.162±0.034	0.094±0.029	0.095±0.024	0.058±0.018	0.087±0.028
В	0.067±0.021	0.136±0.072	0.147±0.039	0.086±0.025	0.034±0.007	0.094±0.040
С	0.040±0.013	0.048±0.016	0.059±0.027	0.045±0.019	0.041±0.014	0.047 ± 0.018
D	0.020±0.007	0.041 ± 0.014	0.038±0.010	0.019 ± 0.004	0.006 ± 0.002	0.025±0.009
Mean	0.038±0.014	0.096 ± 0.041	0.083±0.029	0.061±0.021	0.035 ± 0.013	0.062±0.027
Signifi	ns	*	*	*	*	***
cance						
Néré	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
А	0.243±0.102	0.206±0.057	0.149 ± 0.042	0.145 ± 0.055	0.051±0.025	0.159 ± 0.062
В	0.305±0.116	0.196±0.055	0.142±0.053	0.118±0.053	0.117±0.073	0.176 ± 0.075
С	0.167±0.070	0.198±0.068	0.159±0.051	0.081±0.027	0.075±0.035	0.136±0.053
D	0.069±0.034	0.055±0.013	0.086±0.030	0.028±0.010	0.012±0.006	0.050 ± 0.022
Mean	0.196±0.087	0.164 ± 0.054	0.134 ± 0.044	0.093±0.042	0.064 ± 0.043	0.130 ± 0.058
Signifi	ns	ns	ns	ns	ns	ns
cance						

Data in the same column are not statistically different at P>0.05 = ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.2.2. Millet roots

During the cropping season of 2000, RLD of millet under karité was significantly higher than under néré (0.077±0.010 cm cm⁻³ and 0.033±0.005 cm cm⁻³, respectively). (Table 4.4). Millet RLD decreased significantly with soil depth under all pruning treatments with no significant difference in slope between pruning treatments for karité while there was a significant difference between pruning treatments for néré (Equations 4.4 - 4.9) (all P<0.01). No significant difference was with distance from tree trunk for both species (Figure 4.5c&d). Millet root dominated root population under all pruning treatments of karité and total-pruned treatment of néré at least in the two upper layers (0-20 cm). Millet RLD and RWD under total-pruned néré trees were significant difference was found for these two parameters under karité (Tables 4.4, 4.5). No consistent pattern with distance from tree trunk was found for RWD of both species (Table 4.8).

a:Karite







c: Karite







Figure 4.5: Root length density (cm cm⁻³) of millet under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2000; (a-b) pruning effect; (c-d) effect of distance from tree trunk.

Unpruned karité	RLD = -0.0037*(soil depth) + 0.1593	$[r^2 = 88\% ; P < 0.01]$	(4.4)
Unpruned néré	$RLD = -0.001^{*}(soil depth) + 0.05$	$[r^2 = 87\%; P < 0.01]$	(4.5)
Half-pruned karité	$RLD = -0.0025^{*}(soil depth) + 0.148$	$[r^2 = 91\%; P < 0.01]$	(4.6)
Half-pruned néré	RLD = -0.0013*(soil depth) + 0.0566	$[r^2 = 95\%; P < 0.01]$	(4.7)
Total pruned karité	RLD = -0.0044*(soil depth) + 0.1944	$[r^2 = 91\%$; P<0.01]	(4.8)
Total pruned néré	$RLD = -0.0016^{*}(soil depth) + 0.0908$	$[r^2 = 96\%; P < 0.01]$	(4.9)

Table 4.8: Root weight density (mg cm⁻³) of millet under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season 2000.

				No. of Concession, and the Concession of Concession of Concession, and the Concession of Concession of Concession, and the Concession of Concession of Concession, and the Concession, a		
Karité			Dep	oth		
Zone	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
А	0.017±0.007	0.012 ± 0.002	0.008±0.002	0.005±0.002	0.003±0.002	0.009 ± 0.004
В	0.023±0.006	0.019 ± 0.005	0.010 ± 0.004	0.005 ± 0.002	0.004±0.003	0.012 ± 0.005
С	0.026±0.006	0.015 ± 0.003	0.008 ± 0.002	0.004 ± 0.001	0.003±0.001	0.011 ± 0.004
D	0.014±0.003	0.009 ± 0.002	0.009 ± 0.004	0.006±0.003	0.005±0.003	0.009 ± 0.003
Mean	0.020 ± 0.006	0.014 ± 0.003	0.009 ± 0.003	0.005 ± 0.002	0.004 ± 0.002	0.010 ± 0.004
Signifi-	ns	ns	ns	ns	ns	ns
cance						
Néré	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
А	0.007±0.002	0.006 ± 0.002	0.006 ± 0.002	0.002 ± 0.001	0.001 ± 0.000	0.005 ± 0.002
В	0.008±0.003	0.008 ± 0.004	0.003±0.001	0.001 ± 0.001	0.002 ± 0.001	0.004 ± 0.002
С	0.009 ± 0.002	0.009 ± 0.003	0.004 ± 0.001	0.004 ± 0.002	0.001 ± 0.000	0.005 ± 0.002
D	0.009±0.003	0.005 ± 0.002	0.003 ± 0.001	0.003 ± 0.001	0.002 ± 0.001	0.004 ± 0.002
Mean	0.008 ± 0.002	0.007 ± 0.003	0.004 ± 0.001	0.002 ± 0.001	0.001 ± 0.001	0.005 ± 0.002
Signifi-	ns	ns	ns	ns	ns	ns
cance						

Data in the same column are not statistically different at P>0.05 = ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.3. Fine roots of trees and sorghum in 2001: two years after pruning

4.3.3.1. Tree roots

As in 2000, in 2001 RLD of néré was also significantly higher (P<0.001) than that of karité (0.29 ± 0.02 and 0.18 ± 0.01 cm cm⁻³, respectively) (Table 4.1). RLD of karité and néré varied significantly (P<0.001) with soil depth but there was no significant difference in slope between pruning treatments for karité whereas there was significant difference in slope between pruning treatments for néré. No significant difference was found with distance from tree trunk for karité whereas in néré there was significant with distance from tree trunk (P<0.05) (Figure 4.6). However, RLD of karité increased from zone A to zone B and thereafter decreased as in 2000. There was no significant difference between pruning treatments for both species (Table 4.1).

The pattern of RLD with soil depth observed in 2000 was repeated in half and total pruned treatments of karité two years after pruning. There was less RLD in the

topsoil (0 -10 cm) and reaching a maximum at 10-20 cm soil depth (Figure 4.6a). However, in néré the decreasing pattern of RLD with depth observed in 1999 was repeated in all treatments in 2001.

RWD in total- and half-pruned karité was significantly higher than that of unpruned karité (Table 4.2). The patterns with respect to depth and distance from tree trunk were similar to those of RLD in karité. A decreasing pattern with distance from tree trunk was observed for RWD in néré even though it was not significant (Table 4.9). RWD decreased with depth but its maximum value was observed at soil depth 10-20 cm (Table 4.9). RWD was significantly (P<0.01) lower under total-pruned néré trees compared with the other pruning treatments (Table 4.2).

a: Karite







c: Karite



×





Figure 4.6: Root length density (cm cm⁻³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2001: (a-b) pruning effect; (c-d) effect of distance from tree trunk.

Table 4.9: Root weight density (mg cm⁻³) of differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2001.

Karité	Depth					
Zone	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.162 ± 0.092	0.180 ± 0.060	0.158 ± 0.046	0.140 ± 0.042	0.100±0.033	0.148 ± 0.056
В	0.184±0.102	0.248±0.093	0.062±0.018	0.031±0.006	0.034 ± 0.008	0.112 ± 0.067
С	0.241±0.142	0.074 ± 0.020	0.084 ± 0.027	0.105 ± 0.061	0.059 ± 0.020	0.113 ± 0.072
D	0.098±0.058	0.098±0.042	0.116 ± 0.058	0.073±0.046	0.018 ± 0.008	0.081 ± 0.046
Mean	0.171±0.099	0.147 ± 0.059	0.106 ± 0.041	0.089 ± 0.045	0.053 ± 0.022	0.113 ± 0.060
Signifi-	ns	ns	ns	ns	*	ns
cance						
Néré	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
А	0.340±0.065	0.267±0.071	0.167±0.031	0.100 ± 0.024	0.060 ± 0.014	0.187 ± 0.057
В	0.221±0.039	0.258 ± 0.104	0.111 ± 0.034	0.064±0.019	0.047±0.015	0.140 ± 0.058
С	0.140 ± 0.046	0.174 ± 0.043	0.152 ± 0.060	0.123±0.075	0.030±0.007	0.124 ± 0.052
D	0.124±0.034	0.184±0.082	0.093±0.041	0.070±0.029	0.022±0.010	0.099 ± 0.047
Mean	0.206 ± 0.054	0.221 ± 0.076	0.131 ± 0.042	0.089 ± 0.042	0.040 ± 0.012	0.137 ± 0.054
Signifi-	*	ns	ns	ns	ns	ns
cance						

Data in the same column are not statistically different at P>0.05 = ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.3.2. Sorghum roots

RLD of sorghum under néré was significantly (P<0.001) higher than under karité ($0.24\pm0.04 \text{ cm cm}^{-3}$ and $0.12\pm0.03 \text{ cm cm}^{-3}$, respectively) whereas RWD did not differ significantly between the two species ($0.019\pm0.002 \text{ g cm}^{-3}$ and $0.013\pm0.002 \text{ cm cm}^{-3}$, respectively) (Table 4.4, 4.5). No significant difference was found between pruning treatments in RLD and RWD of sorghum under karité (Tables 4.4, 4.5). RLD of sorghum decreased significantly (P<0.001) with soil depth under karité with no significant difference in slope between pruning treatments. RLD of sorghum decreased significantly with a significant difference in slope between pruning treatments under néré. RLD and RWD of sorghum were significantly (both P<0.01) higher under total-pruned néré trees than under unpruned and half-pruned treatments (Tables 4.4, 4.5). No consistent pattern was observed with distance from tree trunk (Table 4.10) whereas RLD and RWD of sorghum decreased significantly with soil depth under néré sorghum decreased significantly with a significant difference in slope between pruned néré trees than under unpruned and half-pruned treatments (Tables 4.4, 4.5). No consistent pattern was observed with distance from tree trunk (Table 4.10) whereas RLD and RWD of sorghum decreased significantly with soil depth under néré with a significant difference in slope between pruning treatments (P<0.001).

There was an interaction between species, zone and soil depth, and as a consequence under karité sorghum showed the highest RLD in zone A at depth 0-10 cm (Figure 4.7.c). Under néré, however, Zone D gave the highest RLD of sorghum at the depths of 0-10 and 10-20 cm whereas for the rest of the depths Zone A showed the highest values (Figure 4.7d).




b: Nere







d: Nere



Figure 4.7: Root length density (cm cm⁻³) of sorghum under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2001: (a-b) pruning effect; (c-d) effect of distance from tree trunk.

Table 4.10: Root weight density (mg cm⁻³) of sorghum under differentially pruned karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé, Burkina Faso, during the cropping season of 2001.

Karité	Depth					
Zone	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.062 ± 0.024	0.025 ± 0.011	0.012±0.006	0.004±0.001	0.001±0.001	0.021±0.014
В	0.025±0.013	0.012 ± 0.005	0.003±0.001	0.003±0.001	0.010 ± 0.008	0.010 ± 0.007
С	0.031±0.008	0.011 ± 0.002	0.008 ± 0.002	0.005 ± 0.002	0.008±0.005	0.013 ± 0.005
D	0.023±0.007	0.009 ± 0.002	0.006 ± 0.001	0.006 ± 0.004	0.001 ± 0.001	0.009 ± 0.004
Mean	0.035 ± 0.015	0.014 ± 0.006	0.008 ± 0.003	0.005 ± 0.002	0.005 ± 0.004	0.013±0.009
Signifi-	ns	ns	ns	ns	ns	ns
cance						
Néré	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	Mean
A	0.041 ± 0.008	0.022±0.003	0.021 ± 0.007	0.008±0.003	0.032±0.027	0.025 ± 0.013
В	0.030 ± 0.005	0.014 ± 0.003	0.009 ± 0.003	0.007±0.002	0.001 ± 0.001	0.012 ± 0.004
С	0.045 ± 0.014	0.021 ± 0.007	0.011±0.003	0.006±0.002	0.005±0.002	0.018 ± 0.009
D	0.056 ± 0.017	0.025 ± 0.007	0.010 ± 0.002	0.008±0.002	0.008±0.002	0.021±0.010
Mean	0.043 ± 0.012	0.021 ± 0.005	0.013 ± 0.004	0.007±0.002	0.011 ± 0.014	0.019 ± 0.010
Signifi-	ns	ns	ns	ns	·· ns	ns
cance						

Data in the same column are not statistically different at P>0.05 =ns, significantly different at P<0.05 = *, P<0.01 = **, P<0.001 = ***

4.3.4. Correlations between root length density and root weight density

With the exception of karité in 2001, there were significant (P<0.01) linear relationships between RLD and RWD in both two tree species and the two crop species although some of the r^2 values are very low (equations 4.10 – 4.18).

