AN ABSTRACT OF THE DISSERTATION OF

Rajive K. Singh for the degree of Doctor of Philosophy in Forest Science presented on June 6, 1996.
Title: Tree and Crop Productivity and Soil Organic Matter Changes as Influenced by Leucaena Hedge-row management in Sub-humid India.

Abstract approved: Signature redacted for privacy.
William H. Emmingham

The overall objective of this study was to evaluate biomass production and soil ameliorative potential of alley farming in sub-humid India. Effect of the cutting height (40, 80, 120, 160 cm) of Leucaena hedges and root barriers on biomass yield of Leucaena and maize and wheat crops were examined. Trees were pruned at sowing of crops and pruned biomass recycled as surface mulch at the rate of 0, 1.5, 3, 4.5 and 6 Mg ha^{-1} twice every year.

Biomass production from the trees increased with increasing cutting height up to 120 cm without any substantial reduction in the crop yields. Root barriers had little effect on trees, no effect on maize, but significantly increased wheat grain and straw yield near the trees indicating competitive below ground interaction between Leucaena and wheat. Some alteration in pruning timing may help to minimize tree-crop competition.

Crop yields sharply increased with increasing mulch levels when compared on a net-cropped-area basis. However, growing of higher levels of mulch material rapidly reduced area under crops. When adjusted for loss in crop

area, a reduction in the grain production was estimated with increasing mulch levels. Estimates based on tree-crop interactions observed in this study show that an alley cropping system with 20% area under Leucaena hedge-rows would provide about 12% lower grain yield and 15% higher fodder yield from crops compared to sole cropping system. In addition, trees would provide about 3.2 Mg ha^{-1} fuel wood. In such an arrangement, about 3 Mg $ha^{-1}yr^{-1}$ mulch can be recycled which will have little soil ameliorative value as it showed only marginal increase in soil organic matter (SOM). The system should, however, maintain current yield levels.

I used a simulation model SCUAF (Soil Changes Under Agro-Forestry) for predicting expected changes in SOM under different mulch levels. The predicted changes in SOM after a period of 25 years were of the same magnitude as observed changes in soil microbial biomass (Bc) during the 3 year study. Results of this study support the hypotheses that the Bc:Oc ratio tends to return to a climate induced equilibria and early changes in Bc may be used for providing quantitative projections of changes in SOM under different land management options. However, this relationship needs to be validated with long-term field data.

TREE AND CROP PRODUCTIVITY AND SOIL ORGANIC MATTER CHANGES AS INFLUENCED BY LEUCAENA HEDGE-ROW MANAGEMENT IN SUB-HUMID INDIA

by

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TREE AND CROP PRODUCTIVITY AND SOIL ORGANIC MATTER CHANGES AS INFLUENCED BY LEUCAENA HEDGE-ROW MANAGEMENT IN SUB-HUMID INDIA

INTRODUCTION

Degradation of basic resources - soil and water - coupled with an alarming growth rate of human and cattle populations are likely to create serious challenges to meeting food, fodder, fiber and fuel requirements of inhabitants of most developing countries in the immediate future. At present, India supports 16 percent of world population with only 2.4 percent of land surface area. Additionally, India has the largest animal population including more than 480 million ruminants. As the population continues to grow at the rate of about 2 percent per year (DIESA, 1991), the widening gap between demand and supply might further aggravate the process of land degradation. More intensive cultivation of irrigated lands with the stipulation of sustainability and judicious utilization of rainfed marginal lands will be the avenues for meeting demands of food, energy and fiber in the future.

Agroforestry, which has been a way of life for Indian farmers for centuries, offers tremendous opportunities for sustainable utilization of under utilized and production constrained lands, which are either prone to various forms of degradation or have already been degraded. Agroforestry refers to a wide range of combinations of woody and non-woody vegetation and is practiced in innumerable forms the world over. The bush-fallow slash-and-burn cultivation system used by traditional farmers for generations exploited the potential of trees and shrubs for soil fertility regeneration and weed suppression. The effectiveness of this role of trees gradually declined with shortening of fallow periods due to increasing population pressure. Alternative forms of integrating trees with crops are being evaluated which can provide acceptable production levels on a sustained basis.

Nair (1989) proposed a classification scheme and has documented prominent agroforestry systems being practiced in the tropics with a variety of objectives. The positive role of trees in erosion control and soil productivity maintenance on a sustained basis has been proven through experimentation (Young, 1989; Nair, 1987). Alley farming with a fast growing leguminous tree is one of the most popular forms of agroforestry, if the primary objectives are erosion control and fertility maintenance.

Alley cropping is an agroforestry system in which food crops are grown in alleys formed by hedgerows of a woody perennial, often legumes. The hedges are periodically pruned during cropping to provide mulch, to prevent shading and to reduce competition with associated food crops. During non-crop periods hedgerows are allowed to grow freely to cover the land and maximize the total production efficiency of the land use system. Because the technique retains the basic feature (fertility restoration) of traditional bush fallow system or shifting cultivation (Kang et al.; 1984), it can be considered as an improved bush fallow system. The temporal arrangement (rotation in time) of tree and crop is replaced by spatial arrangement (rotation in space).

Though alley cropping was reported to be practiced by Nallad farmers in the Philippines as early as 1923 (Kang et al., 1990), this practice, and a similar approach known as sloping agricultural land technology (SALT) (Laquihan and Watson, 1986), has received wide publicity only recently. Potential benefits of alley cropping include erosion control, fertility restoration and supply of fuel wood and protein rich fodder. The need to optimize these benefits has drawn the attention of agriculture researchers the world over. Various aspects of alley farming with a fast growing leguminous tree, particularly Leucaena and Gliricidia, have been extensively investigated (Kang et al., 1990). Selection of suitable species, establishment and management of hedge rows, interactions between tree and crop, erosion control, effect on soil productivity, benefits to live stock and economic evaluation of alley farming have been topics of interest for researchers (Kang et al., 1990).

Leucaena can be grown anywhere in the tropics and subtropics where annual rainfall ranges from 500 mm to 3000 mm (Hegde, 1982) and can withstand repeated prunings. It is a fast growing multipurpose legume which can produce up to 41 Mg $ha^{-1}yr^{-1}$ of dry matter biomass when grown as a sole plantation (Ferraris, 1979). Nitrogen fixation ranges from 75 to 500 kg N $ha^{-1}yr^{-1}$

(Dommergues, 1987; Mulongoy, 1986). Much of the field research has been focused on above ground production of perennial hedges and little is known about the below ground biomass production (Bansal and Mukerji, 1994; Fownes and Anderson, 1991).

Management of hedge rows refers to the intra and inter-row spacing of trees; frequency and height of pruning of hedges; tree:crop ratio and arrangement of hedge-rows, which primarily aim to minimize competition between tree and crop components for light, nutrient, moisture and growing space. Management options need to be evaluated on the basis of both short-term and long-term tree-crop interactions. The short-term interactions include seasonal competitive or complementary (nutrient mobilization or recycling through prunings) relationships between tree and crop components. Whereas long-term interactions mainly refer to long-term implications on soil productivity through soil organic matter accumulation or depletion, changes in soil physico-chemical properties, and erosion control. Earlier field studies on this subject have focused mainly on short-term interactions like effect of hedge-row management on fuel and fodder production from the trees (Karim et al., 1991; Duguma et al., 1988; Tunkel and Hatipoglu, 1989), their immediate effect on yields of associated crops (Duguma et al., 1988; Kang et al. 1985; Lal, 1989a; Banda et al., 1994) and soil fertility (Lal, 1989b; Mureithi et al., 1994; Onim et al., 1990). There have been relatively few studies examining long-term implications of alley farming and other agroforestry land uses, especially dealing with long-term changes in soil productivity under different management options (Cheatle et al., 1989; Young, 1990).

In the present study an agroforestry system with Leucaena hedges in a maize-wheat cropping sequence in the sub-humid sub-tropical climate of northern India was investigated to determine the effect of hedge row management and recycling of pruned leucaena foliage on the productivity of tree and crop and expected future changes in soil organic matter. The study was conducted at the research Farm of Central Soil and Water Conservation Research and Training Institute, Dehradun, India. Results of this study are presented in three chapters. The first chapter deals with effect of hedge row management on above and below ground biomass production of Leucaena. Chapter 2 presents response of wheat and maize crops to hedge row management and levels of Leucaena foliage recycled as mulch. The carbon cycling aspect of Leucaena based alley farming and its long term impact on soil organic matter are discussed in Chapter 3.

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CHAPTER - I

EFFECT OF CUTTING HEIGHT AND ROOT BARRIER ON BIOMASS PRODUCTION OF LEUCAENA HEDGES

ABSTRACT

Management of the perennial hedge rows in alley farming is important to optimize production of tree and crop components. An experiment was started in October, 1991 to determine the effect of the cutting height of Leucaena hedges and root barriers on production by various components of an alley cropping system. Cutting heights tested were 40, 80, 120 and 160 cm. Biomass production of hedges increased with increasing cutting height. Higher average values of branch and leaf biomass production were recorded for 120 cm cut height for all prunings, but cutting height effect on green foliage and twig biomass production were not significant until the Leucaena plants reached the age of 3 years. Plant size also affected production, only plants in the critical range (3-4.5 cm) of root collar diameter responded to cutting height treatments. Cutting height effect was not significant on live or dead fine root biomass. Fine root biomass of 2 year old hedges ranged from 1 to 2 Mg ha^{-1}. Pulses in live and dead root biomass following shoot pruning indicated the possibility of pruning induced shedding of fine roots.

1.0 INTRODUCTION

Alley cropping systems with fast growing woody perennials offer an opportunity to improve sustainability of tropical low-input farming systems (Kang et al., 1993). In addition to their potential role in meeting fuel and fodder requirements of local inhabitants, perennial hedges can be effectively used to control water erosion (Lal, 1989; Banda et al., 1994) and soil fertility maintenance through recycling of nitrogen-rich foliage (Kang et al., 1984). Management of perennial hedges in alley cropping systems has an important role to play in optimizing both tree and crop productivity. Frequency of cutting and cutting height have been key issues in hedge row management research. Although pruning at greater height is expected to favor biomass production of Leucaena hedges (Herrera, 1967; Karim et al., 1991) lower cutting heights are generally recommended to minimize tree-crop competition (Duguma et al., 1988).

Pruning in woody perennials can potentially influence total dry matter production, dry matter distribution and shape of the canopy. Effect of pruning on production of the woody perennial is reviewed by Cannell (1983). He pointed out that pruning stimulates the growth of dormant buds and distal buds near the cut ends are stimulated to grow more than the basal buds. In apple and Eucalyptus trees pruning nearer to the ground level is found to produce longer shoots (Maggs, 1967; Mullins and Rogger, 1971). As the cutting height of woody perennials increases, a greater proportion of photosynthate is diverted to produce bole wood. If total dry matter production remains constant, bole wood will increase at the expense of branch and leaf production. Cannell (1983) also suggested that regrowth of new shoots may be less vigorous as the distance from root stock increases. Trees cut at greater heights (pollarding), on the other hand, have more reserve capacity left over than those cut at ground level (coppicing). Hence, recovery of pollarded trees may be faster than coppiced trees when all leaf area is removed. Sometimes cutting at greater height is preferred just to keep new foliage out of the reach of animals and to favor timber and thick fuel wood production.

Trees contribute substantial quantities to soil organic matter through roots. Root biomass observed in Central Amazonian rain forest was 25% of total phytomass (Klinge et al., 1975), has been measured as 35-40% in moist savanna (Lamotte, 1975), and could be well above 50% in semi-arid vegetation (Young, 1989). Pruning is also expected to influence below ground net primary productivity because production and mortality of fine roots is found to be linked with the supply of photosynthates (Marshall, 1985).

In an agroforestry system, because of their well established root system, perennials avail preferential access to below ground resources over seasonal crops especially during crop establishment periods. In semi-arid India root barriers and root pruning significantly improved crop yields (Singh et al. 1989;

Ong et al. 1991; Korwar and Radder, 1994). Relatively little is known about the effect of root barriers on biomass yield of trees (Osman, 1996).