Karité 1999	RLD = 0.402*RWD + 0.0899	$[r^2 = 46\%; P < 0.01]$	(4.10)
Karité 2000	RLD = 0.324*RWD + 0.0214	$[r^2 = 43\%; P < 0.01]$	(4.11)
Karité 2001	RLD = 0.0427*RWD + 0.173	$[r^2 = 0.4\%; P > 0.05]$	(4.12)
Néré 1999	RLD = 0.730*RWD + 0.0282	$[r^2 = 73\%; P < 0.01]$	(4.13)
Néré 2000	RLD = 0.676*RWD + 0.0153	$[r^2 = 53\%; P < 0.01]$	(4.14)
Néré 2001	RLD = 0.787*RWD + 0.185	[r ² = 22% ; P<0.01]	(4.15)
Millet 1999	RLD = 6.39*RWD + 0.0646	[r ² = 33% ; P<0.01]	(4.16)
Millet 2000	RLD = 7.13*RWD + 0.0023	$[r^2 = 80\%; P < 0.01]$	(4.17)
Sorghum	RLD = 5.32*RWD + 0.0946	$[r^2 = 24\%; P < 0.01]$	(4.18)

4.3.5. Relationship between fine roots and crop performance

Pearson's correlation analysis performed on data of all depths showed that neither karité RLD nor crop RLD appeared to be significantly related to crop performance under karité during the three years of root assessment. However, grain yield and total dry matter of millet were positively correlated (P<0.05) with RLD of millet under néré both in 1999 (correlation coefficients = 0.37 and 0.45, respectively) and in 2000 (correlation coefficients = 0.58 and 0.68, respectively). In 2000 RLD of néré had a negative significant correlation (P<0.05) both with grain yield (correlation coefficient = -0.35) and total dry matter of millet (correlation coefficient = -0.38) whereas such correlation was not found in 1999 and 2001. Grain yield and total dry matter of sorghum were also positively correlated (P<0.001) with RLD of sorghum under néré in 2001 (correlation coefficients = 0.66 and 0.65, respectively).

The topsoil (0-10 cm) is the depth in which the maximum competition for resources is likely to occur and Figures 4.8, 4.9, 4.10 are produced to show the patterns of RLD of tree and crop in the top 10 cm depth in relation to grain yield and dry matter production of pearl millet and sorghum at the four tree influence zones in 1999, 2000 and 2001, respectively. Under karité in 1999, with the exception of Zone A, millet performance decreased as well as RLD of karité while RLD of millet decreased from Zone A to Zone B and then increased thereafter (Figure 4.8). Apart from half-pruned treatment millet production showed similar trend under néré and karité whereas RLD of néré and millet consistently decreased from Zone A to the outside (Figure 4.8). The pattern in millet performance in 2000 was similar to that of 1999 while the pattern of RLD of karité decreased and RLD of millet increased and then decreased with distance from tree trunk (Figure 4.9). Millet production under unpruned and half-pruned treatments increased with distance from the trunk while RLD of néré and millet increased from zone A to B and then decreased (Figure 4.9). With the exception of total-pruned treatment of néré, the patterns of sorghum performance were similar to that of RLD of trees whereas RLD of sorghum increased with distance from tree trunk except for half-pruned néré and total-pruned karité in 2001 (Figure 4.10).



Figure 4.8: Pattern of millet performance in relation to RLD of millet, karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé in 1999, Burkina Faso.

127



Figure 4.9: Pattern of millet performance in relation to RLD of millet, karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé in 2000, Burkina Faso.



Figure 4.10: Pattern of sorghum performance in relation to RLD of sorghum, karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in a parkland agroforestry system in Saponé in 2001, Burkina Faso.

129

4.4. Discussion

4.4.1. Effect of pruning on root length density and the consequence for crop production

The results of the present study show that crown pruning had different influences on root length density of karité and néré. RLD of karité, which was significantly higher than néré in 1999, became significantly lower than néré in 2000 and 2001. However, in néré, RLD, which did not vary between pruning treatments in 1999, significantly decreased with an increase in pruning intensity in both 2000 and 2001. This indicates that crown pruning has more effect on néré than karité. This finding is in agreement with previous workers who reported different responses of tree species to pruning (Jones *et al.*, 1998). The reduction of RLD of karité in 2000 may be a response to low rainfall during that year (680 mm). Such response to low rainfall is characteristics of most trees in arid regions. It is a mechanism of niche differentiation by plants in simultaneous agroforestry systems to avoid competition for limited resources (Rowe *et al.*, 1999).

However, a reduction of canopy volume by pruning induced a decrease of RLD of néré one year after pruning, corroborating findings of other workers (Gupta and Singh, 1981; Friend *et al.*, 1990; Jones *et al.*, 1998). The lack of pruning effect in 1999 in both species may be due to the large size of the trees which have enough carbohydrate reserves in their stem and coarse roots to compensate for loss of crown thus a delayed response of roots to pruning as also reported by Namirembe (1999).

The high crop production under karité may not, therefore, be due to pruning effects on roots but may be due to other factors such as reduction of light interception by trees (Bayala *et al.*, 2002) and, as shown in the present study, the intrinsic characteristic of karité to grow less roots in upper soil layers to avoid competition with crop roots. On the other hand, increased crop production under total-pruned trees of néré may be attributed to reduction of RLD as a result of crown pruning. In 1999 and 2001 when rainfall exceeded the average for the region (721 mm), more fine roots were found in the upper soil layer of 0-10 cm layer than in lower layers showing a decrease in RLD with increasing depth in the soil profile under both tree species and both crop species, with the exception of pruned trees of karité in 2001, corroborating the findings of previous workers (Johnson *et al.*, 1988; Dhyani *et al.*, 1990; Smith *et al.*, 1999; Akinnifesi *et al.*, 1999; Odhiambo *et al.*, 2001). This rooting pattern is due to better recharge of water (Johnson *et al.*, 1988; Dhyani *et al.*, 1990; Tomlinson *et al.*, 1998) and higher level of nutrients (Tomlinson *et al.*, 1995; Pandey *et al.*, 2000; Hoad *et al.*, 2001; Bayala *et al.*, 2002) in the upper soil layer.

During 2000 when rainfall was less than the average for the region, there were more roots of trees at 10-20 cm soil layer than at 0-10 cm in unpruned and half-pruned trees of karité and the maximum tree roots were found at 20-30 cm soil layer in total pruned trees of both species. Similar findings were reported by Lehmann et al. (1998a). These results confirm the sensitiveness of fine roots to changes in environment such as soil moisture and temperature (Wilczynski and Pickett, 1993). Changes in environment coupled with the reduction of crown projection area of total-pruned trees may be the reasons why in total-pruned trees of both species there. were fewer roots in the upper 0-20 cm soil layer than in the 20-30 cm layer. Tomlinson et al. (1998) found similar trend during dry season under néré. Thus, crop roots dominated root population in the upper 0-10 cm layer under karité regardless of pruning treatments and under total-pruned trees of néré. This may be one of the reasons why there was enhanced crop production under these treatments (Bayala et al., 2002). In fact throughout the three cropping seasons RLD of crop was more than tree RLD in the topsoil layer of 0-10 cm under total-pruned treatment for both species. Lehmann et al. (1998a) reported similar trend in sorghum/Acacia saligna system in Kenya. The mechanism of reduced RLD of trees and increased RLD of crops in the upper layer and vice versa in the deeper layers observed in the present study confirms the safety-net hypothesis in simultaneous agroforestry systems described by van Noordwijk et al. (1996), Cadisch et al. (1997), Rowe et al. (1999), Vanlauwe et al. (2002) and Suprayogo et al. (2002). Pruning effect on tree roots in 2000 led to reduced RLD of all total-pruned trees of both species to less than 0.1 cm cm⁻³, the minimum density needed to meet the demands for nitrate and water for trees (van Noordwijk *et al.*, 1996). A high safety-net efficiency requires a minimal tree RLD to a certain depth, a minimal level of activity of tree roots present in the soil layers considered, and a minimal demand by the tree for the nutrient considered (Cadisch *et al.*, 1997; Vanlauwe *et al.*, 2002).

In the present study, the topsoil being the most fertile, the fact that crop roots dominated tree roots in the topsoil throughout the three cropping seasons may partly explain why there was increased production of crop under total-pruned trees even during the first year in 1999 when there was no significant difference in RLD of trees between pruning treatments.

Better crop performance under treatments that responded to pruning may also be due to inputs of nutrients from the decay of dead roots resulting from pruning (van Noordwijk *et al.*, 1996).

4.4.3. Pattern of fine root distribution in relation to distance from trees

In 1999, while in karité only the soil layer at 0-10 cm depth showed a decrease of RLD with distance, all depths under néré showed a significant decreasing trend with distance from the tree trunk. The trend was, however, unclear for the second and third growing seasons. The findings of 1999 for néré are in accordance with the results of Tomlinson *et al.* (1998) who found a very strong negative linear relationship between number of roots per square meter and the distance from the trunk. Similarly, Odhiambo *et al.* (2001) reported a decrease tree RLD with increasing distance from stems and conversely an increase of crop RLD with increasing distance from trees. The fact that tree roots dominated tree influence zones beneath crowns of néré compared with the open area (control) suggests an existence of potential competition for water and nutrients. Thus, the less crop production under néré than karité may be due to, not only shading (Kessler, 1992; Kater *et al.*, 1992) or reduced temperature (Jonsson *et al.*, 1999), but also due to belowground competition because of niche overlap between tree and crop roots under néré.

4.4.4. Effect of pruning on fine root weight density and its relationship with fine root length density

Over the period of three years, mean tree fine root weight density for all tree influence zones and all soil depths ranged from 0.062 to 0.182 mg cm⁻³ and this was within the range reported in the literature for tree species (Dhyani *et al.*, 1990; Jones *et al.*, 1998; Vanlauwe *et al.*, 2002). Fine root weight density of millet ranged between 0.005 and 0.016 mg cm⁻³ and that of sorghum from 0.013 to 0.019 mg cm⁻³. The values for sorghum are very close to the 0.017 mg cm⁻³ found by Jones *et al.* (1998).

Despite the fact that the data on RWD for the cropping season of 2001 had poor correlations with RLD, the data for the first two years showed that RWD followed the trend of RLD. This was in agreement with the finding by Vanlauwe *et al.* (2002) who reported a very close relationship between RLD and RWD. Close relationships between these two parameters indicate that RLD can be indirectly estimated by directly measuring RWD, which is less tedious than measuring RLD. However, in the present study some of the r² values for 2001 were very low. This may be due to an increase rate of root re-growth in 2001, two years after pruning. Root re-growth in 2000 was retarded due to low rainfall. Thus, there was close relationship between RLD and RWD in 2000. However, in 2001 a vigorous re-growth of roots occurred because of high rainfall and also because of enhanced crown recovery, which may have increased the demand for water and nutrients, which led to the development of more fine roots. These new roots were very fine and long but very light in weight, the reason why RLD and RWD were poorly correlated in 2001.