Although Leucaena is one of the most intensively investigated agroforestry species, published results on the effect of cutting heights on Leucaena biomass production are inconsistent and mainly focus on cutting height effect on fuel and foliage production (Mohatker and Relwani, 1985; Pathak et al.,1980; Dutt and Jamwal, 1987; Duguma et al., 1988; Karim et al., 1991). Diversion of substantial amounts of photosynthates towards growth of other plant parts (bole growth, pods, and roots) need to be taken into account when assessing the effect of hedge management on tree performance.

The present study aimed to determine the effect of cutting height and root barrier on various components of biomass production of *Leucaena leucocephala* (Var. K-8). The hypotheses was that the cutting height of Leucaena and root barrier along the hedge-row will influence the above-ground and below-ground biomass production of trees.

2.0 METHODS AND MATERIAL

2.1 The Study Area

The study was conducted at a location representative of the northwestern hill region of India. Low input rainfed farming with a maize-wheat crop rotation is the predominant land use. The experimental site was the Soil Conservation

Research Farm of CSWCRTI (Central Soil and Water Conservation Research and Training Institute) located at 30°19'N latitude and 78°02'E longitude with an elevation of 680 m above msl. It is 18 km west of Dehradun city in Uttar Pradesh, India. The Research Farm is situated in the synclinal Doon Valley which has developed as a result of the emergence of the parallel ranges of Himalaya and Shiwalik mountains during pre-pleistocene period. The valley is filled with heavy textured old, and gravelly light textured recent alluvium. This very deep alluvium is derived from sedimentary rocks: shale, sandstone, limestone, silt stone and conglomerate. Soil of the research station is "Fine loamy mixed hyper thermic udic haplustalf", and is non-gravelly, non-calcarious with silty loam surface and silty clay texture in sub-soil. Soil contained medium quantities of nutrients and had no physical or chemical constraints (**Table 1.1**).

Climate of the experimental site is sub-humid and sub-tropical. The area receives rain mainly through a South-West monsoon coming from the Arabian sea. The monsoon sets in during the last week of June and remains active through mid-September. During this period about 80 percent of annual average rainfall (1705 mm) is received with high intensity erosive storms. The period from June to October has surplus water, whereas remaining months of the year are water deficit. January and December are the coldest months (3.5°C mean minimum temperature) while highest temperatures are experienced in June (37.9°C mean maximum).

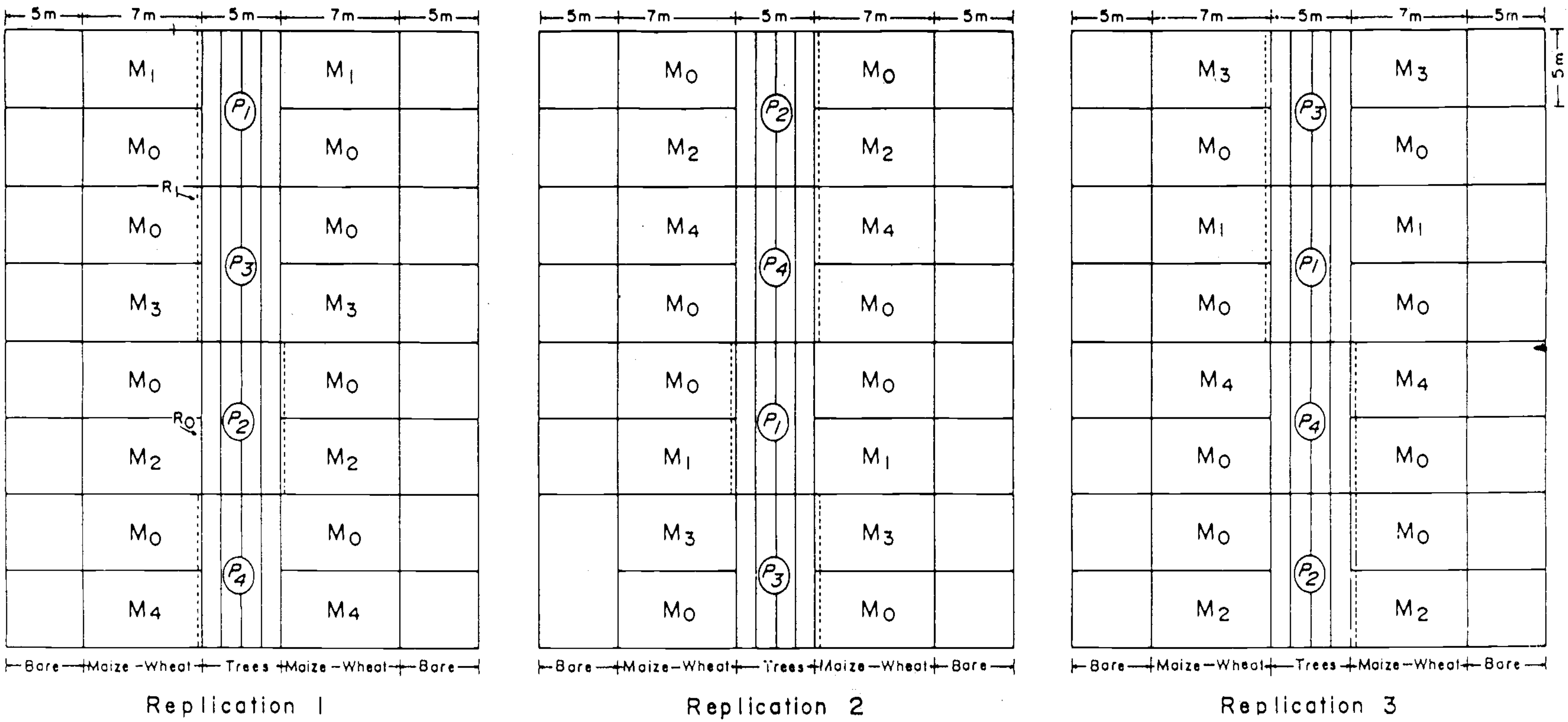
Table 1.1 Initial soil characteristics of experimental site

	Soil Depth (cm)			
	0-20	20-40	40-60	60-100
Texture	Silt loam	Silt clay loam	Silt clay loam	Silt clay loam
Bulk density ($g\ cm^{-3}$)	1.32	1.38	1.44	1.51
pH	5.60	5.60	5.70	5.60
Organic C (%)	0.515	0.490	0.452	0.410
Total N (%)	0.054	0.046	0.036	0.033
Total P_2O_5 (%)	0.064	0.073	0.083	0.086
Total K (%)	2.30	2.34	2.40	2.58
Available P_2O_5 (kg/ha)	55.14	38.80	27.34	18.80
Available K_2O ($kg\ ha^{-1}$)	225.45	185.75	145.15	232.85

The north-western hill region contains perhaps the poorest communities of India. For a human population density of 75 per sq km, only 21 percent of the land is available for cultivation, of which, 67 percent is unirrigated. More than 76 percent of the population depends directly on agriculture for its livelihood. Average farm size is only 0.62 ha per family. Primitive methods of farming prevail. Livestock density (mainly cow and goats) is about 79 per sq km which is 2.5 times higher than the carrying capacity of the region (Gupta and Puri, 1979). Energy requirements of families are met through illicit cutting and lopping of forest vegetation. High dependency on forests, faulty management of cultivated land, lack of off-farm job opportunities associated with prevailing poverty, and insufficient credit facilities are the dominant factors responsible for activating a soil degradation spiral in these hill ecosystems. A downward trend is evident from the fact that the average soil erosion rate from this region is more than 28 Mg $ha^{-1}yr^{-1}$ (Singh and Gupta, 1982; Singh et al., 1992). Consequently, more than one-third of the geographical area has already reached a critical stage of degradation. Thus, the research agenda of the Indian Council of Agriculture Research and the new national forest policy of India encourages large scale afforestation on community owned lands (locally called social forestry) and various forms of agroforestry on crop land.

2.2 Tree Tending

Leucaena leucocephala seeds of variety K-8 were sown in polybag containers of about 1100 cc filled with a farm yard manure (FYM) mixture (soil:FYM:sand ratio of 2:1:1). Four-month-old seedlings were transplanted into 30x30x30 cm (0.027 cu m) holes at 50 cm within row and 100 cm between row spacing, as per the experimental layout (**Fig. 1.1**). Five parallel rows of Leucaena were planted in blocks running southeast to northwest. Each block was divided into four 5x10 m plots. Each plot had 100 trees. Polythene sheets



SHOOT PRUNING :	P_1 = PRUNING AT 40 cm HEIGHT, P_2 = PRUNING AT 80 cm HEIGHT, P_3 = PRUNING AT 120 cm HEIGHT, P_4 = PRUNING AT 160 cm HEIGHT
ROOT PRUNING :	R_0 = NO ROOT PRUNING, R_1 = LATERAL ROOT PRUNING (TO A DEPTH OF 75 cm)
FOLIAGE RECYCLING :	M_0 = NO MULCHING, M_1 = MULCH 1.5 Mg Ha^{-1}, M_2 = MULCH 3.0 Mg Ha^{-1} M_3 = MULCH 4.5 Mg Ha^{-1}, M_4 = MULCH 6.0 Mg Ha^{-1}

Figure 1.1 Field layout of the experiment

(200 gauge) were placed along the border row at one randomly selected side of each plot as a barrier to lateral roots. The root barriers were placed at a 25 cm distance from the row to a depth of 75cm. Cutting height treatments were randomly assigned to plots within replications and imposed 16 months after transplanting in October 1992. Trees were cut at 40, 80, 120 or 160 cm. At each cutting all side branches were also removed, completely defoliating the Leucaena trees.

2.3 Above Ground Production

Leucaena trees were cut twice a year; at the end of June and October. The harvested biomass was separated into twigs, green foliage and pods. Twigs and green foliage weights were taken row wise for each of the five rows of a plot separately. Pods were weighed plot-wise only. Samples were preserved for moisture determination and nutrient analysis. To examine the cutting height treatment effect on biomass production of Leucaena plants, data from individual trees were collected in June 1994. Twelve plants were selected from each treatment representing the entire range of collar diameter. All the components of biomass production, i.e. green foliage (leaves + green tops of twigs), twigs, pods and bole wood were determined for each harvested tree. Bole biomass accumulation was estimated from bole volume increment. At each pruning, 10-15 randomly selected plants in each plot were measured for bole growth and leaf:twig ratio. Three litter traps of 0.25 sq m size were randomly placed in each plot. Litter collected over 1 mm mesh size was weighed bi-weekly during the growing seasons. Biomass production was determined on net area under tree basis (with 1X0.5m spacing=20000 trees ha^{-1}).

2.4 Below Ground Biomass

I extracted three root sampling cores manually from each plot every alternate month starting from January 1992 through November 1994. Cores of two sizes (5.2 cm and 7.0 cm diameter) were collected to a depth of 100 $\pm$ 5.5 cm. Sampling points were selected at random but border rows and distance closer than 10 cm from each bole were avoided. Hole depths were measured and refilled with soil immediately after sampling. Samples of soil cores were taken in 25 cm depth increments. Further division was not done because root biomass sampled per unit volume was low. Samples were stored in plastic bags and refrigerated during the processing period. Each sample was pre-soaked in water for four hours and gently rinsed over a 0.2-mm sieve. Because plots were maintained nearly weed-free, no sorting was required for non-leucaena roots. However, considerable pains were taken to separate dead from living roots.

Because at all sampling dates, dead roots were present in only trace amounts, depth-wise weighing was not possible and hence, dead root data were recorded as core totals. Viability of the roots was determined using physical characteristics of the root fragment. The dead roots were identified through differences in the density, strength and color. The live roots had characteristic yellow color, high density and were not brittle. Root fragments with more than 2 mm diameter were defined as structural roots. These were removed and weighed separately.

2.5 Statistical Analysis

2.5.1 *Cutting height effect on above ground biomass*

Cutting height effects on above ground biomass and its components were tested using complete randomized block design with the plot wise data (100 plants in each plot). Data were checked for normality and variance constancy. For testing interaction between collar diameter and cut height effect, 12 trees from each treatment plot for twig and foliage biomass were sampled at 32 months of age. Cut height and collar diameter effects were examined using a regression model. The final model was selected based on maximum adjusted R^2

and P (<0.05) values for the variables. Also these data were grouped into three diameter classes and were analyzed group-wise. Data were log transformed to stabilize the variance.