CHAPTER V

USE OF PRUNED MATERIAL OF *VITELLARIA PARADOXA* AND *PARKIA BIGLOBOSA* AS MULCH FOR IMPROVED SOIL PROPERTIES AND CROP PRODUCTION

5.1. Introduction

Soil degradation due to nutrient imbalance and inherent low fertility is the main problem of most African soils (Mando, 1997). As a consequence, land use practices such as shifting cultivation and rotation systems are no longer able to meet the increasing demands for food (Kang and Jus, 1986; Kachaka et al., 1993). Under such circumstances, there is a need to find efficient soil management practices that can maintain or improve soil fertility (Kang and Duguma, 1985; Kachaka et al., 1993). Agroforestry technologies such as alley cropping systems were designed for the above purpose and have, therefore, been well studied (Rippin et al., 1994; Muller-Samman and Kotschi, 1994). In these systems it is believed that soil fertility is increased by the application of plant residue as mulch to the soil (Yamoah et al., 1986b; Rippin et al., 1994; Lehmann et al., 1995). However, alley cropping practices have failed in arid and semiarid tropics, where below ground competition for water between trees and crops frequently outweighed the benefits of soil enrichment and microclimate improvements (Ong and Leakey, 1999). In agroforestry parkland systems, on the other hand, there is now growing evidence in the literature of improved soil nutrient, microclimatic conditions and increased crop production beneath large isolated trees due to efficient recycling of nutrients (Ong and Leakey, 1999). In contrast there are also reports such as by Kater et al. (1992), Wilson et al. (1998) and Boffa et al. (2000) who found that sorghum production was reduced under trees. Jonsson et al. (1999), during a year of exceptionally high rainfall, found no significant difference in millet yield between under shade and outside the shade of isolated trees in parklands. These findings suggest that there is a need for an improved method of tree management that increase the beneficial effects of trees while reducing the negative ones.

134

As a management tool, pruning has a potential to reduce the negative effects of trees in agroforestry systems but this needs to be coupled with mulching because finite soil resources such as nitrogen, phosphorus and potassium, which are not naturally replaced over short cycle, should be considered to ensure the sustainability of the systems (Namirembe, 1999). However, there are few data on application of mulch generated by pruning of indigenous parkland trees (Tilander, 1996; Vanlauwe *et al.*, 1997).

Pruning is practiced traditionally by all ethnic groups in parkland agroforestry systems in Burkina Faso (Ki, 1994; Ouédraogo, 1995a; Timmer *et al.*, 1996; Hall *et al.*, 1997). Pruned materials such as leaves are sometimes collected and used at a small scale as mulch applied on eroded farm fields (Hall *et al.*, 1997). By so doing, farmers aimed at combating erosion but also increasing the availability of nutrients. This shows the need to gather information on the quality of plant materials that can be harvested by pruning trees in agroforestry parklands and used as mulch; on their proper management for synchrony between supply of N from the pruned material and N demand by crop; and on possible interactions between applied fertilizers and pruned materials used as mulch.

Experimental data on use of leaf biomass from shrubs as mulch showed improvement of soil physical and chemical properties, as well as microclimatic characteristics leading to better vegetation rehabilitation on bare soil (Mando and Stroosnijder, 1999). However, the extent to which these improvements occur in cropping systems depends on farming practices and synchronization of nutrient release with crop demands (Myers *et al.*, 1997, Becker and Ladha, 1997). Decomposition and subsequent nutrient release may have an important influence on the organic matter and nutrient budget of soil (Lehmann *et al.*, 1995). Thus, there is a need to understand the mechanism of decomposition and nutrient release when pruned materials are used as mulch. The quantification of decomposition rate in relation to the quality of pruned material used must be assessed through variable ratios (C:N, lignin:N, polyphenol+lignin:N), climatic conditions (soil temperature, soil moisture, number of rains) and decomposers community (Palm and Sanchez, 1990; Heal *et al.*, 1997; Vanlauwe *et al.*, 1997). If the two latter parameters appear to be difficult to change, quality of the pruned material can be manipulated to achieve the maximum

benefit of mulching in terms of both chemical and physical improvements of soil (Vanlauwe et al., 1997; Handayauto et al., 1997; Mando and Stroosnijder, 1999).

The present study was, therefore, carried out to investigate decomposition and nutrient release patterns in leaves obtained by pruning karité and néré and used as mulch and to assess the consequences of applying the leaves as mulch for soil fertility improvement and crop production. The hypotheses tested were:

(1) the quality of leaf mulch, combination of leaf mulch with fertilizer (urea, compost) and the mode of application of leaf mulch (surface Vs incorporation) determine decomposition rate and nutrient release patterns;

(2) as trees modify the micro-environmental conditions, the effects of applying leaf mulch on soil properties and crop production depend on the quantity of leaf mulch applied and the environmental conditions where it is applied (light zones); and

(3) because of high contents of phenolic compounds in leaves of many ligneous species, allelopathic effects occur when applying leaves with high phenolic compounds as mulch.

Two field and one laboratory experiments were carried out to test the above hypotheses and to determine how best leaves of néré and karité can be applied as mulch to influence soil fertility and crop yield.

5.2. Material and Methods

5.2.1. Decomposition experiment

5.2.1.1. Experimental design

The patterns of leaf litter mass loss and nutrient release from prunings of karité and néré when applied as mulch were investigated in the field using the method of incubation of disturbed mixed soil in plastic tubes (PVC) buried in soil. The experiment was conducted in parklands at Saponé, Burkina Faso (see details in Chapter 1) between June 2000 and May 2001 over a period of one year. The leaves of néré and karité constituted the pruned material used. The plastic tubes (10 cm diameter and 20 cm depth) were placed in the soil in June 2000 and the dynamics of leaf mulch biomass and nutrients were monitored six times at monthly intervals during the rainy season over a period of four months (June – September) and two times during the dry season (once during the cold period in December and once during the hot period in April/May). Three factors were investigated:

- Two methods of incorporation of leaves in the soil: incorporation of prunings into the soil (hereafter called under soil) and application of prunings on the soil surface (hereafter called upper soil);
- Three types of management: zero fertilizer, 37 kg N ha⁻¹ using urea (29 mg tube⁻¹), 37 kg N ha⁻¹ using compost (2.2 g tube⁻¹);
- Two types (quality) of substrates: leaves of karité and néré.

Combinations of the three factors gave the following treatments:

- 1. leaves of karité under soil without fertilizer;
- 2. leaves of karité upper soil without fertilizer;
- 3. leaves of néré under soil without fertilizer;
- leaves of néré upper soil without fertilizer;
- 5. leaves of karité under soil with urea;
- 6. leaves of karité upper soil with urea;
- 7. leaves of néré under soil with urea;
- 8. leaves of néré upper soil with urea;
- 9. leaves of karité under soil with compost;
- 10. leaves of karité upper soil with compost;
- 11. leaves of néré under soil with compost;
- 12. leaves of néré upper soil with compost.

These treatments were replicated four times (blocks) in a randomised complete block design repeated six times corresponding to the six sampling times. The number of plastic tubes used was: (2X3X2)X4 blocksX6 sampling dates = 288 plastic tubes. During each sampling time, 48 tubes were removed and assessed.

In each litter tube 3.93 g of leaf litter of néré or of karité that is the equivalent of 5 t ha⁻¹ of leaf litter was placed. The amount of N originating from each fertilizer in treatments 5 to 12 was 37 kg ha⁻¹, which is the recommended dose of N for millet in semi-arid zones of Burkina Faso. In the treatments in which leaf litter was incorporated under soil (treatments 5-12), each tube was filled with local soil up to 12 cm leaving the top 8 cm of the tube. A sub-sample of the local soil was mixed with urea or compost and a layer of 2 cm of the mixture was added in the tube on top of which the leaf litter was applied up to 3 cm before another layer of 2 cm of the mixture was added to cover the leaf litter. In the treatments where the leaf litter was applied on the upper soil surface, the leaf litter was placed on top and was covered with mosquito net tied with wire around the tube to protect the leaf litter against wind and in treatments where fertiliser was used the mixture of local soil and the fertiliser was placed below the leaf litter.

5.2.1.2. Laboratory analyses of leaf chemical composition

Prior to the field decomposition experiment, ten samples of leaves from each tree species (i.e. 20 samples) were analysed for initial C, N, P, K, Ca, Mg, ash, lignin, cellulose and polyphenols in the laboratory of the University of Wales Bangor in October 1999. For C and N analysis samples were air-dried and analysed with a CHN-2000 Carbon, Hydrogen and Nitrogen analyser. For the rest of the analyses samples were oven dried. Phosphorus, potassium, calcium and magnesium were analysed after ashing in a muffle furnace at 550°C for three hours and dissolving the ash in 10% HCl. P and K were determined photometrically. Ca and Mg were measured by atomic absorption spectrometry. Lignin and cellulose were analysed by the acid detergent fibre method. Polyphenols were extracted in 50 percent aqueous methanol for one hour in a water bath (80°C) and analysed by Folin-Denis method and reported as percent acid equivalent. Ash dry mass was determined by ashing in a muffle furnace at 560°C for three hours (Anon., 1986; Anderson and Ingram, 1993).



Plate 5.1: Plots of mulching experiment in Saponé, Burkina Faso

The decomposing leaves remaining in the tubes and removed at each sampling time from the field decomposition experiment were cleaned manually to remove roots, organic debris, and mineral soil. The cleaned samples were oven dried at 70°C for 48 hours, weighed and ground for laboratory analyses of N, P, and K in the laboratory of INERA, Burkina Faso at each sampling time between June 2000 and May 2001. Nitrogen was analysed by Kjeldahl method using a mixture of K₂SO₄, H₂SO₄, and selenium for digestion. P and K were measured photometrically. The percent of nutrients remaining in decomposing leaves at each sampling time was calculated by multiplying the leaf biomass remaining in the tube by the nutrient contents of the leaves.

5.2.2. Field mulching experiment

5.2.2.1. Experimental design

This experiment was carried out in parklands at Saponé, Burkina Faso (See details in Chapter 1) twice during the cropping seasons of 1999 and 2000. Six mature trees three from each tree species (néré and karité) were randomly selected. Around each tree four light zones were distinguished: a Central zone which was centred around the trunk of a tree, a Western zone situated on the western side of the tree, partially shaded (1/2 of the area under crown and half outside), an Eastern zone situated on the eastern side of the tree (Plate 5.1, Figure 5.1). Each light zone was taken as a block (replication) and the treatments were randomly applied within it (block). Each plot around each tree had an area of 5.2 m x 5.2 m to accommodate all the treatments. The treatments were leaf litter from pruning of néré and karité applied at the rates shown in Table 5.1. The crop used in this experiment was pearl millet (*Pennisetum glaucum* L.), which is one of the most common crops in Saponé. The leaf litter was spread in each treatment plot at the time of sowing.

Treatment 1 (T1) is a control without leaf litter. In Treatment 3 (T3) leaf litter was applied to the equivalent of 74.8 kg N ha⁻¹, which was twice the recommended dose of N

fertiliser for millet to take into account for possible loss and recovery of N from the leaf litter in the process of decomposition. The amount in Treatment 2 (T2) was based on a compromise between the maximum potential of leaf litter production from pruning each species that can be obtained from the area and the minimum equivalent of N that is required to influence crop production. Leaf litter of each species was applied only under the trees of the same species. The difference in the amounts of leaf litter of karité applied in 1999 and 2000 was due to the fact that in the first year quantities of leaf litter applied were calculated using leaf N content of karité of 0.72% obtained from literature (Hall et al., 1996) and this gave the equivalent N rates similar to néré (18.7 and 74.8 kg ha-1 for T2 and T3, respectively) as shown in the table 5.1. In the second year, however, the results of the chemical analyses showed that leaves of karité N content was twice higher than the value in the literature and as a consequence the quantity of leaf litter used in 1999 was very high and this was corrected in 2000 by applying the new conversion rate of 1.56% N. The N content of néré in the literature (Hall et al., 1997) was, however, similar to what was found from the chemical analyses and, therefore, the amount of leaf litter applied remained the same. Triple Super Phosphate (TSP) fertilizer was applied at the rate of 17 kg P har on each treatment plot in order to alleviate P limitation to nitrogen response.

	Néré					
Treatments	1999	N equivale	ent 2000	N eq	uivalen	t
		@2.2%		@2.2%		
T1 (control)	0	0	0	0		
T2	850	18.7	850	18.7		
T3	3400	74.8	3400	74.8		
	Karité					
	1999	N equivalent	N equivalent	2000	N	equivalent
		@0.72%	@1.56%		@1.5	6%
T1 (control)	0	0	0	0	0	
T2	2600	18.7	40.5	1200	18.7	
T3	10400	74.8	162.2	4800	74.8	

Table 5.1: Quantities of leaf litter and their N equivalents (kg ha-1) applied in the field mulching experiments in 1999 and 2000 in Saponé, Burkina Faso.