2.5.2 *Root barrier effect on above ground biomass*

Effect of root barriers was tested on border rows only. Hence foliage and twig biomass data from the border rows were analyzed separately using split plot design with cut height as main plot treatment and root barrier as sub-plot treatment.

2.5.3 *Repeated measure analysis of fine root biomass*

With any experimental design, when the same experimental unit is measured over time then correlation between the measurements is expected, violating the assumption of independence. The simplest method to deal with this is to analyze each time separately. However, for testing the time effect this approach is not very useful. Repeated measure analysis is suggested in such a situation (Winer, 1971). Repeated measure can be thought of as similar to a split plot design as it considers time as sub-unit of experimental unit. In this procedure conditions of compound symmetry (that all variance are equal and all covariance are equal to a constant times the variance) or Type H matrix (variation of the difference between two observation is constant) is examined. If these conditions are met, split plot design is used, otherwise adjusted P values are considered. Live and dead root biomass data were analyzed using repeated measure analysis to test effects of cut heights and sampling dates. The data were checked for normality and constant variance and were transformed to $(n+1)^{1/2}$, where n is live or dead root biomass (g m $^{-2}$). The Mauchley's criterion was used to test for a type H matrix.

3.0 RESULTS

3.1 Above Ground Production

Cutting height effect on green foliage and twig biomass were not significant until the Leucaena plants reached the age of 3 years (**Table 1.2**). During the 3 year study period there was gradual reduction of the P values with age for cut height effect on foliage and twig biomass. At the age of 36 months, the highest twig and foliage biomass were harvested at 120 cm cut height.

Data from twelve individual trees from each treatment plot representing the whole range of collar diameter collected in June 1994 (32 months after planting) show an interactive effect of cutting height with collar diameter. Anova of log transformed biomass data produced a P value of 0.25 for cutting

Table 1.2 Harvested above ground biomass* (dry weight Mg ha^{-1}) of Leucaena at different pruning dates : effect of pruning height

Yield component	Age (months)	Pruning Height (cm)					
		40	80	120	160	P value	$LSD_{0.05}$
Leaves	12	2.31	1.76	1.93	1.49	0.25	--
	20	3.05	3.28	3.67	3.17	0.27	--
	24	2.64	2.69	3.55	3.45	0.12	--
	32	2.97	3.13	3.84	3.56	0.09	--
	36	4.65	5.21	6.15	5.74	0.002	0.54
Branches (Twigs)	12	2.80	2.47	2.26	2.08	0.09	--
	20	1.97	2.53	3.03	2.96	0.03	0.68
	24	3.30	3.15	4.06	4.03	0.09	--
	32	2.86	3.30	4.31	3.64	0.13	--
	36	4.33	5.56	7.65	6.92	0.003	1.25
Pods	12	0.29	0.32	0.29	0.27	0.8	--
	24	0.89	0.74	0.91	0.81	0.61	--
	32	0.03	0.06	0.09	0.04	<0.001	0.02
	36	1.53	1.55	1.59	1.37	0.03	0.14

*Biomass accumulated between two pruning dates

height effect. The data set was divided into three collar diameter classes; small (<3 cm), medium (3-4.5 cm) and large (>4.5 cm). An independent analysis for each of these three class revealed that the plants falling only in the middle category of collar diameter were sensitive to cutting height treatments whereas in the other two collar diameter classes treatments effect were not significant, although the trends were alike (**Table 1.3**). The regression relationships of foliage and twig biomass with collar diameter and cut height were:

log Leaf = 1.483 + 0.594 D + 0.001129 H*D [adj. R^2=0.73]

log Twig = 1.666 + 0.497 D + 0.0024 D*H - 0.000012 H^2 [adj. R^2=0.78]

Where leaf and twig biomass (dry weight) are g $plant^{-1}$, D is collar diameter (cm) and H is cut height (cm).

Unlike the effect on green foliage and twig production, cutting height treatments were consistently significant on stem growth (**Table 1.4**). With the increase in cut height from 40 cm to 160 cm proportion of annual above ground biomass diverted to bole growth increased from 12.4% to 35.4% during the dry season and 9.4% to 25.2% during the wet season (**Table 1.5**). Growth observed for all components was much higher during the 4-month wet season than the 8-month dry season, and increased with increasing cutting height (**Table 1.5**). The dry season pod production was such a small fraction of total biomass that even if statistically significant, the pattern of influence of height on pod production is apparently inconsequential. During wet season, however, substantial amounts of photosynthates were diverted toward pod formation, but the effect of cutting height was not significant.

Table 1.3 Cutting height effect on dry matter production per tree (g $tree^{-1}$) for different diameter classes at 32 months

Collar diameter class		Cut height (cm) 40	80	120	160	P value ($LSD_{0.05}$)
Small (<3cm) n=12	Leaves	18.85	22.11	31.11	22.75	0.22
	Twigs	19.60	25.30	25.30	20.81	0.43
	Total	38.46	47.41	47.41	43.56	0.37
Medium (3-4.5cm) n=12	Leaves	48.76	71.98	138.45	101.01	<0.01 (5.53)
	Twigs	44.98	63.45	96.07	72.27	0.04 (5.53)
	Total	93.73	135.43	234.48	173.28	<0.01 (5.47)
Large (4.5cm) n=12	Leaves	196.53	166.94	190.67	183.16	0.64
	Twigs	189.35	175.94	229.73	196.00	0.30
	Total	385.88	342.88	420.39	379.16	0.58
Pooled n=36	Leaves	88.05	87.01	120.26	102.30	0.20
	Twigs	84.64	88.23	118.22	96.36	0.39
	Total	172.69	175.24	238.47	198.67	0.26

Although proportion of foliage and twig biomass declined with increasing cutting height, it can not be concluded that the increase in bole growth occurred at the expense of foliage or twigs growth as all components of above ground biomass increased with increased cutting height.

Table 1.4 Leaf litter and stem growth biomass* (dry weight Mg ha-1) of Leucaena at different pruning dates : effect of pruning height

Yield component	Age (months)	Pruning Height (cm)					
		40	80	120	160	P value	$LSD_{0.05}$
Leaf litter	12	0.13	0.20	0.17	0.13	0.7	--
	20	0.30	0.27	0.23	0.16	0.06	0.10
	24	0.26	0.34	0.37	0.22	0.33	--
	32	0.31	0.29	0.35	0.29	0.57	--
	36	0.49	0.48	0.42	0.38	0.36	--
Stem growth	12	0.19	0.34	0.63	0.95	0.02	0.44
	20	0.23	0.59	1.49	1.56	0.01	0.73
	24	0.43	1.03	1.73	1.97	0.01	0.77
	32	0.87	1.84	3.60	4.12	0.02	1.93
	36	1.17	2.71	3.89	4.85	0.004	1.45

*Biomass accumulated between two pruning dates

Root barriers had little effect on biomass production of Leucaena. The barrier effect on leaf production was found significant at early stage on wet season growth only **(Table 1.6)**, when foliage production was reduce by 31% due to restriction to lateral spread of roots.

Table 1.5 Biomass partitioning (% of total above ground biomass) during dry and wet season growth of Leucaena in 3rd year after plantation.

NPP Components	June harvest (8 months dry season growth)				October harvest (4 months wet season growth)			
	Cutting height (cm)				Cutting height (cm)			
	40	80	120	160	40	80	120	160
Bole growth	12.4	21.4	29.5	35.4	9.5	17.1	19.8	25.2
Twigs	40.6	38.3	35.4	32.2	35.1	35.1	38.8	35.9
Foliage	42.2	36.3	31.5	30.6	39.1	35.0	31.2	29.8
Pods	0.4	0.7	0.7	0.3	12.4	9.8	8.02	7.11
Litter	4.5	3.4	2.87	2.49	3.97	0.47	2.18	1.97
Total biomass ($Mg\ ha^{-1}$)	7.04	8.62	12.19	11.65	12.35	15.83	19.7	19.26

Table 1.6 Effect of root barrier on leaf and twig production ($Mg\ ha^{-1}$)

	Age of Leucaena (months)							
	20		24		32		36	
	Leave	Twig	Leave	Twig	Leave	Twig	Leave	Twig
With root barrier	3.39	2.52	2.97	3.79	4.07	4.99	6.08	6.85
Without root barrier	3.98	3.12	3.91	4.42	3.65	4.12	6.86	9.07
$LSD_{0.05}$	-	-	0.14	-	-	-	-	-
P Value	0.89	0.16	0.04	0.22	0.46	0.48	0.22	0.093

3.2 Below Ground Biomass

Cutting height effect on fine root biomass was not significant. Because pruning treatment effect on live and dead root mass for all the dates were not significant, date-wise average across the blocks and treatments provided an average from 36 cores which was reasonable for determining seasonal patterns of fine root biomass. This approach provided stable treatment averages and showed definite seasonal patterns. Significant changes in live and dead root biomass were observed over time . Dead root biomass ranged between 1.5 to 12 % of total fine roots **(Fig. 1.2, Table 1.7)**. During both years, the highest standing root biomass (160 and 183 g m^{-2}) was observed in the month of September. Highest dead root biomass were 10 and 12 g m^{-2} observed in July. These seasonal patterns apparently coincided with growing periods and pruning events.

Repeated measure analyses of fine root data showed that live and dead root biomass differed significantly among dates. Linear polynomial contrast were significant for both live and dead root biomass confirming linear increase in the fine root biomass over two years of sampling period. Pruning before onset of rains (June end) resulted in about a 7% decline in live root during both years. The reduction in live root biomass following post rainy season (October) pruning was about 15-17%. These root samples were taken 5-6 weeks after pruning treatments.

Table 1.7 Effect of cut height on fine root (<2mm) biomass g m^{-2} ($\pm$ SE) on different dates (samples were taken at 6 to 7 week interval starting on January 15 1993)

Date of Sampling	Cutting height (cm)			
	40	80	120	160
January 1993	102.3 (10.71)	90.8 (11.51)	105.9 (10.36)	106.3 (14.32)
March 1993	123.9 (20.61)	143.5 (20.91)	134.3 (19.74)	142.8 (23.90)
May 1993	147.0 (20.54)	155.1 (33.27)	150.9 (29.37)	158.5 (33.02)
July 1993	139.8 (11.72)	148.6 (29.60)	150.9 (28.23)	153.4 (17.09)
September 1993	159.8 (34.92)	152.0 (34.71)	171.8 (20.41)	185.4 (34.56)
November 1993	131.6 (16.59)	136.0 (18.67)	151.9 (21.99)	150.1 (12.42)
January 1994	117.1 (14.66)	104.7 (23.89)	135.2 (17.51)	139.0 (24.26)
March 1994	123.3 (19.80)	147.8 (17.07)	158.7 (17.19)	153.3 (22.26)
May 1994	164.1 (22.63)	159.2 (25.59)	157.4 (29.43)	151.8 (22.55)
July 1994	149.6 (23.52)	142.5 (18.85)	149.6 (21.98)	159.4 (19.81)
September 1994	197.5 (22.98)	192.4 (41.23)	205.5 (22.57)	168.9 (23.34)
November 1994	146.9 (21.19)	137.3 (19.93)	167.2 (21.15)	194.3 (31.26)