5.2.2.2. Data collection in the field mulching experiment

5.2.2.2.1. Soil physical properties

In December 2000, two undisturbed soil cores of 100 cm³ were taken from 0-5 cm soil layer of each experimental plot to determine soil bulk density and porosity. They were oven-dried at 105°C for 24 hours to obtain their dry weight, from which bulk density was determined (Culley, 1993).

Soil porosity was calculated using the following formula (Carter and Ball, 1993):

Porosity (%) =
$$(1-(d_b/d_p))^*100$$
 (5.2)

Where d_b is the dry bulk density and d_p is soil particle density, which is assumed to be 2.6 g cm⁻¹ (Carter and Ball, 1993).

Saturated hydraulic conductivity (K_{sat}), which describes the ability of bulk soil to transmit water, was determined from the same undisturbed soil samples using the constant head method based on Darcy law (Klute, 1986). K_{sat} was calculated as follows:

$$K_{sat} = ((V/(t^*S))^*((h/(h+l)))$$
(5.3)

where

K_{sat} = saturated hydraulic conductivity (cm day⁻¹), V = volume of water filtered during a time t (cm³) t = time of the measurement S = the surface of the sample (cm²) h = high of soil sample (cm) l = water layer high (cm) This measurement was repeated twice for each plot.

Furthermore, a small rainfall simulator developed by Kamphorst (1987) was used to assess soil water infiltration in relation with the quality and the quantity of the mulch applied. Two replicates of rain simulation were done in each plot. Essentially the simulator consists of three parts:

- a sprinkler with a built-in pressure regulator for the production of standard rain shower;
- a support for the sprinkler, which also functions as a wind shield in the field;
- a stainless steel frame, which is hammered into the soil and is meant to prevent the lateral movement of water from the test plot to the surrounding soil. Attached to the plot frame is a gutter for the removal of the runoff to a sample bottle.

The sprinkler consists of a calibrated cylindrical water reservoir with a capacity of approximately 1200 ml, which is in open connection with the sprinkling head. Water is discharged from the sprinkling head through 49 capillaries. The discharge rate is determined by the length and the inner diameter of these capillaries.

Before filling the sprinkler with water, a plot with a slope of 20% was prepared with the aid of a spade. The slope length was at least 0.4 m, to accommodate both the test plot and the gutter. At the bottom of the slope a small trench was made, in which the sample bottle for the collection of runoff was placed. The support was placed on the plot, to check that the latter had the required slope of 20% and was level in the direction perpendicular to the direction of the slope. These requirements were fulfilled when the upper rims of the support were all horizontal, which was checked with level instrument. Adjoining to the test plot an auxiliary plot was made, which was used for filling the sprinkler with water. Then the aeration pipe was closed with a cork and the sprinkler was placed upside down on the support. The cork on the filling pipe was removed and the sprinkler was moved with the support to the test plot, the level of the water in the reservoir was noted and the simulation started by removing the cork from the

aeration pipe. The ponding was considered to be the time elapsed between the beginning of the rain event and that of runoff.

5.2.2.2.2. Soil chemical properties

Composite soil samples, consisting of bulked samples from two random sampling positions, were taken from each treatment plot in the upper 0-10 cm soil layer. The samples were air dried for chemical analyses. Soil organic carbon was determined using potassium di-chromate, sulphuric acid and Mohr's salt (Anderson and Ingram, 1993). Total nitrogen was analysed using a Kjeldahl digestion. For total phosphorus and total potassium the soil was mineralised using sulphuric acid and determined by colorimetry and flame photometry, respectively. Available phosphorus was extracted using ammonium molybdate and ascorbic acid and determined by colorimetry (Walinga *et al.* 1989).

5.2.2.2.3. Millet performance

The performance of pearl millet (*Pennisetum glaucum* L.) in each treatment plot was assessed during cropping seasons of 1999 and 2000. During both cropping seasons, the farmers who owned the trees sowed the millet in the second week of June each year at the rate of 32,000 hills ha⁻¹. Grain yield and total dry matter production were measured at harvest.

5.2.3. Allelopathy experiment

To test the possible inhibition of germination and growth of crop by leaf litter of néré and karité, two laboratory experiments were conducted in the laboratory of INERA, Burkina Faso. In November 2001, leaves of néré and karité, ground to 2 mm size, were soaked at the rates of 25 g and 50 g in 250 ml of distilled water for 24 h. Ten seeds of *Sorghum bicolor* (L.) Moench were placed in a Petri-dish containing two thicknesses of Whatman's No. 1 filter papers. In the first experiment, five treatments were compared, i.e. two doses of the leachate (25 g and 50 g) per species and a control (distilled water only).

Karité 1 – 25 g of karité leaf in 250 ml distilled water Karité 2 – 50 g of karité leaf in 250 ml distilled water Néré 1 - 25 g of néré leaf in 250 ml distilled water Néré 2 – 50 g of néré leaf in 250 ml distilled water Control - distilled water only

To confirm the results of the first experiment, a second experiment was set up to compare only between Karité 2, Néré 2 and the control, i.e. three treatments. In both experiments each treatment was repeated six times (six Petri-dishes) and each Petri-dish received 5 ml of either leachate or distilled water. The Petri-dishes were then placed in a dark and after 10 days the number of seeds germinated were counted and the length of radicle on each germinated seed was measured.

5.2.4. Data analysis

The difference between treatments for the different parameters including crop performance and soil properties in the mulching experiment was analysed using GLM Analysis of Variance (ANOVA). For decomposition experiment species, method leaf litter incorporation and time of assessment were used as factors in the ANOVA. Where significant differences were observed Tukey's comparison test was used to separate all the means. The data of the decomposition experiment were also subjected to regression analysis. Decomposition and nutrient release constants, k, were determined for each treatment by a single exponential model (Wieder and Lang, 1982):

$$X = X(o)e^{-kt}, (5.4)$$

where X(o) is the original amount of leaf litter applied, k is a constant, X is the proportion of initial mass or nutrient remaining at t time, t is in months.

Decomposition and nutrient release constants (k) were compared statistically by performing pairwise t-tests (Palm and Sanchez, 1990).

5.3. Results

5.3.1. Decomposition of karité and néré leaf litter

5.3.1.1. Initial characteristics of leaves

Carbon, nitrogen, phosphorus, calcium, ash and lignin concentrations were greater in néré than karité leaves whereas the rest of the chemical constituents (potassium, cellulose, polyphenols) were greater in karité leaves (Table 5.2). The concentration of magnesium was of similar magnitude in both species.

Table 5.2: Initial nutrient, ash, lignin, cellulose and polyphenols concentrations (%±SE) in leaves of karité and néré from Saponé, Burkina Faso.

	Karité leaves	Néré leaves
C	48.44±0.50	50.39±0.21
N	1.56 ± 0.04	2.20±0.10
Р	0.18 ± 0.01	0.24±0.01
К	0.43±0.01	0.22±0.02
Mg	0.11±0.01	0.12±0.01
Ca	1.63 ± 0.14	2.36±0.22
Ash	5.10±0.17	5.46±0.23
Lignin	15.74 ± 4.28	20.78±1.32
Cellulose	18.99±0.66	16.26±0.80
Polyphenols	5.91±0.07	5.51±0.28

5.3.1.2. Decomposition and release of nutrients

The two species exhibited different decomposition patterns. The pattern in néré leaves had a rapid first phase of decomposition lasting for three months followed by a slower phase, whereas the pattern seen in karité was slow but decomposing at constant rate throughout the 11 months (Figure 5.2). Analysis of variance revealed significantly (P<0.05) lower decomposition rate of karité leaves compared with néré and leaves in under soil position decomposed faster than upper soil position (P<0.05). Addition of fertilizer did not affect the rate of decomposition. This was further confirmed by t-test comparison. However, significant interaction was observed between species and method of incorporation, with leaf litter of néré incorporated under soil giving the highest rate of decomposition (P<0.05). Analysis of decomposition rates at each sampling date confirmed lower rate in karité leaves than in néré, except during the last two sampling times (7th and 11th month) in which the two species had similar rates of decomposition. However, t-test comparison between decomposition constants did not confirm that néré decomposed significantly faster than karité (Equations 5 – 16; Table 5.3). On the other hand t-test comparison of decomposition constants confirmed that leaf litter placed under soil decomposed significantly (P<0.05) faster than that in upper soil position (Table 5.3).



Figure 5.2: Effects of treatments on the percent of original leaf mass remaining with time for decomposing leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in Saponé, Burkina Faso.

Karité	compost/under	6.0103e ^{-0.2811x}	$[r^2 = 0.87 ; P < 0.01]$	(5.5)
	compost/upper	4.3707e ^{-0.1487x}	$[r^2 = 0.92; P < 0.01]$	(5.6)
	Under	5.4513e ^{-0.2668x}	$[r^2 = 0.98; P < 0.01]$	(5.7)
	Upper	5.0564e ^{-0.2168x}	$[r^2 = 0.79; P < 0.01]$	(5.8)
	Urea/under	4.61e ^{-0.2378x}	$[r^2 = 0.81; P < 0.01]$	(5.9)
	Urea/upper	4.7541e ^{-0.1852x}	$[r^2 = 0.87; P < 0.01]$	(5.10)
Néré	compost/under	3.7427e ^{-0.1799x}	$[r^2 = 0.56; P < 0.01]$	(5.11)
	compost/upper	3.8529e ^{-0.1595x}	$[r^2 = 0.59; P < 0.01]$	(5.12)
	Under	4.4035e ^{-0.2897x}	$[r^2 = 0.51; P < 0.01]$	(5.13)
	Upper	3.7795e ^{-0.2068x}	$[r^2 = 0.50 ; P < 0.01]$	(5.14)
	Urea/under	4.3833e ^{-0.252x}	$[r^2 = 0.79; P < 0.01]$	(5.15)
	Urea/upper	4.169e-0.206x	$[r^2 = 0.69; P < 0.01]$	(5.16)

In general decomposing leaves of néré released nutrients significantly (P<0.05) faster than leaves of karité except for potassium (Equations 17 – 52; Figure 5.3, 5.4, 5.5 and Table 5.3). In a period of three months corresponding to the period of cropping season for most of the cereals cultivated in the study area, leaves of karité released 40%, 70% and 80% of their original contents of nitrogen, phosphorus, and potassium (Equations 29-52), respectively. The percentages released from néré leaves were 80%, 90% and 75% for nitrogen, phosphorus and potassium, respectively (Figure 5.3, 5.4, 5.5).

Addition of urea or compost did not show significant effect on nutrient release in both species (Table 5.3). Within each species, nutrient loss constants (k), for all nutrients except for nitrogen were greater than those for leaf mass loss constants (k) (Table 5.3). The rate of release of nutrients from decomposing leaves followed the general trend potassium > phosphorus > nitrogen. An exception to this general trend was phosphorus in néré, which appeared to be released more rapidly than potassium (Table 5.3).

There was a short net immobilization of nitrogen for the first month in the treatment where karité leaves were associated with urea and incorporated under soil and during the first two months in the treatment where karité leaves were associated with compost incorporated under soil (Figure 5.3). This period was followed by low but positive net mineralization during the remainder of the experiment. In general, nitrogen release was very slow in karité for all the treatments (Figure 5.3). Contrarily, there was no immobilization for phosphorus and potassium in karité and for all nutrients in néré. Thus, there was similarity between leaf litter mass loss and nutrient release in both species, with the exception of nitrogen in karité (Figures 5.2, 5.3, 5.4, 5.).

Karité	compost/under	109.56e-0.2658x	$[r^2 = 0.70; P < 0.01]$	(5.17)
	compost/upper	72.517e-0.1459x	$[r^2 = 0.97; P < 0.01]$	(5.18)
	Under	95.836e ^{-0.2494x}	$[r^2 = 0.84; P < 0.01]$	(5.19)
	Upper	80.312e ^{-0.2011x}	$[r^2 = 0.83; P < 0.01]$	(5.20)
	Urea/under	89.015e ^{-0.2096x}	$[r^2 = 0.68; P < 0.01]$	(5.21)
	Urea/upper	74.964e ^{-0.1709x}	$[r^2 = 0.70; P < 0.01]$	(5.22)
Néré	compost/under	86.345e ^{-0 2119x}	$[r^2 = 0.52; P < 0.01]$	(5.23)
	compost/upper	86.317e ^{-0 2180x}	$[r^2 = 0.75; P < 0.01]$	(5.24)
	Under	111.11e ^{-0.3265x}	$[r^2 = 0.51; P < 0.01]$	(5.25)
	Upper	79.357e ^{-0 2615} x	$[r^2 = 0.42 ; P < 0.01]$	(5.26)
	Urea/under	99.741e ^{-0 2956x}	$[r^2 = 0.72; P < 0.01]$	(5.27)
	Urea/upper	107.95e ^{-0 2883}	$[r^2 = 0.84; P < 0.01]$	(5.28)

Karité	compost/under	10.732e ^{-0.3807x}	$[r^2 = 0.94 ; P < 0.01]$	(5.29)
	compost/upper	6.999e ^{-0.2474x}	$[r^2 = 0.81; P < 0.01]$	(5.30)
	Under	8.5179e ^{-0.3092x}	$[r^2 = 0.92; P < 0.01]$	(5.31)
	Upper	7.9683e ^{-0.2949x}	$[r^2 = 0.84; P < 0.01]$	(5.32)
	Urea/under	7.9078e ^{-0.3078x}	$[r^2 = 0.86; P < 0.01]$	(5.33)
	Urea/upper	7.041e ^{-0.2471x}	$[r^2 = 0.75; P < 0.01]$	(5.34)
Néré	compost/under	8.3355e ^{-0.3035x}	$[r^2 = 0.67; P < 0.01]$	(5.35)
	compost/upper	7.6966e ^{-0.2757x}	$[r^2 = 0.64; P < 0.01]$	(5.36)
	Under	9.499e ^{-0.4131x}	$[r^2 = 0.63; P < 0.01]$	(5.37)
	Upper	6.5071e ^{-0.279x}	$[r^2 = 0.41; P < 0.01]$	(5.38)
	Urea/under	8.211e ^{-0.3687x}	$[r^2 = 0.70; P < 0.01]$	(5.39)
	Urea/upper	9.2612e ^{-0.206x}	$[r^2 = 0.78; P < 0.01]$	(5.40)
Karité	compost/under	22.347e ^{-0.479x}	$[r^2 = 0.92; P < 0.01]$	(5.41)
	compost/upper	14.931e-0.3107x	$[r^2 = 0.81; P < 0.01]$	(5.42)
	Under	19.405e ^{-0.4811} x	$[r^2 = 0.95; P < 0.01]$	(5.43)
	Upper	17.708e ^{-0.3744} x	$[r^2 = 0.81; P < 0.01]$	(5.44)
	Urea/under	19.325e ^{-0 4444} x	$[r^2 = 0.84 ; P < 0.01]$	(5.45)
	Urea/upper	18.829e ^{-0 4074x}	$[r^2 = 0.85; P < 0.01]$	(5.46)
Néré	compost/under	7.5255e-0 2693x	$[r^2 = 0.56; P < 0.01]$	(5.47)
	compost/upper	9.2012e ^{-0.2221x}	$[r^2 = 0.56; P < 0.01]$	(5.48)
	Under	9.3653e ^{-0.4046x}	$[r^2 = 0.67; P < 0.01]$	(5.49)
	Upper	7.6572e ^{-0 2859x}	$[r^2 = 0.48; P < 0.01]$	(5.50)
	Urea/under	8.083e ^{-0.3455x}	$[r^2 = 0.74; P < 0.01]$	(5.51)
	Urea/upper	9.4893e ^{-0.2685x}	$[r^2 = 0.71; P < 0.01]$	(5.52)

Species	Decomposition	N release	P release	K release
Karité	0.23±0.02a	0.21±0.02a	0.30±0.02a	0.42±0.03a
Néré	0.22±0.02a	0.27±0.02b	0.33±0.02a	0.30±0.03b
Position				
Upper	0.19±0.01a	0.21±0.02a	0.28±0.02a	0.31±0.03a
Under	0.25±0.02b	0.26±0.02b	0.35±0.02b	0.40±0.03b
Fertilizer				
No	0.25±0.02a	0.21±0.02a	0.32±0.03a	0.39±0.04a
Urea	0.22±0.01a	0.21±0.02a	0.32±0.03a	0.37±0.04a
Compost	0.19±0.03a	0.26±0.03a	0.30±0.03a	0.32±0.06a

Table 5.3: Decomposition and nutrient release constants, k, for leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) as determined from litter tube experiment in Saponé, Burkina Faso.

Data in the same columns with different letters are statistically different at P < 0.05



Figure 5.3: Percent of original leaf nitrogen remaining with time in decomposing leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in Saponé, Burkina Faso.



Figure 5.4: Percent of original leaf phosphorus remaining with time in decomposing leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in Saponé, Burkina Faso.



Figure 5.5: Percent of original leaf potassium remaining with time in decomposing leaves of karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) in Saponé, Burkina Faso.

5.3.2. Soil properties and millet performance as influenced by leaf litter mulch

5.3.2.1. Soil physical properties in relation to the quantity of mulch applied

There was no significant difference between treatments in either soil bulk density or soil porosity in the plots mulched with leaves of either karité or néré (Table 5.4a). No significant difference was also found according to light zones under néré. However, under karité the control zone (away from trees) gave a significantly higher density and lower porosity than the central zone (both P<0.05) (Table 5.4b).

Ponding time increased consistently with an increase in the quantity of leaf litter applied of both species (Table 5.4). There was a significant (P<0.05) lower ponding time in the control zone compared with all the zones under néré. Although there was no significant difference under karité, higher ponding time was observed in the central zone (Table 5.4b).

Saturated hydraulic conductivity did not differ significantly both between treatments and light zones under karité as well as under néré (Table 5.4). Yet, the highest values were obtained in T3 plots of karité (208±117 cm day ¹) and néré (171±39 cm day ¹) (Table 5.4b).

Table 5.4: Soil physical properties (mean \pm SE) according to tree species, treatments and light zones in topsoil (0-5 cm) in Saponé, Burkina Faso.

	Karité			
	Bulk density	Porosity (%)	Ponding time	K _{sat} (cm day ⁻¹⁾
			(mn)	
T1	1.63±0.02a	37±1a	1.55±0.14a	91±38a
T2	1.66±0.02a	36±1a	2.15±0.36a	123.4±38a
T3	1.59±0.04a	39±1a	$3.00 \pm 1.56a$	208±117a
	Néré			
T1	1.54±0.03a	41±1a	1.86±0.21a	138±30a
T2	1.51±0.04a	42±2a	1.89±0.42a	144±43a
T3	1.54±0.03a	41±0a	2.47±0.37a	171±39a

a: Treatments

Data in the same column with different letters are significantly difference at P<0.05

b: Light zones

	Karité			
	Bulk density	Porosity (%)	Ponding time (mn)	K₅at (cm day-1)
Central	1.59±0.02a	39±1a	2.90±0.93a	179±73a
Eastern	1.64±0.01ab	37±0ab	2.28±0.72a	131±102a
Western	1.66±0.02ab	36±1ab	1.57±0.26a	129±30a
Control	1.68±0.02b	35±1b	1.43±0.31a	43±11a
	Néré			
Central	1.52±0.02a	42±1a	2.36±0.20a	117±47a
Eastern	1.48±0.06a	43±2a	2.34±0.68a	211±45a
Western	1.52±0.03a	42±1a	2.04±0.31a	144±13a
Control	1.62±0.02a	38±1a	1.03±0.21b	134±66a

Data in the same column with different letters are significantly difference at P<0.05

5.3.2.2. Soil chemical properties in relation to the quantity of mulch applied

Apart from total potassium, the quantity of soil nutrients increased with an increase in the quantity of karité leaf mulch applied while the trend for the C:N was the reverse (Table 5.5a) yet the difference was not significant. Nitrogen showed a significant (P<0.05) higher value in central zone when compared with other zones mulched with karité leaf litter (Table 5.5b).

There was a significant (P<0.05) increase of soil carbon and organic matter with an increase in the quantity of néré mulch applied (Table 5.4a). There was no significant difference in nitrogen and C:N, yet nitrogen showed an increasing trend with an increase in the quantity of néré mulch applied (Table 5.5a). According to light zones, total phosphorus and potassium were significantly (both P<0.05) higher in the central zone (Table 5.5).

Table 5.5: Soil chemical properties (mean \pm SE) according to tree species, treatments and light zones in topsoil (0-10 cm) in Saponé, Burkina Faso.

	Karité					*************	
	ć	OM (%)	N	C.N	P-Bray I	P-total	K-total
	(g kg-')		(g kg-1)		(mg-P kg-1)	(mg-P kg-1)	(mg-K kg ⁻¹)
T1	5.89±1.36a	1.02±0.23a	0.29±0.06a	22±2a	9±2a	112±15a	348±100a
T2	6.27±0.77a	1.08±0.13a	0.32±0.04a	20±1a	9±0a	133±12a	284±27a
Т3	6.98±0.47a	1.20±0.08a	0.39±0.01a	18±1a	10±1a	150±1a	343±70a
	Néré						
T1	4.64±0.85a	0.80±0.15a	0.28±0.04a	17±1a	10±1a	78±19a	357±76a
T2	5.69±0.69a	0.98±0.12a	0.33±0.04a	17±1a	7±1a	84±33a	295±47a
Т3	10.14±3.27b	1.75±0.56b	0.38±0.06a	29±13b	12±3a	74±26a	320±81a

a: Treatments

Data in the same column with different letters are significantly difference at P<0.05

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	Karité						
	С	OM (%)	N	C:N	P-Bray I	P-total	K-total
	(g kg-1)		(g kg-1)		(mg-P kg-1)	(mg-P kg-1)	(mg-K kg ⁻¹)
Central	8.08±1.00a	1.39±0.17a	0.42±0.03a	19±1a	11±1a	159±6a	388±129a
Eastern	5.60±0.70a	0.97±0.12a	0.26±0.03ab	25±4a	8±2a	111±12ab	278±12a
Western	6.24±0.92a	1.08±0.16a	0.31±0.05ab	20±1a	10±1a	129±12ab	347±41a
Control	4.22±0.05a	0.73±0.01a	0.23±0.01b	19±1a	8±2a	100±15b	228±16a
	Néré						
Central	6.17±0.68a	1.06±0.12a	0.34±0.05a	19±1a	10±2a	126±26a	451±66a
Eastern	5.39±1.55a	0.93±0.27a	0.34±0.10a	16±0a	8±3a	98±18ab	325±47ab
Western	8.29±2.65a	1.43±0.46a	0.34±0.04a	25±8a	9±1a	46±11b	266±19b
Control	3.71±0.73a	0.64±0.13a	0.24±0.02a	15±2a	8±4a	42±10b	223±42b

Data in the same column with different letters are significantly difference at P<0.05

5.3.2.3. Millet performance as influenced by the quantity of mulch applied

In 1999, there was significant difference between karité mulch treatments in both grain yield (P<0.05) and total dry matter production (P<0.05). Millet production consistently increased as the quantity of leaf mulch applied increased (Figure 5.6a). Consequently, T3 gave the highest values both in grain yield (831±36 kg ha⁻¹) and total dry matter production (3711±195 kg ha⁻¹). In 2000, however, there was no significant difference both in grain yield and total dry matter whereas the trend remained similar to that of 1999. The highest grain yield (1071±387 kg ha⁻¹) and the highest total dry matter (3357±49 kg ha⁻¹) were achieved on T3 plots.

There was no significant difference in both grain yield and total dry matter of millet according to light zones both in 1999 and 2000 on karité leaf mulched plots. Nevertheless, western zone gave the highest grain yield both in 1999 (675±87 kg ha⁻¹) and in 2000 (1084±215 kg ha⁻¹) (Figure 5.6b). The highest dry matter was achieved on western zone in 1999 (3385±521 kg ha⁻¹) and on the control zone in 2000 (4883±195 kg ha⁻¹).



b: Total dry matter



Figure 5.6. Millet grain yield (kg ha⁻¹ \pm SE) and dry matter production (kg ha⁻¹ \pm SE) over two growing seasons (1999-2000) according to the type and the quantity of mulch applied in Saponé, Burkina Faso. KGrain = grain yield on karité leaf mulched plot; NGrain = grain yield on néré leaf mulched plot; KTDM = total dry matter on karité leaf mulched plot; NTDM = total dry matter on néré leaf mulched plot.