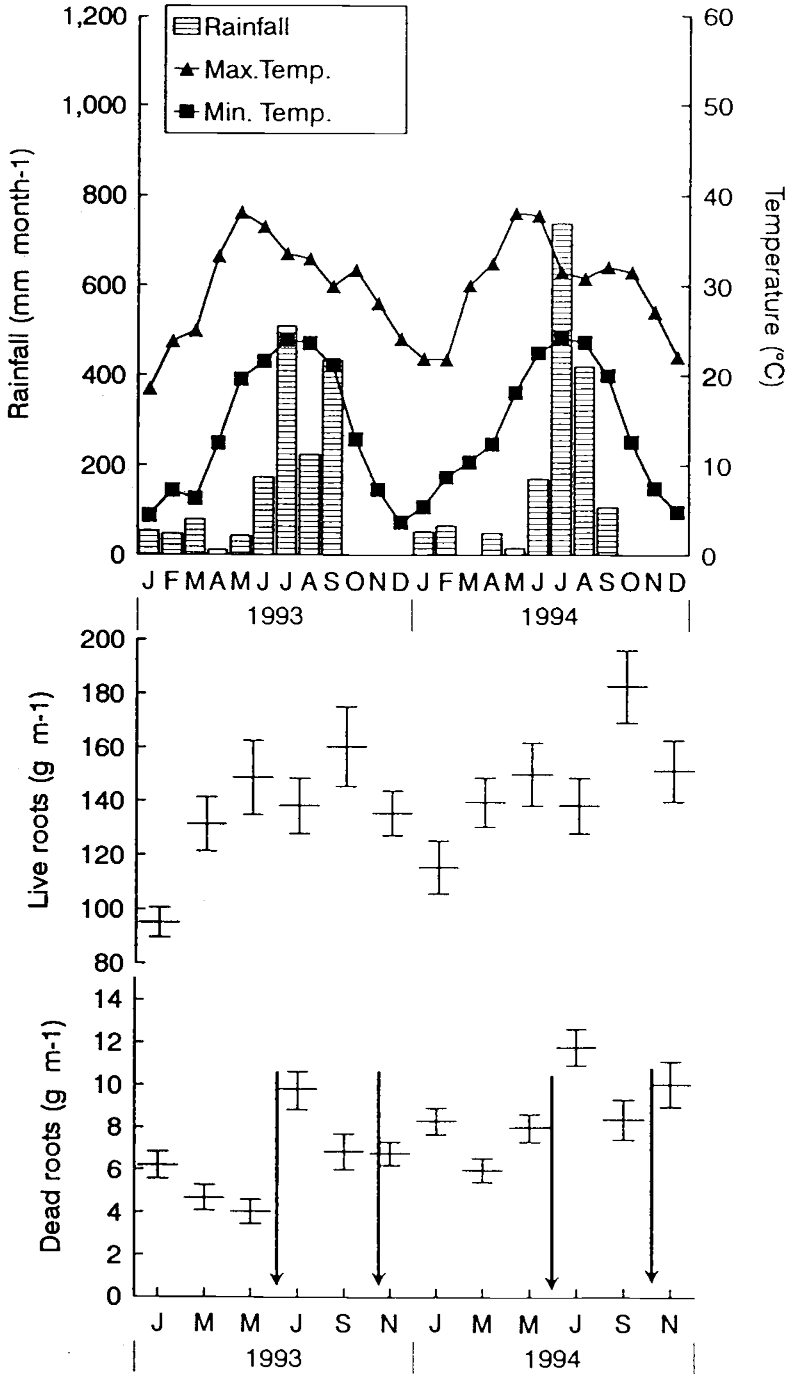


Figure 1.2 **Seasonal changes in live and dead fine roots (<2mm), mean (± SE) of 36 samples for each date, Arrows indicate time of pruning events.**

Simultaneous increase in the dead root biomass were also observed following pruning of hedges.

4.0 DISCUSSION

The trend of increasing production of harvestable biomass with increased cutting height is in accordance with many earlier reports (Tunkel and Hatipoglu, 1989; Herrera, 1967; Osman, 1981; Krishna Murthy and Mune Gowda 1982; Duguma et al., 1988; Karim et al. 1991) excepting a contradiction to findings of Takahashi and Ripperton (1949). Sampet and Pattaro (1987) and Gutteridge (1988) found no significant effects of cutting height on yield but in these cases maximum height did not exceed 50 cm. This positive effect of increasing cutting height observed in our study and reported earlier was expected and may be attributed to faster recovery after pruning through increased reserve capacity for nonstructural carbohydrates in residual bole volume. Duguma et al. (1988) reported that annual foliage (leaves + small green branches) production of *L. leucocephala* (Var. K-28) with 25 x 200 cm spacing increased approximately three times as cutting height increased from 25 to 150 cm. Effect of cutting height was much stronger in their study than observed in our study. Also, the foliage yield at the six-month cutting interval reported by Duguma et al. (1988) was much higher (13.3 Mg ha^{-1} at 150 cm cut height) than observed in our study (6 Mg ha^{-1} at 160 cm cut height, 4-month cutting interval). These differences were possibly due to differences in spacing, pruning interval and length of rainy season. Cutting height effect on growth, as observed by Duguma et al. (1988), became more apparent when pruning frequency was reduced from monthly to bi-annually intervals and during rainy season growth as against dry season growth. This indicated that increased cutting height favors greater biomass production when plants have the opportunity to accumulate photosynthates. Karim et al. (1991) also observed this interactive relationship between cutting height and cutting frequency. They found that *L. leucocephala* cut at monthly interval were not significantly affected by cutting height treatments (25, 50, 75, and 100 cm), whereas at three month cutting intervals dry matter yield of Leucaena increased significantly with increasing cutting height. A similar relationship between cutting height and foliage production was observed with *Gliricidia sepium* and *Sesbania grandiflora* (Duguma et al., 1988).

We found that cutting height effect is also related to collar diameter of plants. The plants in smaller and larger collar diameter classes were not sensitive to cutting height. The lack of response in the small diameter class can be attributed either to the fact that increased cutting height does not substantially influence the bole volume or reserve capacity of these thin stemmed plants, or may be there are other genetic or environmental factors responsible for the poor performance of these plants. It is probably related to the suppression of these smaller plants. As plants with large collar diameter show vigorous recovery after pruning because of preferential exploitation of light and water these plants might have suppressing effect on thinner stemmed plants. The lack of response of pruning height in large diameter plants can be attributed to the possibility that these plants were able to maintain sufficient reserves at lower cut heights also for rapid recovery after prunings.

It has been suggested that vigor of regrowth after pruning or decapitation is related to the size of root system of the tree (Tschopilinski and Blake, 1989; Dannial et al., 1979). Tschopilinski and Blake (1993) measured the change in primary and secondary carbon metabolites in roots and coppice shoots following shoot decapitation, and defoliation in root cuttings of Populus species. In the stem of treated plants they found that ten days after complete shoot defoliation or decapitation the concentration of starch, glucose, fructose, sucrose, galactose and shikimic acid declined to one-half of that of intact plants. In the roots of treated plants, they found an increase in concentration of fructose and glucose followed by accumulation of shikimic acid, salicyl alcohol, salicin and an unknown compound. They linked these changes in carbon metabolites concentration with reinvigoration process and suggested that normal passive water flow in actively transpiring plant, which is reduced by shoot decapitation, is substituted by active adsorption of water facilitated by reduced xylem pressure potential due to solute accumulation in roots. Therefore solute accumulation in roots could help in increasing root pressure, tissue hydration and reestablishing of the water column. Increased water flow up the stem would supply the growth-promoting substances synthesized and accumulated in roots to the remaining shoot and new sprouts and thereby facilitate reinvigoration of net photosyntheses and subsequent coppice growth. This relationship between carbohydrate mobilization and reinvigoration highlights the importance of root system in reinvigoration. Because larger size of root system is expected to be associated with increasing collar diameter, observed differences in biomass production in the three diameter classes and vigorous recovery after shoot pruning in larger collar diameter class may be attributed to the differences in the size of root system associated with these classes.

The performance of trees in large collar diameter class was independent of cutting height indicating possibility of maintaining higher biomass production even at lower cutting heights. Considering the important role of root system size in reinvigoration, production potential of perennials in hedge-row intercropping (alley cropping) could be expected to improve by adoption of nursery techniques which favor early root development and improve the root:shoot ratio of seedlings.

Fine root biomass observed in our study ranged from 90 to 200 g m^{-3} (up to 1m depth) and was comparable with the earlier reported values 88 g m^{-3} (up to 30 cm depth) under unpruned leucaena plants of 3 years of age at sandy loam soil in Delhi, India (Bansal and Mukerji, 1994). The dead fine root biomass observed in our study (2.6 to 7.85 of total fine root) was also similar to the values (7.93%) reported by Bansal and Mukerji (1994). These values were smaller compared to other studies where the annual loss of fine roots ranged from 42 to 92% (Fogel 1985; Kummerrow et al. 1990). The strong seasonal pattern on live and dead root mass observed in both years suggest two pulses of fine root turn over in a year. Minima and maxima of live and dead roots follow time of pruning and foliage development. Decline in live root biomass and increase in dead root biomass after each pruning suggest the possibility of pruning induced shedding of fine roots. However this needs to be confirmed by comparing seasonal pattern of root biomass with unpruned controls. This effect of pruning is logically explainable through the findings of Marshall (1984), who linked fine root turnover with the supply of starch and sugar and proved that environmental factors like moisture and temperature have only indirect effect on fine root turnover. In a pot culture experiment, Fownes and Anderson (1991) sampled fine roots of 15-week-old *Leucaena leucocephala* and *Sesbania sesban* at bi-weekly intervals to determine the effect of defoliation on shedding of fine roots and nodules. They observed reduction in fine root biomass by approximately 25% in Sesbania and 10% in Leucaena in first two weeks after defoliation, followed by recovery in the following two weeks. Reduction in the live root biomass following pruning was much larger than observed changes in dead root biomass during the same period. This indicated the possibility of rapid fine root turn-over than detectible from bimonthly sampling of roots, and below ground productivity of hedges could be much larger than the size of root biomass would normally suggest.

The reduction in live and dead root biomass coupled with an increase in dead root biomass following shoot pruning suggests that by regulating the timing of pruning of hedges it may be possible to synchronize nutrient release through root shedding with crop requirements.

5.0 CONCLUSIONS

Our results and most other studies suggest that above ground biomass production of Leucaena hedges increases with increasing cutting height up to 120 cm. If crop yields in alleys are not severely affected, cutting height at 1.2 m is recommended for maximizing foliage and fuel production.

Plants with larger collar diameters did not responded to cutting height and maintained biomass production at (40 cm), the lowest cutting height tested in this study. Higher biomass production and vigorous recovery of these plants as compared to the plants with smaller collar diameter indicated their competitive dominance and better reinvigoration (renewed vigor after pruning). Exponential relationship between collar diameter and biomass production of Leucaena hedges suggest that much higher biomass production may be possible by improving seedling quality and selection.

Fine root biomass of Leucaena hedges ranged from 1 to 2 Mg ha^{-1} and was not influence by cutting height of hedges. However, the pulses of live and dead root biomass following shoot pruning indicated possibility of pruning induced shedding of fine roots. A substantial contribution to soil productivity through root litter is expected under alley farming which may be regulated through pruning management.

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CHAPTER II

EFFECT OF HEDGE MANAGEMENT AND FOLIAGE RECYCLING ON CROP PRODUCTIVITY

ABSTRACT

In spite of the existing experimental evidence for the soil conservation potential of hedge-row intercropping of perennial legumes with grain crops, it has not been adapted by large numbers of farmers primarily because of competitive interactions between hedge and crop components and lack of short-term benefits. This study conducted in sub-humid, sub-tropical climate of north-western hill region of India aimed to examine the effect of : 1) cutting height of Leucaena hedges, 2) root barriers and 3) levels of Leucaena pruning mulch on maize and wheat crop yields.

Four cutting heights of hedgerows (40, 80, 120 and 160 cm) with or without polyethylene root barriers were tested on a maize-wheat cropping sequence. Hedges were cut twice a year and applied as surface mulch with five levels (0, 1.5, 3, 4.5, and 6 Mg ha^{-1}) at planting of maize and wheat. Leucaena hedges had little effect on maize as only the crop row nearest (60 cm) to hedges was suppressed by vigorous recovery of Leucaena. Competitive effect of hedges was further minimized when hedges were cut at lower heights. Root barriers had no effect on maize yields.

In spite of low foliage biomass on Leucaena during the wheat cropping periods, wheat seed yield was reduced by 35% at the tree-crop interface (crop rows in a 2 m wide strip along the hedge rows) as compared to sole crop plots

(crop rows from 2 m to 7 m from hedges). This reduction in wheat yield was attributed to tree-crop competition for soil moisture. Root barriers were partially effective in improving soil moisture at the time of wheat sowing and marginally improved seed yield of wheat. Tree cutting height had no effect on wheat grain and straw yields.

Mulches reduced weed growth and recycled about 26.5 kg N, 2.1 kg P and 16.2 kg of K per Mg of mulch recycled. Recycling of Leucaena prunings sharply increased the yield of both crops, when compared on net cropped area basis. However, when adjusted for loss in crop area, a reduction in the grain production was estimated with each increase of mulch levels. Estimates based on tree-crop interactions observed in this study show that an alley cropping system with 20% area under Leucaena hedge-rows would provide about 12% lower grain yield and 15% higher fodder yield from crops as compared to a sole cropping system.

1.0 INTRODUCTION

The sub-humid climate of northern India is characterized by erratic and high intensity monsoon rains. About 80% (1240 mm) of annual rainfall occurs from mid-June to mid-September. Low-input rainfed farming of maize in the rainy season followed by wheat in the winter season is the most popular traditional land use. Water erosion and weed infestation in the rainy season and insufficient soil moisture for post-rainy season wheat crops are major constraints to improving crop production from rainfed areas in this region. Narain et al. (1994) reported 28.1 Mg ha^{-1} yr^{-1} of average soil loss after conventional tillage on 8% slopes under maize. Use of woody perennials as barrier hedges across the slope were found effective in reducing soil loss in the region (unpublished data) and elsewhere under similar conditions (Lal, 1989a). Living hedges on contours have greater potential adaptability in preference to mechanical erosion control measures such as contour or graded bunding. Such live barriers are less expensive and yield multiple outputs like fuel and fodder. An additional advantage in crop production can be realized from recycling of prunings as soil-amending mulch. Presence of mulch cover suppresses weed growth (Lal, 1975; Yamoah et al., 1986a; Jama et al., 1991). Addition of prunings increases nutrient availability to associated grain crops (Kang, 1987; Dalland et al., 1983) and improves soil physical properties such as reducing soil temperature, and temperature fluctuations, and increased moisture infiltration and retention (Lal, 1975; Lal, 1989b).

Despite these advantages reported in the literature, alley farming has a poor adoption rate by farmers primarily because of the general apprehension that competition for resources and loss of land area to hedgerows may result in reduction of food grain production. Protective or soil ameliorative advantages of hedge rows do not compensate these losses on a short-term basis. Presence of trees in farmlands can influence crop yield causing 32 to 39% reduction in wheat and rice yield (Khybri et al., 1989). Tree and crop competition can be minimized by repeated pruning of trees (Osman, 1996). Duguma et al. (1988) found higher maize and cowpea yields with increased pruning frequency and decreasing pruning height. The level of competition between hedges and crops varies from humid to semi-arid climates and is dependent on distribution of rainfall (Sanchez, 1995). Therefore, there is a need to examine management options specific to agro-climatic and socio-economic needs.

The present study aimed to evaluate the effect of cutting height of Leucaena hedges, root barriers and levels of foliage recycling on maize and wheat yields in the north-western hill region of India. It was hypothesized that lower cutting height, placement of root barrier along the hedge rows and recycling of prunings will favor the production of crops grown in alleys.

2.0 METHODS AND MATERIAL

The study site was a field research station of a soil conservation research farm located 18 km west of Dehradun city in the northwestern hill region of India. The experiment was conducted on gently sloping (1.5%) silty clay loam alfisols. Agro-ecological and socio-economic details of the region were given in Chapter I.

2.1 Field Layout and Treatments

The experiment was laid out as per the field plan given in **Fig. 1.1** and **2.1**. Five rows of *Leucaena leucocephala* (var: K-8) seedlings were planted as a hedge at a 100x50 cm spacing. Leucaena trees were cut at 40, 80, 120, and 160 cm height one year after field planting and were maintained as hedges by cutting twice a year at planting of maize and wheat crops. Crops were grown on both sides of the hedge rows as open alleys. The pruned biomass was spread on the soil surface at the rate of 0, 1.5, 3.0, 4.5 and 6.0 Mg ha^{-1} dry weight basis. Twigs were removed to be used as fuel wood after leaves were shed in the plots. Root barriers were placed on one randomly selected side of the hedge row strip for each cutting height. Polyethylene root barriers (200 gauge) were installed 25 cm from hedge row to a depth of 75 cm one year after planting of Leucaena by opening a 40 cm wide trench. The trench was refilled back with excavated soil with sub-soil first and top-soil later.

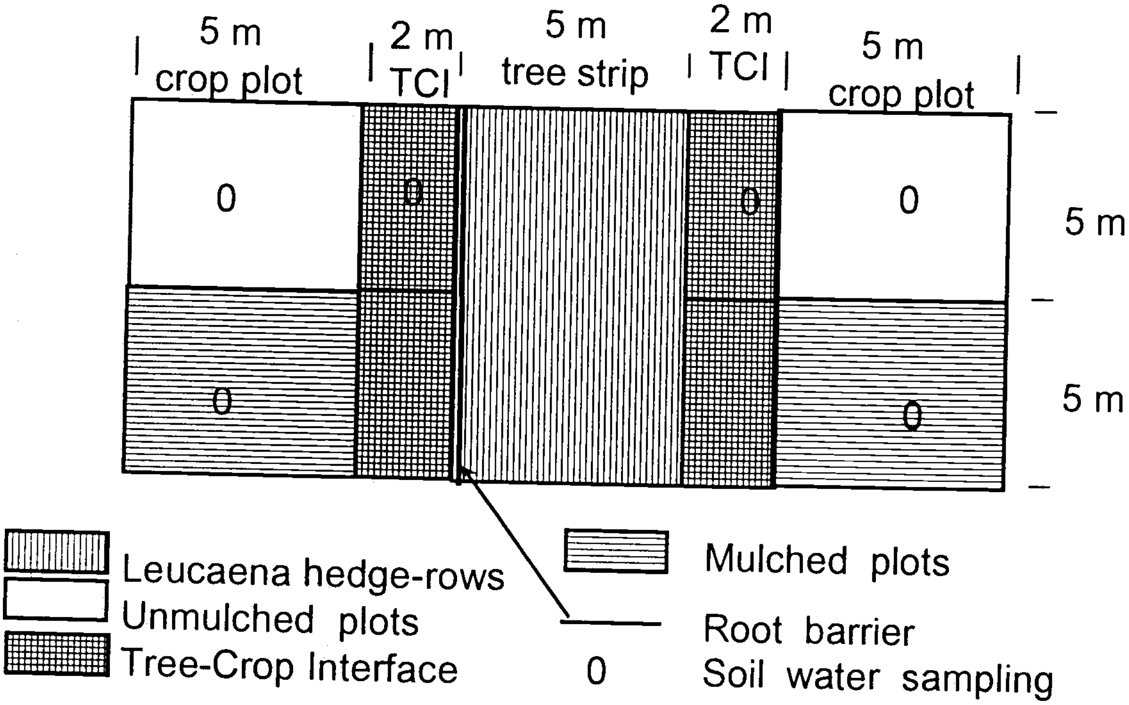

Figure 2.1 Tree - crop arrangement in a unit plot

2.2 Cropping System

In the sub-humid, sub-tropical hill lands, two grain crops per year are possible without irrigation (**Figure 2.2**). The maize season starts with the onset of monsoon rains near the end of June. In spite of a few rain events during April-June period, soil moisture remains insufficient for maize sowing until the end of June when monsoon rains begin. Normally a small window is available for completing land preparation and sowing operations before the incessant high intensity monsoon rains quickly make soil too wet for any field operation. Efficient weed management during the crop establishment period is necessary for success of maize crops. Application of the pre-emergence herbicide atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and two manual weedings 15 and 30 days after sowing are recommended weed control practices (Mittal et al., 1989) and were followed. Because effectiveness of pre-emergence herbicides remain uncertain due to incessant rains during maize sowing, farmers often depend on manual weeding which is carried out with small hand tools and is highly labor demanding (10-20 man days ha^{-1}). Sometimes soils remain too wet for even manual weeding.

Maize was harvested in late September. Plots were plowed immediately after maize harvest to conserve residual soil moisture. Wheat was sown in late November and harvested in late April. Application of herbicide (Isoproturan) with one manual weeding 60 days after sowing effectively controlled weeds in

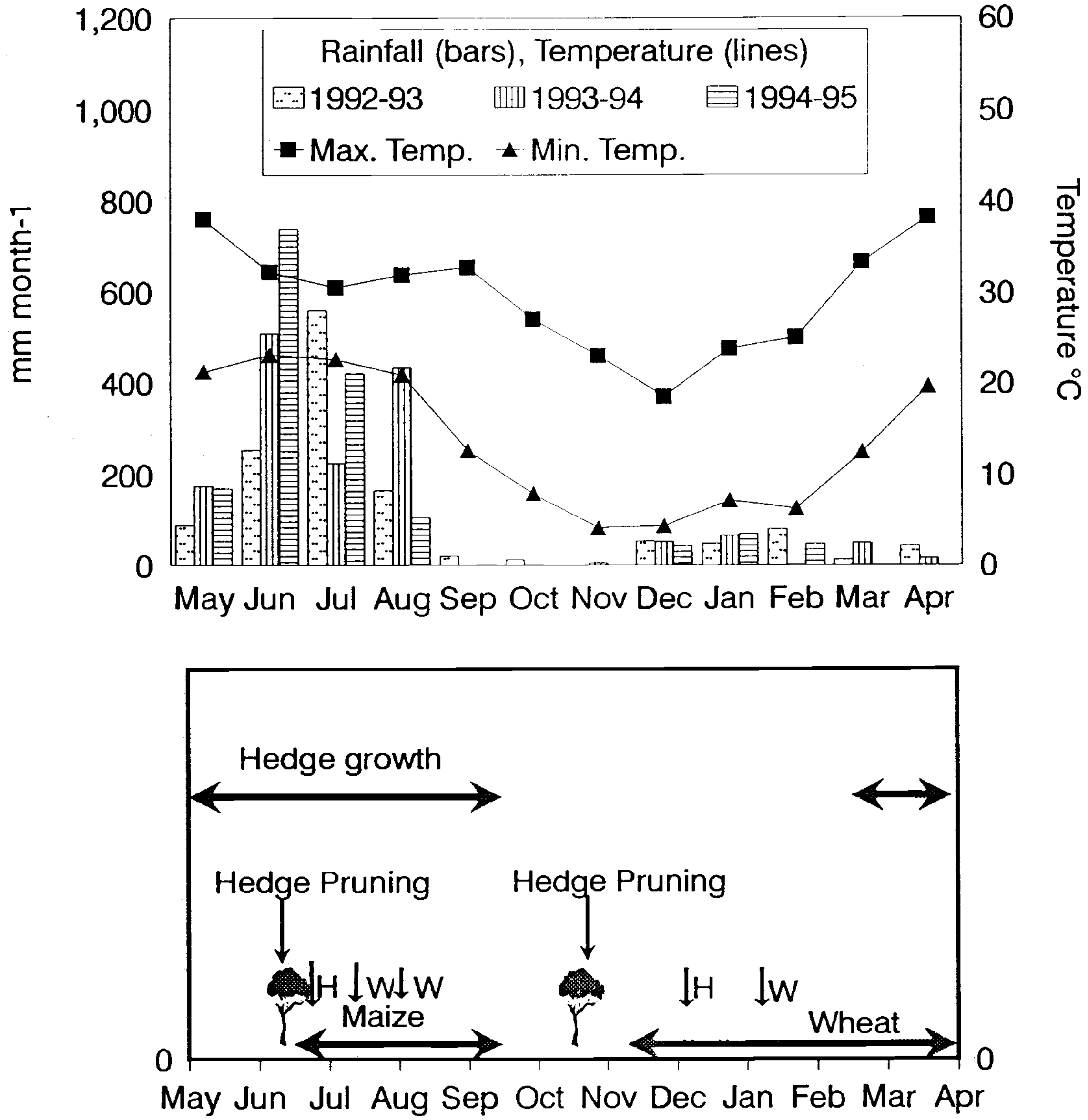

Figure 2.2 **Tree and crop growing periods in a year (H and W indicate time of herbicide application and hand weeding respectively).**

the wheat crop. Because little rain occurs during the wheat season, soil moisture was a major limiting factor in wheat production. Crop yields largely depend on amount of residual soil moisture after maize harvest, and amount and distribution of winter rains. Leucaena hedges were cut at maize and wheat sowing. Prunings were recycled as surface mulch. Leucaena trees recovered quickly after pruning at the maize sowing, however little foliage was produced during the wheat season. The trees slowly recovered at the end of winter in March when the wheat was at grain filling stage. During both cropping seasons all the plots were uniformly fertilized. Both crops were fertilized with recommended rates of P and K while half of recommended N was applied. Agronomic details for both crops are given in **Table 2.1**.