There was no significant difference between treatments in both grain yield and dry matter production either in 1999 or 2000 on néré leaf mulched plots (Figure 5.6). Nevertheless, the control treatment (T1) consistently produced better than the plots that
received néré leaf mulch. According to light zones, the eastern zone performed significantly better (P<0.05) than the other zones in 1999, with grain yield of 1348±384 kg ha⁻¹ and total dry matter production of 8008±2148 kg ha⁻¹ (Figure 5.6). Similarly, in 2000 millet production (384±220 kg ha⁻¹ and 990±648 kg ha⁻¹ for grain yield and dry matter production, respectively) was higher in the same eastern zone than the other light zones although the difference was not significant (Figure 5.7).



Figure 5.7. Millet grain yield (kg ha⁻¹ ± SE) and dry matter production (kg ha⁻¹ ± SE) over two growing seasons (1999-2000) according to the type of mulch and light zones in Saponé, Burkina Faso. KGrain = grain yield on karité leaf mulched plot; NGrain = grain yield on néré leaf mulched plot; KTDM = total dry matter on karité leaf mulched plot; NTDM = total dry matter on néré leaf mulched plot

- 2 -

5.3.3. Inhibition of crop development due to allelopathy

In the first allelopathy experiment, although there was no significant difference, the least sorghum germination was observed in Karité 2 treatment (50 g karité leaves in 250 ml distilled water) (Table 5.6). In the second experiment, however, Karité 2 significantly reduced (P<0.01) sorghum germination when compared with the control (Table 5.6). In terms of radicle growth, Karité 2 was also significantly (P<0.01) the least among all treatments with leachate in both experiments (both P<0.01). All the treatments with néré leachate gave significantly higher radicle length compared with the control in both experiments (Table 5.6) (both P<0.01).

Table 5.6: Effects of leaf leachates on number of seeds of sorghum germinated (mean \pm SE) and radicle length (mean \pm SE) after 10 days. Karité 1 = 25 g in 250 ml distilled water, Karité 2 = 50 g in 250 ml distilled water Néré 1 = 25 g in 250 ml distilled water, Néré 2 = 50 g in 250 ml distilled water Control = distilled water

		Number germinated	
	Treatments	(out of 10 seeds)	Radicle length (mm)
First	Control	8.2±0.8a	3.8±0.2a
experiment	Karité 1	8.5±0.5a	8.2±0.6b
	Karité 2	7.0±0.5a	4.3±0.4a
	Néré 1	8.5±0.3a	6.8±0.5b
	Néré 2	8.2±0.5a	6.8±0.6b
Second	Control	9.0±0.4a	4.8±0.4a
experiment	Karité 2	5.7±1.0b	4.5±0.4a
	Néré 2	7.3±0.7ab	8.2±0.6b

Data in the same columns with different letters are significantly difference at P<0.01

5.4. Discussion

5.4.1. Decomposition and nutrient release patterns of pruned leaves of karité and néré

Nitrogen content was higher in néré leaves than in karité because néré is a leguminous species even though it doesn't fix nitrogen (Dommergues, 1987; Tomlinson *et al.*, 1995). N content in leaves of néré was of the same magnitude as to what has been reported by Zech and Weinstabel (1983 cited by Hall *et al.*, 1997) while P and K contents were lower in the present study. Hall *et al.* (1996) reported data on chemical composition of karité fallen leaves or abscised leaves in Burkina Faso and the values in the present study were much higher than those reported by these authors perhaps because of translocation processes that may have taken place during abscission and abscised leaves are mostly aged. Oglesby and Fownes (1992) and Vanlauwe *et al.* (2001) made comparison of nutrient content of leaves of different ages and found that nutrient content decreased with age. In general, the chemical composition of the leaves of both karité and néré was within the range of published data (Palm and Sanchez, 1990, 1991; Oglesby and Fownes, 1992; Lehmann *et al.*, 1995; Vanlauwe *et al.*, 2001).

Decomposition rates of leaves of both karité and néré were within the range of values reported by Budelman (1988) and Palm and Sanchez (1990) for leguminous trees. r^2 values of the exponential equations for decomposition against time ranged between 51% and 79% for néré, and between 79% and 98% for karité (Equations 5.5 – 5.16). This indicates that the exponential models reasonably explain the decomposition patterns for karité leaves better than for néré. A double exponential model may have fitted better the data of néré decomposing leaves if there were more sampling dates during the dry period.

Néré has composite leaves and the leaflets are so small that when mixed with soil it becomes very difficult to separate them. This difficulty is more significant when the soil is dry because of fragmentation losses (Oglesby and Fownes, 1992). This may explain the sharp decrease of néré leaf biomass on the 7th month. Leaves of néré were also found to attract termites (Pers. Observ.) and their attack can lead to faster decomposition of néré leaves compared with leaves of karité (Lehmann *et al.*, 1995). A considerable proportion of nutrients may have also been immobilized by the termites in their mounds (Lehmann *et al.*, 1995). Conversely, the persistence of karité leaves to termite attack may be an advantage particularly if they are used to protect soil against erosion on farm fields (Hulugalle *et al.*, 1990; Lehmann *et al.*, 1995; Lal, 1998; Buerkert and Lamers, 1999).

Combining leaves of both species with either urea or compost did not improve the rates of decomposition suggesting that fertilisers were not capable of accelerating decomposition of leaf litter. On the other hand, incorporating leaf litter under soil surface led to faster decomposition but this may have taken place at the expense of other beneficial effects of mulching on the soil surface such as soil protection and reduction of surface runoff and erosion.

Nitrogen immobilization appeared to occur during the first two months for karité leaf as shown by the net immobilization in leaves associated with urea and compost, and incorporated under soil (Figure 5.2). These two fertilisers sources of N and higher soil moisture may have induced an increase in soil microbial population as well as its activity leading to an immobilization of N released from leaves. This is in contradiction with the findings of Palm and Sanchez (1990), who stated that lack of nitrogen immobilization in the tropics may be the norm regardless of the leguminous nature or not of leaves and litter. Poor rainy season and poor distribution of rain events may also be the cause of N immobilization. Vanlauwe *et al.* (1997) observed that plant residue dry matter loss was correlated with the number of rain events rather than with the total amount of rainfall. Contrary to karité, néré leaves with a polyphenol:N ratio of 3.8 were not found to produce net immobilization that may partly be due to termites breaking down the leaves and therefore stimulating microbial activity (Tian *et al.*, 1997).

The two species showed two distinct patterns in N release. All treatments in karité showed little net mineralization or immobilization followed by a low but net mineralization. Similar trend was found in *Inga sp.* by Palm and Sanchez (1991) and they

ascribed this to high lignin content (>16%). The pattern of N release in néré was similar to the patterns of the other two nutrients showing two phases coinciding roughly with rainy and dry periods in Burkina Faso. In the first phase (rainy period) which lasted for three months, the concentrations of nutrients decreased more sharply than in the second phase (dry period). The trend of nutrient release was also sharper in néré compared with karité in which there was no distinction between the two phases. The first phase of decomposition in néré may correspond to mineralization or leaching of soluble or easily decomposable compounds due to the rains (Wieder and Lang, 1982; Palm and Sanchez, 1990, 1991; Vanlauwe et al., 2001). The slow release of nutrients in the second phase may be due to the binding of nutrients to polyphenols in leaves (Palm and Sanchez, 1991; Harborne, 1997; Heal et al., 1997). The general lower rate of decomposition or nutrient release during the 7th and 11th month sampling times may be due to unfavourable conditions of the dry season causing decrease in decomposers population and diversity (Wahcendorf et al., 1997). In spite of higher lignin content in néré, this species had lower lignin:N ratio because of its higher nitrogen content. The other ratios (C:N, polyphenol+lignin:N) had the same trend in both species suggesting that any of these ratios may be used to predict nutrient release in leaf of the two species.

During the first three months, corresponding to the cropping season in the study area, the release of N, P and K ranged from 40 to 80% for karité and from 75% to 90% for néré, respectively. Release of nutrients of similar order has been reported in the literature and the fact that potassium was released faster than leaf decomposition rate has also been reported and this was attributed to dominance of leaching processes for this nutrient (Palm and Sanchez, 1990; Palm, 1995; Lehmann *et al.*, 1995).

5.4.2. Mulching effect on soil properties

Bulk density and porosity did not show any improvement due to either the quality or quantity of mulch applied (Table 5.4). Soil preparation and weeding through hoeing or ploughing may have hidden the effect of mulch because tillage had been shown by Ouattara (1984) to improve soil physical properties. Ponding time, saturated hydraulic conductivity, carbon, organic matter and nitrogen showed an increasing trend with increase in mulch quantity for both species (Tables 5.4, 5.5). For example, organic matter content was significantly higher in T3 and this was much greater than the value reported by Bayala *et al.* (2002) under néré (1.02 \pm 0.09%) and karité (0.97 \pm 0.08%), showing the additional effect of mulch application. Available P was also 2 to 3 times the value reported by Bayala *et al.* (2002). However, total P was lower under néré. The low content of total P under néré has also been reported by Tomlinson *et al.* (1995) and was attributed to the presence of endomycorrhizal symbioses, which certainly enable the root system of this species to exploit the existing P more efficiently and thus reduce its availability.

Despite the difference in N content of the leaves of the two species (Table 5.2), there was no difference in N content under néré mulched plots compared with N content under karité mulched plots. This may be due to the fast decomposition of the leaves of néré as shown in the decomposition experiment. Such fast decomposition may lead to losses of N through leaching (Smithson, 2001) due to the rainy season. This is in agreement with Wachendorf *et al.* (1997) who reported a C-loss of 10% and 40% in dry and wet sites, respectively after one year of decomposition.

The immobilization of N for two months in karité leaves suggests that the greater proportion of N may have been released when the crop demand for N was high. The temporal pattern of nutrient release is as important as the total quantity released (Lehmann *et al.*, 1995). Karité leaves released more P and more gradually than néré leaves and this may have contributed to better grain production on plots with karité mulch. Nevertheless, it should be born in mind that the quantities released from leaves are in addition to the recommended dose of P applied in all plots. Such association has been reported to have additive effect, which induced increase in total dry matter production by 16% and 73% in sudanian and Sahel zones respectively (Buerkert *et al.*, 2000).

5.4.3. Mulching effect on millet production

Over a period of two years, the results of the present study indicate that application of pruned leaves of both néré and karité as mulch had an effect on millet performance as a consequence of changes in soil physical and chemical properties. While néré leaf mulch consistently depressed millet performance (Figures 5.6 and 5.7), karité leaf mulch appeared to improve its performance (Figures 5.6 and 5.7), even though the difference was not always significant. The results with karité mulch agree with the findings of other researchers who worked on biomass transfer systems and showed large increases in crop or vegetation production where tree leaf litter is added (Mando, 1997; Mafongoya et al., 1997; Jama et al., 2000; Wallace et al., in press). On the other hand, the effects are not always beneficial as shown by the reduction of millet production with néré leaf litter due to perhaps very low total P under néré. Similar depressive effects of leaf mulch of some species in semiarid areas have been reported in the literature (Mathuva et al., 1998; Snapp et al., 1998; Nair et al., 1999). In previous studies by Tomlinson et al., (1995) and Bayala et al., (2002) it was found that P content was lower under néré than outside and this may be due its high demand for P and thus competing with associated crop.

Good infiltration rate, high total P and good supply of light (Bayala *et al.*, 2002) may explain why mulched plots of karité outperformed the control and the mulched plots of néré in crop production. Shade has also been found to be a major constraint of crop production underneath néré (Kessler, 1992; Kater *et al.*, 1992; Wilson *et al.*, 1998; Boffa *et al.*, 2000).

Millet performance decreased in 2000 on mulched plots with néré leaves compared with the production of 1999 and this may be due to the poor rain season of 2000. In another hand, millet performed better in 2000 than in 1999 on mulched plots of karité leaves. This may be due to cumulative effects of such persistent material and this is corroborated by the results of the decomposition experiment. Only 40% of the nitrogen contained in karité leaves was released after three months corresponding to the cropping cycle of millet and the decomposition rate during the dry period was very slow. This may have contributed to the better performance of millet because of both mulching effects of the new mulch applied in 2000 and chemical effects of the mulch applied in 1999. Similar cumulative effects may take longer time to appear on plots mulched with néré leaves because of their fast decomposition and this agrees with Buerkert *et al.* (2000) who observed the beginning of the mulching effect the third year of application of millet straw mulch.

Because of wind, fallen leaves were often accumulated on the western side of karité (Pers. Observ.) and the cumulative effect of this source of organic matter may be the reason why crop performed better in this zone in 1999. However, during the low rainfall season of 2000, the low decomposition rate of karité mulch may explain why there was better crop production in the control zone than in the zones under trees (Tian *et al.*, 1997; Wachendorf *et al.*, 1997).

In the case of néré, the eastern zone produced better crop compared with the other light zones. In this zone, soil bulk density was low and soil porosity as well as hydraulic conductivity was high which may have induced a more efficient use of nutrients and this is in agreement with the findings of Yamoah *et al.* (1986b), and Buerkert *et al.*, 2000

5.4.4. Allelopathy

Allelopathy is defined as chemical interactions between and among both plants and microorganisms via releases of biologically active chemical compounds into the environment (Inderjit and Keating, 1999). One such compound is phenolics, which are allelopathic agents producing an inhibitory effect on the germination of seeds of competing species (Hobbs and Atkins, 1991; Harborne, 1997; Inderjit and Keating, 1999). The results of the present allelopathy experiments showed that germination of sorghum seeds treated with leachate of 50 g of leaf of karité and néré in 250 ml distilled was reduced by 37% and 19%, respectively. There was also a reduction in radicle length by 6% under the same treatment only for karité. These results are in accordance with

previous researchers who demonstrated allelopathic effects on germination and growth of herbaceous plants with leaves of several agroforestry species (Suresh and Vinaya Rai, 1987; Chaturvedi and Jho, 1992; Schroth and Lehmann, 1995).

Poor germination has been reported to account for the reduction in crop production under karité and néré by previous workers (Kessler, 1992; Kater et al., 1992). Allelopathic effects may partly explain the observed poor establishment of crop under these two species. Despite the fact the leachate of karité showed more depressive effects than néré, in the natural conditions the situation seems to be the reverse. The effect of karité leachate may be due to high concentration in phenolics. Such high concentration may not occur in the natural conditions because of the slow decomposition rate of karité leaves as shown in the decomposition experiment of the present study and this is also in agreement with the work reported by Inderjit and Keating (1999). In addition, farmers practices involving the gathering of leaves and burning them when preparing land for sowing may also not allow the accumulation of sufficient plant residue to generate pronounced inhibition effects on crops under natural conditions. Such difference between experimental laboratory findings and allelopathic effects under natural conditions has been reported in the literature to be due to the modification of allelopathy in the natural environment by several biotic and abiotic stress factors, uncertain meteorological events, or physical, chemical, and biological soil factors, all of which being able to influence the residence time, persistence, concentration, and fate of allelopathic compounds in the environment (Inderjit and Keating, 1999). According to the same authors, allelopathic effects can also be due to direct release or degraded or transformed products, and direct leaching of inhibitive substances from the crown.

In general, the results of the present experiments indicate possible inhibitory effects of pruned leaves of karité and néré on crop.

CHAPTER VI

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

Agroforestry parkland systems, which have been practised for many centuries by farmers, constitute the most widespread farming systems in the savannah regions of Africa where farmers deliberately select wild multipurpose trees when converting a natural woodland to farmland and retain them on their farms (Chevalier, 1907; Ruyssen, 1957; Pullan, 1974; Pelissier, 1980). The dominant tree species in parklands of West Africa and parts of Central and Eastern Africa are *Vitellaria paradoxa* and *Parkia biglobosa*. Nevertheless, the system that attracted most scientists has been the parklands of *Faidherbia* (*Acacia*) *albida* because of the positive impact of this species on soil fertility, and more importantly because of its spectacular reverse phenology, being leafless during the rainy season thus competing less with associated crops for water and nutrients (Depommier, 1996; Roupsard, 1997).

Since natural woodlands are degrading and woodland resources are diminishing in many parts of West Africa due to population pressure, parklands are increasingly becoming the only resource base to many farmers. Thus, similar attention to *Acacia* parklands has also been extended to karité and néré parklands recently. Yet, parkland trees particularly karité and néré have, so far, been subjected to very few interventions (Boffa, 1995; Hall *et al.*, 1996; Timmer *et al.*, 1996). Recently emerging research results indicate a reduction of crop production in these systems despite higher soil fertility under karité and néré compared with the open area (Maïga, 1987; Kater *et al.*, 1992; Kessler, 1992). The reduction in crop production has been attributed to shading by the dense and spreading crowns of these two tree species. Crown pruning of these trees has been recommended to improve associated crop production (Bonkoungou, 1987a&b; Agbahungba and Depommier, 1989). According to farmers' surveys conducted by de Saint Sauveur (1999) farmers in West Africa prune néré to improve fruit production but do not prune karité for this purpose. Experimental data on pruning of other tree species showed that the effect of pruning on crop is species

and site specific (Mann and Saxena, 1980; Kessler; 1992; Samba, 1997; Namirembe, 1999; Droppelmann *et al.*, 2000).

The present study was, therefore, designed as a participatory field research and carried out with farmers to investigate the potential of crown pruning of karité and néré to improve associated crop production in agroforestry parkland systems in semi-arid region of West Africa. Three main research activities were conducted to assess the effects of pruning: tree and associated crop production, above and belowground interactions between trees and associated crops, and the application of pruned material to improve soil fertility and crop production.

6.2. The response of karité, néré and associated crops to crown pruning

In contrast to what has been reported by Kater *et al.* (1992) and de Saint Sauveur (1999) karité appeared to have a potential to re-sprout as well as néré after crown pruning even though the rate is lower. In line with crown recovery, fruit production of total-pruned trees was also partially recovered two years after pruning. Half-pruned trees of both species did not, however, differ significantly from unpruned trees in terms of crown size and fruit production.

The seasonality feature of both species has slightly been affected as a result of pruning. New shoots appeared to emerge during leaf fall period and there was a slight asynchrony in flowering and fruiting due to allocation of more resources to new shoots in total-pruned trees.

An attempt to establish a relationship between Direct Harvest method (DH) and Random Branch Sampling method (RBS) of Jessen (1955) in order to estimate fruit production in karité and néré was not a success. This may be due to the large crown size of these two species or due to the inappropriateness of the option chosen in the present study. According to Jessen (1955) there are three options in RBS method. The option chosen was the assumption of equality of the probabilities of each branch in a crown. This option was chosen because it was simple, less time consuming and yielded good estimates of fruit production in some wild fruit tree species such as *Uapaca sp.* and *Strychnos sp.* (Nguvulu, 1997) although these were small crowned trees. All the three options tested by Jessen (1955) may involve preliminary investigation to determine the appropriate month in which the estimation must be made as shown for the forecast of the production of almond in California (Anon., 2001a&b). Thus, further research is still required to find an appropriate method for estimation of fruit production in karité and néré.

In terms of resource capture and use, total crown pruning had a significant effect on transpiration and light transmission when compared with unpruned and half-pruned trees. Two years after pruning, total-pruned trees transpired significantly less and allowed more light to reach crops beneath tree crowns. However, half-pruned treatment did not show significant difference with unpruned trees. The difference in crop production between unpruned and total-pruned trees may, therefore, be due to reduction in light interception and transpiration which are known to be the most limiting factors for crop production in arid environments. The extent to which these factors exerted a depressive effect on crop production was not similar between the two species, with néré showing more reduction in crop production. This is in agreement with the findings of other workers who reported similar reduction of millet and sorghum production under néré (Maïga, 1987; Kater *et al.*, 1992; Kessler, 1992; Wilson et *al.*, 1998).

Furthermore, because of the reduction of the demand for resources by the crown due to pruning, root length densities of total-pruned trees were reduced and dominated by crop roots at least in the 0-10 cm topsoil layer over the time span of the present study. However, the intensity of reduction varied depending on the amount of rainfall received.

When rainfall was much higher than the average for the study area as in 1999 and 2001, the effect of total crown pruning on tree root length density was not significant, yet crop roots dominated root population in the upper 0-10 cm soil layer. This means total-pruned trees of both species are capable of maintaining high root densities when environmental conditions are favourable despite the reduction in crown size. Fine root dieback also did not occur in 1999 perhaps because of the resilience of root systems of mature trees due to high nutrient and carbohydrate reserves in their stems and coarse roots that enabled pruned trees to maintain and replace fine roots

during new shoot re-growth. Osonubi and Fusehun (1987) and Teklehaimanot *et al.* (1998) reported a high tissue capacitance and internally stored water in seedlings of néré. Despite this capability, total-pruned trees of néré and karité transpired 3 and 10 times, respectively, less than unpruned trees, confirming the fact that, although pruned trees were able to maintain high root length density, the activities of these roots were very low. These findings agree with reports in the literature (van Noordwijk *et al.*, 1996; Lehmann, 1998b, 1999; Namirembe, 1999; Vanlauwe *et al.*, 2002). These findings have also proved the fact that it was the leaf that exerted the most direct effect on tree water uptake as also reported by Namirembe (1999) who found a close correlation between leaf area and sap flow in *Senna spectabilis*. The results of the present study also suggest that there is not always a direct relationship between root length density and root activity and this finding is also in agreement with reports in the literature (Cadisch *et al.*, 1997; Hinsinger, 1998; Rowe *et al.*, 1999).

However, when rainfall was poor as in 2000, total crown pruning significantly reduced tree root length density and induced the development of less roots in the 0-10 cm soil layer than in the 20-30 cm layer in both species. The overall reduction of root length density in total-pruned trees was large enough to create a safety-net for water and nutrients at least in the top 10 cm of soil depth for the benefit of crop (van Noordwijk et al., 1996; Vanlauwe et al., 2002). Root dieback in the 50 cm soil depth during poor rainy season suggests that trees may rely on deeper soil layers for water when soil water becomes limiting, agreeing with the findings of Namirembe (1999). The results of the present study also show the potential of crown pruning to create temporal belowground niche differentiation, suggesting a complementarity of pruned trees and crops especially between karité and sorghum or millet. One possible reason why karité didn't depress crop production even under unpruned trees as much as néré may be due to its ability to reduce its root length density in the topsoil layer and develop deeper roots more than néré during poor rainy season. This may be an intrinsic characteristic of karité, which may have also been accentuated by pruning. Lehmann et al. (1998b) made similar observations under Acacia saligna in response to drought. As a result of this characteristic karité may have an ecological advantage over néré, and therefore a good candidate for intercropping systems in semi-arid areas.

Both karité and néré appeared to improve soil fertility under their crowns, with soil under néré being more fertile than under karité. This feature is a characteristic of large trees on farms in semi-arid areas (néré was much bigger than karité both in tree diameter and crown projection area) and this corroborates findings by previous workers (Kater *et al.*, 1992; Samba, 1997; Jonsson *et al.*, 1999; Ong and Leakey, 1999; Pandey *et al.*, 2000). Once the constraints of light and water limitations were reduced by pruning, the presence of high soil fertility under tree crowns resulted in higher associated crop production under pruned trees and this is in accordance with previous findings by Kessler (1992), Samba (1997) and Kho (2000a, b).

From the results of the present study it may be concluded that crown pruning of both species improved associated crop production as a result of positive above and belowground interactions between trees and crops in terms of light, water and soil nutrient capture and utilisation. However, good understanding of the relative contribution of each of the above three environmental factors (light, water and nutrients) is essential for making proper decision concerning tree pruning as a management tool in agroforestry parkland systems (Kho *et al.*, 2001). This is still to be established.

Millet and sorghum responded similarly to tree crown pruning. Both crops developed higher root length density than trees under total-pruned trees in the top 0-10 cm soil depth throughout the time course of the present study. Moreover, during the poor rainy season of 2000, millet roots dominated root population up to 50 cm soil depth. This may have created spatial complementarity and contributed to high millet production during 2000. Less water taken up by trees and dominance of root population by crops may mean crops had more access to water and nutrients thus achieving a high safety-net efficiency in the system (van Noordwijk *et al.*, 1996; Cadisch *et al.*, 1997). However, the extent to which crop benefited from this, needs to be evaluated with further research that may involve the use of isotopes (Rowe *et al.*, 2001). The improvement in crop production must also be balanced with tree fruit production before concluding whether pruning is beneficial of not.