2.3 Crop Yield Measurements

To determine tree-crop competition in response to pruning height of trees and root barriers a tree-crop interface (TCI) up to 2m distance from hedge-rows was arbitrarily assumed. On the basis of earlier observation of rooting behavior of Leucaena trees (unpublished data), a lateral root spread of <2 m was expected for 3-year-old hedges. Because Leucaena trees were completely defoliated after pruning at each crop sowing event, effect on crop through micro climatic alteration (wind, shade or temperature) was expected to be minimal and within 2m distance from tree rows. Patterns of grain and straw yields of maize indicated

Table 2.1 Agronomic details of maize and wheat cultivation

		Maize	Wheat
Variety		Composite Naveen	HD 2021
Spacing		60 x 30 cm	25 x 3 cm
Land preparation		2 tiller, 1 harrow and 1 planking*	1 harrow, 3 tiller and 2 planking
Seed rate		18 kg ha^{-1}	120 kg ha^{-1}
<u>Weed control</u> Herbicides used Spray timing Manual weeding		 Atrazine Pre-emergence 15 & 30 DAS**	 Isoproturan 35 DAS 60 DAS
Fertilizer rate (kg ha^{-1})		$N : P_2O_5 : K_2O$ 50 : 60 : 40	$N : P_2O_5 : K_2O$ 50 : 50 : 40
Mode of fertilizer application		Basal 25: 60 : 40 Remaining N in two splits	Basal 25: 50 : 40 Remaining N in two splits
Sowing dates	1992	--	Nov 21.1992
	1993	June 23.1993	Nov 25.1993
	1994	June 25.1994	Nov 17.1994
Harvesting dates	1993	Sept 28.1993	April 25.1993
	1994	Sept 30.1994	April 29.1994
	1995	--	April 22.1995

*planking is leveling plow induced surface roughness with leveled bottom log;
**DAS = Days after sowing.

that above assumption of 2m TCI was reasonable. However reduction in wheat yields were observed up to 2m distance indicating possibility of trees influencing crops to beyond 2m. Within 2 m distance, individual rows of 5.0 m length were harvested in unmulched plots. Grain and straw yields (air dry weights) were recorded row-wise. Crop yields at TCI were compared with crop yields at 4m distance which were considered free from tree influence and were treated as sole crop plots.

Mulch levels were tested in another set of plots at 4m distance only. Quadrants of 2 x 2 m size were harvested to determine effect of mulch levels on crop yields. Above ground weed biomass was weighed (dry weight) at each manual weeding from 5 x 5 m sole plots of size.

All crop yield measurements presented and discussed are on net cropped area basis. With increasing mulch levels, however, greater proportion of land would be occupied by the mulch producing trees. Production of grain, fodder and fuel wood under alley cropping system with different tree:crop ratios is discussed in the later section of this chapter. Estimates for crop yields under different tree:crop ratios were based on crop response to mulch levels influence of trees on crops at tree-crop interface as observed in this study. It was assumed that trees would provide 6 and 8 Mg ha^{-1} of leaf and twig biomass at each pruning from the unit area under the trees.

2.4 Soil Moisture

Soil water content was measured gravimetrically at wheat sowing in 1993 and 1994 to a depth of 90 cm at 15 cm depth intervals in all the three replications at 1m and 4m distance from trees in unmulched plots. Soil moisture measurement were taken with minimum (40 cm) and maximum cutting height (160 cm) with or without root barriers. In mulched plots soil moisture samples were collected under all mulch levels and from all six replications at 4m from trees.

2.5 Soil and Plant Analysis

Leucaena foliage (leaves and tender twigs), and straw and grain of maize and wheat were analyzed for N, P and K to determine nutrient transfer through mulches and crop removal of these elements under different mulch rates. Leucaena sampled were collected in June 1994, and wheat and maize samples for straw and grain were collected at crop harvest in April and September 1994. For all plant samples a 500 gm of fresh weight was oven dried (65^{0}C) to constant weight. Two runs from three replications were made for all plant samples. Plant analyses for nitrogen was done using Kjeltec Auto 1030 analyzer (Kalra and Maynard, 1991) and phosphorus and potassium were analyzed using wet digestion method (Piper, 1950).

Soil samples from six replications were collected from 0-20 cm depth. Within each replicated treatment plot, ten sub-samples collected from randomly selected spots were mixed to prepare one composite sample for each plot. Samples were screened through 2-mm sieve without further air drying and refrigerated in polythene bags until processed. Soil analysis of total N (Kjeldahl digestion, Piper 1950), available P (Olsen et al., 1954) and available K (Wood and De Turk, 1940) was done at beginning and at the end of experimentation (3 years later).

2.6 Statistical Analysis

Cutting height and root barrier effects were studied at tree-crop interface using a repeated measure design (Winer, 1971). Four cutting heights (main plot), each having barrier and no barrier treatment (sub-plot) were replicated three times. There were a total of 24 interface plots (3 blocks x 4 cutting height x 2 root barriers). Repeated measures for crop yield were made over four distances (crop rows) in maize and nine distances in wheat in each of these plots. Crop yield data for the interface plot were collected for two years for both the crops and were analyzed year wise. Soil moisture at interface was analyzed for individual depth using split-split plot design.

Five mulch levels were replicated six times using complete randomized block design. Three years of wheat yield and two years of maize yield data were analyzed year wise as randomized block design. Soil moisture data in mulched plots were analyzed by depth.

Linear and quadratic regression relationship of crop yields with mulch levels and distance from hedge-rows (in unmulched plots) were tested. Models were selected based on highest R^2 (Coefficient of determination) and P value

(<0.05) for selected variables. All the data were analyzed using Statistical Analysis System (SAS 1994).

3.0 RESULTS

3.1 Crop Yields in Response to Cutting Height of Leucaena

Trees had no effect on maize grain and straw yields during year 1993, but in following year cutting height of trees had significant effect (P=0.01) on maize grain yield (**Table 2.2** and **2.3**) as yield decreased with increasing cutting height of Leucaena. Reduction was confined, however, only to crop rows closest to trees (60 cm from hedge-rows) (**Table 2.4**). When average yield at 0-2m TCI was compared with yield at 4m from trees, these differences were not significant (**Table 2.5**). In the case of wheat, pruning height had no effect on crop yield.

3.2 Effect of Root Barrier on Crop Yields

Root barriers had no effect on maize but significantly (P<0.05) increased the grain and straw yields of wheat (**Table 2.2; Fig. 2.3**). Averaged over two years, and across barrier treatments, reduction in wheat grain yield in interface plots was 30% compared to sole plots. Wheat grain yield reduction without barrier was 35% which was reduced to 26% by installing root barriers. Thus placement of root barrier was only partially effective.

Table 2.2 Crop yields in response to cutting height of Leucaena root barriers at tree-crop interface: significance levels of main effects and interactions

Effects	Maize				Wheat			
	1993		1994		1994		1995	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Cut height of hedges (H)	NS	NS	**	NS	NS	NS	NS	NS
Root barrier (R)	NS	NS	NS	NS	*	*	*	NS
Distance from hedges (D)	NS	NS	**	**	**	**	**	**
H x R	NS	NS	NS	NS	NS	NS	NS	NS
H x D	NS	NS	*	*	NS	NS	NS	NS
D x R	NS	NS	NS	NS	NS	NS	*	*
H x D x R	NS	NS	NS	NS	NS	NS	NS	NS

NS=P>0.05; *=P 0.05-0.01; **=P<0.01.

Table 2.3 Effect of cut-height of hedge on maize grain yield (kg ha^{-1}) in year 1994

Distance from trees (cm)	Cutting height of Leucaena hedges (cm)			
	40	80	120	160
60	1645	1617	1500	1200
120	2022	2022	1822	1667
180	1828	2045	1933	1734
400	1778	1822	1800	1822
$LSD_{(0.05)}$ (Height*Distance) = 206				

Table 2.4 Effect of distance from hedge row on crop yields (kg ha^{-1})

Distance from tree rows (cm)	Maize 1993		Maize 1994	
	Grain	Straw	Grain	Straw
60	2040	3883	1490	2906
120	2519	4816	1883	3482
180	2421	4526	1885	3638
400	2481	4496	1806	3505
$LSD_{(0.05)}$	NS	NS	190	190
Distance from tree rows (cm)	**Wheat 1994**		**Wheat 1995**	
	Grain	Straw	Grain	Straw
25	1478	2305	1096	1271
50	1800	2716	1257	1418
75	1838	2796	1377	1495
100	1961	2981	1480	1632
125	2033	3103	1637	1973
150	2258	3410	1928	2226
175	2098	3136	1868	2160
200	2168	3271	1932	2304
400	2632	3976	2437	3661
$LSD_{(0.05)}$	328	457	192	304

Soil moisture down to 90 cm depth at wheat sowing was significantly higher (P=0.02) at 4.0 m distance from hedgerow than in interface plots (1.0 m distance from hedgerow) to 90 cm depth (**Table 2.6**). Although presence of root

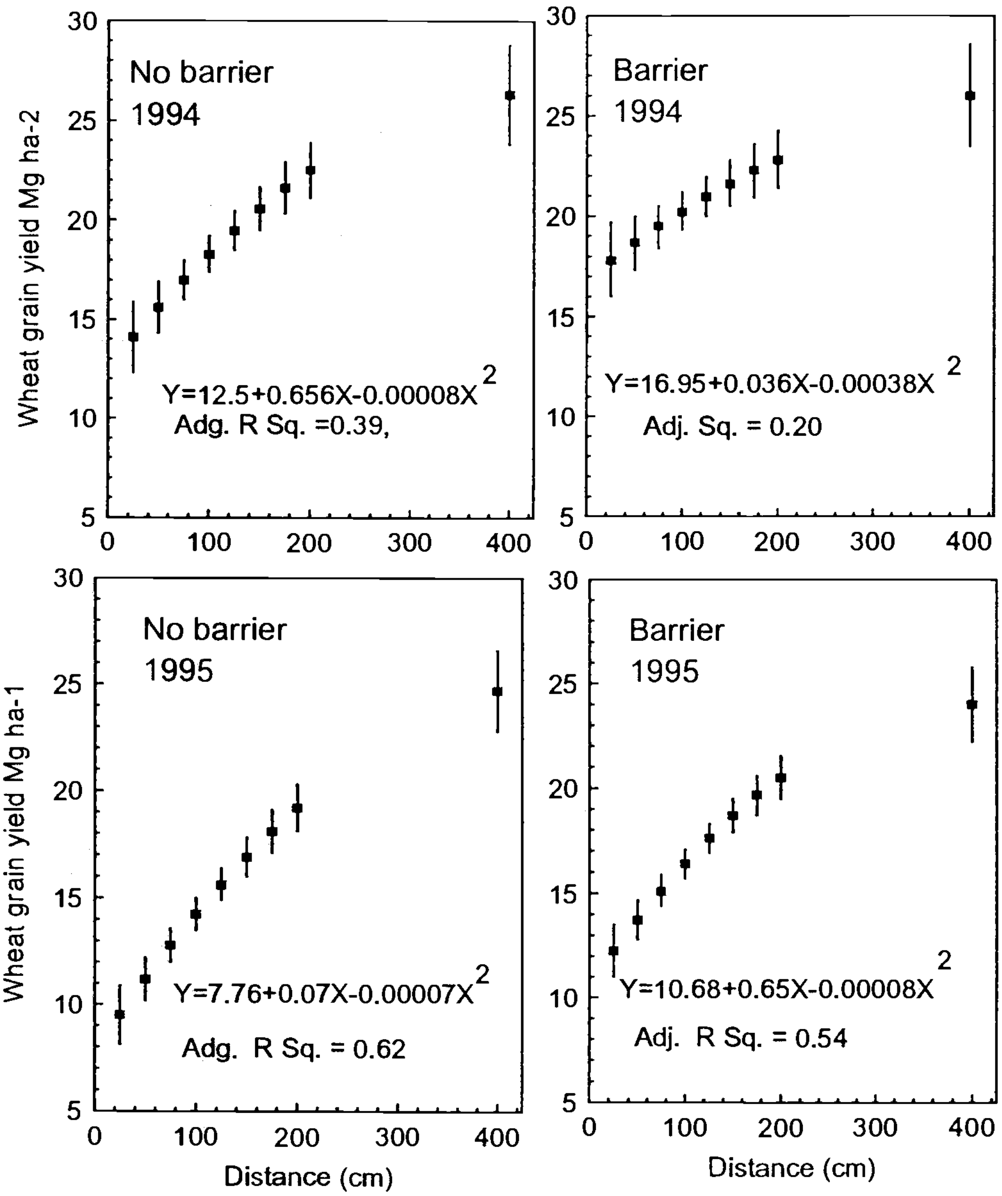

Figure 2.3 **Effect root barrier on wheat grain yield at TCI : predicted values with 95% confidence limits for means.**

Table 2.5 Contrast between mean crop yields at 0-2m and 4m from hedge-rows (averaged over 2 years)

		TCI	Sole plot	$LSD_{0.05}$	Reduction (%) at TCI
Maize	Grain	2040	2144	NS	4.9
	Straw	3875	4001	NS	3.1
	Total	5915	6145	NS	3.7
Wheat	Grain	1763	2535	192	30.5
	Straw	2389	3819	760	37.4
	Total	4152	6354	944	34.7

Table 2.6 Depth wise soil moisture at TCI: level of significance of main effects and interactions

Soil depth (cm)	Pruning height (H)	Root barrier (R)	Distance from hedge(D)	H x R	H x D	D x R	H x D x R
0-15	NS	*	**	NS	**	*	NS
15-30	NS	*	*	NS	NS	*	NS
30-45	NS	**	*	NS	NS	**	NS
45-60	NS	**	**	NS	NS	*	NS
60-75	NS	*	**	NS	NS	**	NS
75-90	NS	NS	*	NS	NS	NS	NS

NS=P>0.05; *=P 0.05-0.01; **=P<0.01.

Table 2.7 Effect of root barrier (R) and distance from hedge row (D) on soil moisture (% by volume; averaged over 2 years) at different depths

Soil Depth (cm)	Distance (m)	Root Barrier	No Barrier	Average	$LSD_{0.05}$
7.5	1	13.71	11.49	12.60	D x R = 1.45
	4	14.95	14.79	14.87	
22.5	1	20.09	17.91	19.00	D x R = 1.34
	4	21.33	21.31	21.32	
37.5	1	25.93	22.65	24.29	D x R = 0.92
	4	27.11	26.91	27.01	
52.5	1	28.85	26.73	27.79	D x R = 0.91
	4	30.18	29.83	30.01	
67.5	1	31.42	29.80	30.61	D x R = 0.33
	4	32.72	32.40	32.56	
82.5	1	32.08	31.30	31.69	D = 1.75
	4	34.27	34.06	34.17	

barriers increased the soil moisture content at TCI to a depth of 75 cm, soil water remain lower at all depths of interface plot even with root barriers as compared with sole crop plots **(Table 2.7)**.

3.3 Effect of Foliage Recycling on Crop Performance

Mulch levels had a strong effect ($P<0.01$) on grain and straw yields of both crops **(Table 2.8 & 2.9)**. Maize showed greater response to mulching than wheat. Averaged over two years, maize grain yield increased by 24, 45, 66 and

Table 2.8 Effect of mulch levels on maize yields (kg ha^{-1})

Mulch (Mg ha^{-1})	1993		1994		Pooled over 2 years		
	Grain	Straw	Grain	Straw	Grain	Straw	Total
0	2482	4497	1805	3505	2144	4001	6145
1.5	3291	6100	2328	4169	2809	5135	7944
3.0	3634	7354	2565	5110	3099	6232	9331
4.5	3957	9156	3144	6841	3550	7998	11549
6.0	4285	11152	3767	9279	4026	10216	14241
$LSD_{0.05}$	480	1193	604	1309	368	847	1863

Table 2.9 Effect of mulch levels on wheat yields (kg ha^{-1})

Mulch (Mg ha^{-1})	1993		1994		1995		Pooled over 3 years		
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Total
0	2350	3463	2632	3976	2440	3667	2474	3702	6176
1.5	2988	3875	2942	4446	2942	3350	2977	3890	6837
3.0	3267	4275	3208	4841	3437	3450	3304	4189	7493
4.5	3413	4854	3429	5096	3655	4033	3499	4662	8260
6.0	3554	5438	3571	5239	3857	4483	3661	5053	8714
$LSD_{0.05}$	457	1004	269	420	343	NS	200	414	992

88% over unmulched control in response to respective mulch rates of 1.5, 3, 4.5 and 6 Mg ha^{-1}. Corresponding increase for corn stalk yields were 28, 56, 100 and 155%. With the same mulch rates, wheat grain yields averaged over 3 years increased by 20, 34, 41, and 48%; straw yield increased by 11, 21, 34 and 41%. Maize yields differed significantly with year ($P<0.01$) but no differences in wheat yields were noticed among the years.

With increasing rate of mulching, maize grain yield increased linearly whereas wheat grain yield had a quadratic response. Regression relationships were:

Maize grain = 2225+0.3M [$R^2 = 0.31$; $P<0.001$; n=60].. Eq. 2.1

Maize straw = 3658+1.02M [$R^2 = 0.69$; $P<0.001$; n=60].. Eq. 2.2

Wheat grain = 2480+0.344M-0.00003M^2 [$R^2 = 0.65$; $P<0.001$; n=60].. Eq. 2.3

Wheat straw = 3604+0.232M [$R^2 = 0.31$; $P<0.001$; n=60].. Eq. 2.4

Where crop yields are kg ha^{-1} and M is the rate of Leucaena mulch in kg ha^{-1}.

When crop yields were adjusted for loss in cropped area for growing different levels of mulch material, total grain yield declined with increasing mulch rates (**Fig. 2.4**). The leaf fodder from crops increased with 1.5 Mg ha^{-1} mulching then declined. Planting the Leucaena hedge rows in 20% of land area would provide about 1.5 Mg ha^{-1} mulch and yield about 4200 kg ha^{-1} of grain yield, 8100 of leaf fodder from crops and 3200 kg ha^{-1} of fuel from trees.

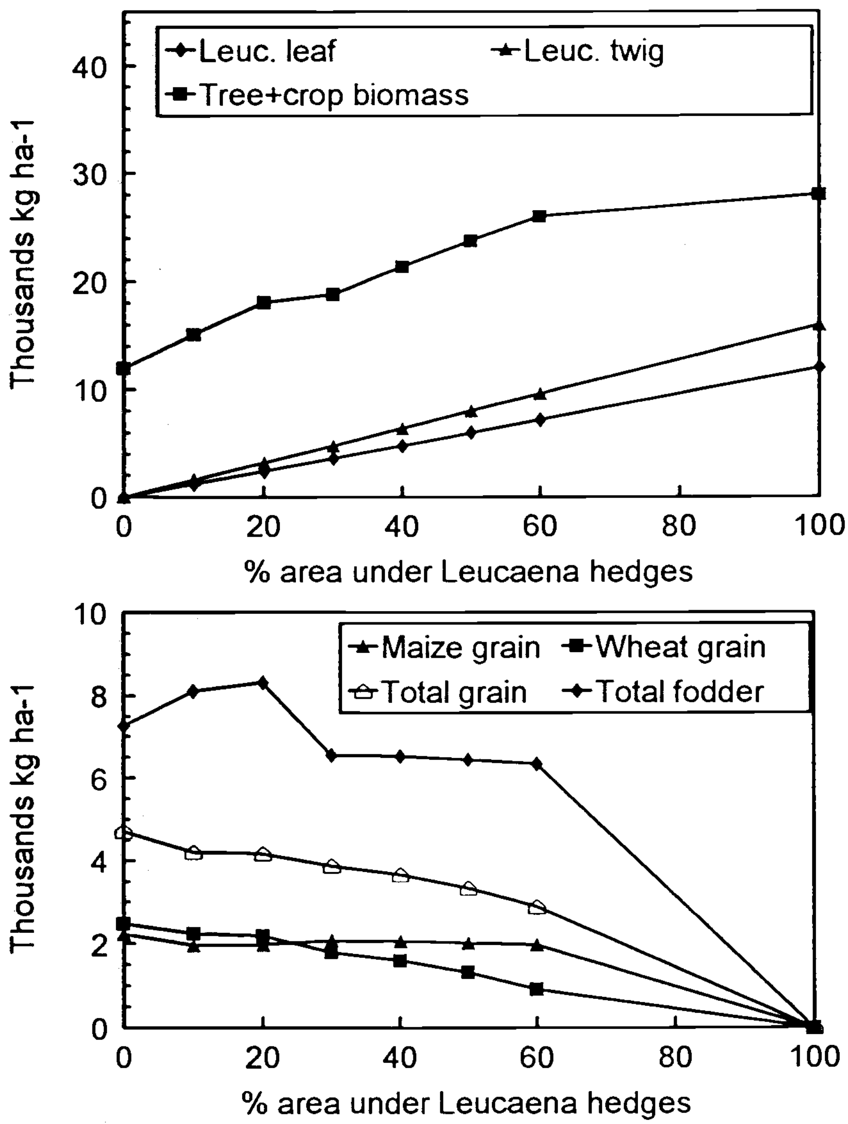

Figure 2.4 Grain, fodder and fuel production under different tree:crop ratios.

Table 2.10 Effect of mulching on weed dry mass (kg ha^{-1})

Mulch (Mg ha^{-1})	Maize			Wheat		
	1993	1994	Av. of 2 yrs	1993	1994	Av. of 2 yrs
0	1383	1900	1642	410	646	528
1.5	1450	2167	1808	467	780	623
3.0	900	1533	1217	250	657	453
4.5	350	850	606	143	390	267
6.0	183	483	333	133	293	213
$LSD_{0.05}$	313	295	209	94	185	104

Mulching with 3 Mg ha^{-1} of prunings or higher effectively suppressed weed growth during both the cropping seasons (**Table 2.10**). Although weed infestation differed significantly between ($P<0.01$) years as greater weed growth was observed under all treatments in 1994 than 1993, mulch application was equally effective in both the years. Average reduction over two years in weed growth during maize was 74, 37 and 24% with 3, 4.5 and 6 Mg ha^{-1} when compared to control (unmulched), although it increased by 10% with application of 1.5 Mg ha^{-1}. A similar trend was noticed in the wheat season though the weed growth was much less as compare to the maize season.

Table 2.11 Effect on mulching on soil moisture (% by volume) at wheat sowing

Soil depth (cm)		Rate of mulching Mg ha^{-1} yr^{-1}					P value	$LSD_{0.05}$
		0	1.5	3.0	4.5	6.0		
1993	0-15	15.00	15.42	15.32	14.46	16.33	0.26	--
	15-30	21.61	21.77	22.75	21.93	23.34	0.12	--
	30-45	27.16	28.25	29.57	29.83	30.27	<0.01	1.18
	45-60	29.78	30.05	31.12	30.95	32.75	<0.01	1.34
	60-75	32.40	33.28	33.15	34.24	35.09	<0.01	1.08
	75-90	34.37	33.94	34.08	34.08	34.37	0.08	--
1994	0-15	14.74	14.02	14.12	15.15	15.46	0.08	--
	15-30	19.53	19.22	20.26	21.15	21.11	0.04	1.47
	30-45	26.46	26.19	25.94	26.98	27.83	0.04	1.27
	45-60	30.00	29.99	30.57	30.53	31.45	0.004	0.743
	60-75	32.67	33.16	33.27	34.68	34.75	0.002	1.13
	75-90	33.72	33.06	33.59	33.86	34.66	0.18	--

Residual soil moisture measured at wheat sowing was also significantly influenced by mulch treatments. Depth wise analysis of moisture data (**Table 2.11**) showed that treatment effects were significantly higher ($P<0.01$ in 1993, $P<0.04$ in 1994) only at mid-subsurface layers. In both the years, mulch had no effect on soil water contents of surface depths (0-20 cm) and below 75 cm.