6.3. Decomposition and nutrient release of pruned materials and their mulching effects on soil and crop

As a result of pruning or reduction of crown area, the contribution of trees to soil fertility may be reduced in the long term. This may be alleviated by using the pruned material as mulch provided the effect of mulching on crop is persistent while achieving the synchrony between nutrient release from decomposing pruned material and crop nutrient demand. This also implies that the pruned material shouldn't release substances with inhibitory effects on crop germination and/or growth. Because parkland trees have rarely been subjected to management and research, information on decomposition and nutrient release from leaf litter applied as mulch is scarce. The amount of nutrients that can be provided by pruning is determined by tree biomass production and nutrient concentrations of leaves both of which depend on climate, soil type, tree species, tree density and tree pruning regime (Palm, 1995).

The pruned leaves of the karité and néré in the present study showed two distinct decomposition patterns with a persistence pattern in the former and more rapid decomposition in the latter. Néré leaves decomposed faster, with less than 32% of the initial weight remaining after the rainy season (4 months) while karité leaves had slower decomposition rate with 43% of the leaf litter remaining at 4 months. This means there was large quantity of residual leaf litter of karité in the soil when the second mulching experiment was conducted in 2000. Except for nitrogen, nutrient release patterns were similar in both species. Nitrogen immobilization was observed in karité leaves because of its low N content and high content in phenolics and this is in contrast with the report by Palm and Sanchez (1990) who generalised by stating that lack of N immobilization may be the rule in the tropics.

The mulching experiment of the present study showed the potential of improving crop production by applying leaves of karité as mulch. This may be because better synchrony between leaf litter decomposition and crop nutrient demand was achieved in karité leaf mulch due to its slow and constant rate of decomposition. In addition, due to the slow decomposition rate, leaves of karité may have had more mulching effect than leaves of néré in terms of protecting soil against excessive heat, runoff and erosion. In spite of the similarity of the effect of leaf litter mulch of both species on soil properties, crop production was suppressed by the application of néré leaves. The fast decomposition rate of néré leaves may have significantly reduced its mulching effect. The fast release of nutrients and the rainy season may have also caused nutrients to be leached beyond the reach of crop roots. Despite the low rainfall in 2000 the effect of karité mulch on crop production in 2000 was much higher than in 1999 perhaps because of the residual leaf litter mulch remaining in the soil from the previous year. This means that the effect of mulching is both short and long term. Buerkert *et al.* (2000) reported that mulch-induced total dry matter increases in millet became obvious only during the third year of application of the mulch.

Poor soil physical properties may also contribute to limitation on efficient use of nutrients (Yamoah *et al.*, 1986b; Buerkert *et al.*, 2000). Although it was not significant, bulk density was lower and porosity higher in plots mulched with either karité or néré leaves. There was also more ponding time under these plots. These may explain why there was improved crop production on mulched plots due to perhaps increased nutrient uptake by crops. For instance, Buerkert and Lamers (2000) reported that improvements in soil physical properties induced by mulch led to increased total nutrient uptake of millet at harvest by between 34 and 86% for N, between 31 and 161% for P and between 56 and 126% for K.

Leaves of ligneous species have been reported to display inhibitory effect on seed germination of competing species (Harborne, 1997; Inderjit and Keating, 1999). This possibility was evaluated in the present study but there was a discrepancy between laboratory results and field observations. Leachate of karité seemed to have more inhibitory effect than that of néré while in the field it was the mulch of néré that depressed crop. This suggests that the existence of inhibitive substances in leaves doesn't always imply that they will have inhibitive effects on crops under natural conditions in the field. This is due to the fact that allelopathic effects are mediated by environmental conditions and decomposers community under natural conditions (Inderjit and Keating, 1999). However, caution must be taken in this regard because the laboratory experiments used sorghum while the field experiment was based on millet. There may be differences in the two species of crop in the way they respond to either leachate or mulching.

6.4. Limits of the approach used in the present study

The use of concentric zones aimed at controlling directional biases related to leaf and rain fall, and micro-variability of soil fertility. With the approach used in the present, it was not possible separate the effects of the different factors nor the effect of microsite. Pruning resulted in a reduction of water transpired and therefore to reduction in competition for this resource as well as nutrients. However, the extent to which untapped water was used by associated crop remains unknown. Similarly, the uptake of nutrients released from applied mulch material was not determined.

A theoretical approach to separate the tree effects is to conduct detailed process measurements and synthesise the different processes by modelling (Kho et al., 2001). This is still possible with the data collected in the present experiment and this approach has the advantage of giving results that can be extrapolated to other circumstances. More empirical approaches are to directly control a component effect in the field experiments. Examples are pruning of branches and/or separating root systems with barriers allow separation of competition effects for radiation and/or for water and nutrients from other effects. Transfer of mulch or soil from under the tree to the open and vice versa allows separation of the mulch or soil effects from other effects (Kho *et al.*, 2001). The use of isotopes allows assessing the layer from which water and nutrients are drawn as well as the quantity taken (Cadish *et al.*, 1997; Rowe *et al.*, 1999). These approaches were beyond the scope of the present study but should be considered for future work.

6.5. General conclusions and recommendations

Crown pruning induced a significant increase in light transmission and a significant decrease in water transpired. Water being the vehicle of the nutrients, the reduction in water consumption may have be associated with a reduction in nutrient uptake. This confirmed the first hypothesis of the present study even though the nutrients uptake was not directly measured (refer to page 10). A reduction of tree root density

was also observed when comparing unpruned and total-pruned trees and that confirms the second hypothesis. Finally, because of the intrinsic trends of resource factors with distance from tree trunk, the effects of pruning were found to decrease accordingly with these trends confirming the third hypothesis.

Even though the improvements were not statistically significant, better physical and chemical properties of soil can be assumed to have contributed to better crop production at least under karité mulch during the two years of the experiment. This confirms the last hypothesis. Nonetheless, the quantity of nutrients released from the decomposing mulch and taken up by crop is still to be established.

A key conclusion that can be drawn from the present study is that total crown pruning is beneficial to crops in the short term.

From the results of the present study, it appeared that fruit production of totalpruned trees did not recover fully two years after pruning. This implies that there is a need to continue monitoring the pruned trees over a longer period to determine if complete recovery of fruit production or an optimum compromise between fruit and crop production could be achieved before conclusions are made whether pruning is beneficial or not.

Total crown pruning of karité and néré induced positive below and aboveground interactions between tree and crop over a period of three years. Light transmission to the associated crops was increased. This effect was more significant under néré because of its larger crown projection area before pruning, which casted more shade and exerted more negative effect on associated crop than karité. Total pruning also induced a sharp reduction in tree transpiration rate by 1000% and 300% in 1999 in karité and néré, respectively. In 2001, however, because of partial recovery of the crowns of total-pruned trees, the reduction in transpiration rate was less than in 1999. Total pruning of the crowns of karité and néré also resulted in a positive tree and crop belowground interaction. This effect was more significant in karité than néré particularly during the dry season of 2000. Karité showed more sensitivity to dry conditions than néré and this resulted in a reduction of its root length density in the topsoil 0-10 cm soil depth regardless of whether the tree was pruned or not. Thus

it was concluded that karité may be a more suitable agroforestry species in semi-arid areas than néré.

The application of pruned leaves of karité as mulch improved crop production probably because of its mulching effects such as reduction of soil temperature and soil evaporation thus increasing soil moisture and reduction of runoff and erosion.

From the above results and conclusions, the following general recommendations are made.

1. Since half crown pruning did not negatively affect either tree fruit or crop production, it is recommended that this practice may be used by farmers for producing wood for fuelwood and leaf litter for mulching. This technique can also be used to combat plant parasites like *Tapinanthus* by cutting off the infested branches.

2. Pruning practice to reduce above- and belowground competition for benefit of associated crops can be recommended in the light of the increased light supply and the reduction of root density in crop rooting zone and consequently the increase in crop production observed in the present study.

3. Based on increased production by applying the mulch of karité and since fertilisers are expensive and inaccessible to many farmers, it is recommended that extension workers promote the use of pruned materials on farms as a source of organic matter to improve crop production and at the same time protect soil against excessive heat, runoff and erosion.

6.6. Specific recommendations for further investigation

Despite advances made by the present study, some aspects merit further investigation in order to get a full understanding of the mechanisms involved in resource capture and sharing in agroforestry parkland systems with pruned trees. 1. Further research is required to find an appropriate method for estimation of fruit production in karité and néré and to assess the quality of fruit produced as a result of pruning.

2. Crops benefited from total crown pruning but the benefit of total crown pruning to fruit production has not yet been established. It is, therefore, recommended that the monitoring of total-pruned trees is continued over a longer period to determine if full recovery of fruit production or an optimum compromise between fruit and crop production can be achieved.

3. Soil fertility has been shown to be higher under pruned trees than in the open but it is not known for how long pruned trees are able to maintain their effects on soil fertility. Thus, further research is recommended to assess the effect of pruning on soil fertility on long-term basis.

4. A reduction of aboveground biomass was associated with a reduction in water transpired by trees and probably a reduction of nutrient uptake due to a reduction in root length density in the upper soil layers. However, the extent to which crop is benefiting from such reduction in terms of water use and nutrient capture has not been assessed. It is, therefore, recommended that further research is conducted using isotopes.

5. Since soil fertility improvement caused by nutrient cycling via tree leaf litter biomass decomposition in agroforestry systems is very site-specific, it is recommended that similar studies are replicated elsewhere with different climatic and soil conditions.

6. Since leaf litter mulch is applied directly in fields where trees are pruned, the practice proposed in the present study may be more profitable than cut-and-carry system. However, an economical evaluation of the practice is recommended before recommending the practice to farmers.

7. The effect of mulching on crop production may also be due to weed control and increase in soil fauna. Thus, these aspects need to be assessed in future studies as well as combinations of leaf litter mulches of the two species with other fertilizers.

8. Because of the paucity of organic matter in soils of semi-arid areas and the potential and effective cumulative and residual effects of mulching over a longer period, the practice of applying pruning materials as mulch deserves further studies on a larger scale with a larger number of crops and tree species.

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APPENDICES

Appendix 1: Example of Anova analysis carried out on crop yield data

Factor Type Level Species fixed Pruning fixed Zone fixed	s Val 2 kan 3 0.0 4 A B	lues rite nere) 0.5 1.0 3 C D				
Analysis of Variance	for (Grain, using	Adjusted SS	for Tests		
Source .	DF	Seq SS	Adj SS	Adj MS	F	P
Species	1	2262208	2922837	2922837	8.38	0.006
Pruning	2	2097351	2862997	1431498	4.10	0.023
Zone	3	4820698	5710368	1903456	5.45	0.003
Species*Pruning	2	223216	336347	168174	0.48	0.621
Species*Zone	3	2375982	2752827	917609	2.63	0.061
Pruning*Zone	6	2122209	2244885	374147	1.07	0.393
Species*Pruning*Zone	6	557853	557853	92975	0.27	0.950
Error	47	16400524	16400524	348947		
Total	70	30860042				

Appendix 2: Example of covariance analysis carried out on root length density (RLD)

General Linear Model: RLD (cm cm-3) versus Pruning

Factor Ty	pe Levels	Values				
Pruning fix	red 3	0% 100% 5	508			
Analysis of V	Variance fo	or RLD (cm,	using Adju	sted SS fo	or Tests	
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pruning	2	0.01209	0.00511	0.00255	0.21	0.811
Depth (Pruning	J) 3	0.80306	0.80306	0.26769	22.00	0.000
Error	169	2.05624	2.05624	0.01217		
Total	174	2.87139				
Term	Co	ef SE Coef	т	Р		
Constant	0.282	54 0.01699	16.67	0.000		
Depth (Pruning	1)					
08	-0.0045	0.00100	-4.56	0.000		
100%	-0.0049:	26 0.001052	-4.68	0.000		
50%	-0.0048	54 0.001007	-4.82	0.000		