With increasing mulch levels P and K concentration in grain and straw of both crops significantly increased (**Table 2.12**). Even though major nutrients

Table 2.12 Concentration of major nutrients (%) in grain and straw of maize and wheat as influenced by levels of foliage recycling

Mulch Mg ha^{-1}	Wheat						Maize					
	Grain			Straw			Grains			Straw		
	N	P	K	N	P	K	N	P	K	N	P	K
0	1.23	0.427	0.43	0.22	0.16	1.09	0.83	0.32	0.407	0.22	0.16	0.71
3	1.27	0.437	0.44	0.23	0.14	1.18	0.87	0.34	0.43	0.22	0.163	0.73
6	1.32	0.437	0.44	0.25	0.15	1.39	0.92	0.33	0.447	0.24	0.153	0.85
9	1.37	0.463	0.46	0.26	0.16	1.44	0.99	0.33	0.463	0.25	0.173	0.86
12	1.46	0.477	0.48	0.28	0.17	1.49	1.07	0.32	0.463	0.27	0.170	0.89
$LSD_{0.05}$	0.124	0.039	0.032	0.039	NS	0.2	0.15	NS	0.022	0.032	NS	0.16

Table 2.13 Annual nutrient addition and crop removal (kg/ha) under different mulch rates

Mulch rate (Mg ha^{-1}yr^{-1})	Through pruning			Pruning + Fertilizer			Annual crop removal		
	N	P	K	N	P	K	N	P	K
0	-	-	-	100	48.4	66.4	65.17	28.74	88.13
3	79.5	6.3	48.6	179.5	54.7	115	82.5	36.28	108.57
6	159	12.6	97.2	256	61.0	163.6	97.55	40.16	139.59
9	238.5	19.9	145.8	338.5	68.3	212.2	107.21	48.86	168.45
12	318	25.2	194.4	418	73.6	260.8	138.68	56.3	202.42

added through fertilizer and recycled through Leucaena prunings considerably exceeds the total crop removal at all mulch levels (**Table 2.13 & 2.14**), a significant increase in soil was noticed for total nitrogen only after three years of

Table 2.14 Changes in major soil nutrients (depth 0-20cm) after 3 years of recycling of Leucaena foliage

Mulch ($Mg\ ha^{-1}$)	Total N ($kg\ ha^{-1}$)	Available P ($kg\ ha^{-1}$)	Available K ($kg\ ha^{-1}$)
0	1409	50.85	207
3	1436	42.75	209
6	1548	47.25	202
9	1665	47.25	211
12	1755	52.65	215
$LSD_{0.05}$	147	NS	NS
Initial nutrient status	1404	55.14	225

mulching at the rate of 4.5 $Mg\ ha^{-1}$ or higher. Available P and K were not influenced by mulch treatments.

4.0 DISCUSSION

4.1 Crop Performance at Tree-Crop Interface

Moisture was not expected to be a limiting factor during the rainy season when maize was cultivated. The hedges were pruned at time of sowing which further minimized the competition for light and moisture, therefore little effect of cutting height and no effect of root barriers on maize yields was observed. Leucaena hedges recovered quickly after pruning in the rainy season and height of hedges reached to 2.5-3m height when the maize was harvested. Higher pruning height reduced maize yield. Because maize is fast growing crop and quickly gains height of about 2m within 8 weeks after sowing, the growth of maize was suppressed only in the row closest to hedges.

Although tree-crop interaction at interface has been widely investigated recently (Gaddanakeri, 1991; Lawson and Kang, 1990; Singh et al., 1989); results are not readily comparable in many cases because of differences in rainfall pattern, soil type, hedge management (cutting frequency and cutting height), or lack of consistency in presenting the results. Results of this study were similar with the findings of Rosecrance et al. (1992) conducted in Hawaii (vertic haplustoll soil, irrigated once every two weeks). He reported reduction in maize yield by 10% in the row closest to the hedgerow (cut at 50 cm). Mureithy et al. (1994) (average annual rainfall 1200 mm, orthic ferrosols) reported 30% reduction in maize grain yield in the presence of Leucaena hedgerow pruned at 50 cm height in sandy soils of coastal lowland of Kenya. This reduction in crop yield was mainly due to the loss of cropped area (20%) to the hedgerows.

In the post-rainy season when wheat was cultivated, new leaf growth of Leucaena was restricted, possibly due to low temperature. In spite of the fact that the hedge maintained little foliage after pruning at wheat sowing, there was considerable reduction in wheat grain and straw yields. This result was unexpected as trees remain defoliated until the grain filling stage. A significant effect of distance and root barriers on profile water content at wheat sowing suggests that the reduction in wheat yields might be due to continued soil water depletion by hedges after the cessation of monsoon rains until wheat sowing. Some competition for water was possible at the grain filling stage of wheat in March when regrowth of hedges was activated. Lower water in interface plots where root barriers were in place compared to sole plots suggests that polyethylene root barriers were only partially effective in controlling the lateral root growth of the Leucaena hedgerows. At the end of experiment I reopened the trench and found that some Leucaena roots grew back in the crop root zone from underneath the barriers. Pruning the hedges after the monsoon season may improve residual soil water and wheat yields at the tree-crop interface.

Other studies in the from semi-arid tropics where moisture was the limiting factor showed that Leucaena hedges aggressively compete, mainly for soil moisture, with associated crops grown in alleys. Singh et al. (1989) at Hyderabad, India (average annual rainfall 750 mm, shallow alfisols), noticed that growth and yield of cowpea, castor and sorghum declined to the extent of 70% of sole crop near the hedge rows (0.3 m from hedges). They found that presence of root barriers completely eliminated any reductions in crops yield. Korwar and Radder (1994) working with root pruning in deep vertisols (average annual rainfall 644 mm) reported 33% increase in post-rainy season sorghum grain with root pruning over unpruned compared to 12% increase for wheat grain in our study.

Results suggests that tree-crop competition during the maize growing season (rainy) is negligible and reduction in wheat yield (post-rainy) can be minimized further with appropriate modification in timings of pruning or maize crop management aimed at reducing depletion of soil water after cessation of monsoon rains.

4.2 Effect of Foliage Recycling on Crop Performance

Under the favorable growing environment (warm temperature and sufficient water supply) during the rainy season, a sharp increase in maize yield in response to increasing rate of mulching with Leucaena prunings is attributable to increased nutrient availability, and to some extent weed suppression through mulches. A significant improvement in the N concentration of straw and grain of maize and wheat and also in the soil indicate the nutritional advantage under mulched plots. In this study it was not possible to segregate nutritional effects from the weed suppressions effect of mulching in this study.

Patterns of nutrient release and their uptake by crops under different mulch qualities have been examined by others (Rubaduka et al., 1993; Mulongoy et al., 1993; Rosecrance et al., 1992). Leucaena prunings decompose quickly, releasing about 60% of total N within 2 weeks after incorporation in the soil (Rubaduka et al., 1993). Kachaka et al., (1993) observed a rapid increase in soil microbial biomass during the same period following incorporation of prunings of different qualities including Leucaena . They found that magnitude of increase in soil microbial biomass and following rate of decline were proportional to the observed decomposition rate of the material added. Also, temporary immobilization of N during first two weeks followed by N release was observed in their study. This trend of N accumulation followed by N release is reported by others also (Aber and Melillo, 1980; Bosatta and Berendse, 1984). Swift et al. (1979) suggested that same general trends of immobilization-mineralization should apply for other nutrients as well. Because nutrient demand of maize and wheat is expected to be highest from 4th to 8th week (period of maximum vegetative growth) after sowing, the above findings indicate that Leucaena prunings applied at crop sowing would synchronize the release of nutrients with peak crop requirement periods.

On degraded alfisols (pH 5.8, 1.2% organic carbon, 0.14% N) Mulongoy et al. (1993) compared the effect of time of pruning application on N uptake by maize in alley cropping. They found that application of Leucaena and *Senna siamea* prunings close to sowing contributed the largest amounts of N to crop in comparison to 4 or 2 weeks before planting or 2, 4, or 6 weeks after planting of maize. Rosecrance et al. (1992) evaluated alley cropping of maize with nine leguminous trees including four Leucaena species on a N deficient soils of Hawaii. They reported that maize yield responded linearly to increasing level of N applied as green manure. They observed an increase of 12 kg of maize grain with each kg of N applied through prunings. This is very similar to our results as maize yield increased by 11.3 kg with each kg of N applied through Leucaena prunings.

Even though Leucaena mulch decomposed rapidly, it was effective in reducing the weeds growth when applied at higher rate, especially during the crop establishment period of maize. Though weed were controlled through herbicides and manual weeding, it may be possible that weeds had a competitive effect at early growth stages of maize. For some reason Atrazine was less effective in 1994 than 1993 maize season. A close relationship between soil organic matter and adsorption of Atrazine has been reported (Rodgers, 1968). Since soil of study site was low in organic matter (0.5%) it is possible that high intensity rain following Atrazine application reduced the effectiveness of the herbicide. Reduced weed growth observed with increasing mulch levels could also be due to better adsorption of Atrazine in mulched plots. Lower maize yield in 1994 associated with greater weed infestation compared to 1993, also indicated possibility of crop improvement through weed suppression by mulch. In a similar mulching study Jama et al. (1991) found 90% reduction in weed biomass under Leucaena-maize alley cropping compared to pure crop. Parihar et al. (1975) found that weed control was greater on mulched plots than on unmulched plots with or without Atrazine.

Suppression of weeds by mulch is attributed to factors such as lower temperature and shading (Day, 1968; Wesson and Wareing, 1967) or allelopethic effects. Lieble and Worsham (1983) for example, found toxic microbial products from decomposing mulch material influencing weed germination. Because light is necessary to stimulate seed germination in many weed species (Wesson and Wareing, 1967), mulch may reduce germination of such weeds. Even partial smothering by thin layer of mulch weakens a plant by reducing its photosynthetic capacity and thus can aid its control (Day 1968). We observed that mulch applied at the rate of 4.5 Mg ha^{-1} provided almost complete surface coverage, however, weed growth was further reduced by increasing mulch application to 6 Mg ha^{-1}.

Wheat was less responsive to Leucaena mulching at higher rates because moisture became a more limiting factor during the wheat crop season. Although greater residual water content at wheat sowing was found in sub-surface layers, differences were small and of little advantage to wheat crop. Marginally higher water content observed at subsurface layers (30-75 depth) was possibly due to better receptivity of rain water and effective weed control during maize season under the plots mulched at 4.5 Mg ha^{-1} or higher. Mulching did not influence the soil water in surface layers, perhaps because of surface evaporation during 2 months (October and November) of fallow period after rainy season. Substantial reduction in weed growth at higher mulch rate was also expected to favor higher wheat yields.

Along with increased crop harvest, recycling of prunings accelerated the rate of nutrient export from the system. Crop removal of N, P and K exceeded the nutrient input through fertilizers. As the trees efficiently mobilize nutrients through recycling of prunings, nutrient requirements of alley cropping system might be quite different from that of monocropping systems, and shall be re-examined in view of N_2 fixing ability of the trees and internal nutrient cycling within the system.

Based on crop response to mulch levels and reduction in crop yields at TCI observed in this study, and leaf and twig yield of Leucaena presented in Chapter 1, I estimated production potential of alley cropping system with different tree:crop ratios. Though we observed sharp increase in crop yields with increasing mulch rates, the area under crop rapidly decline with increasing mulch level. Also, tree:crop competition increased with increasing number of rows in unit area. This would result in net reduction of grain yield as we increase tree:crop ratio **(Fig. 2.4)**. However, fodder yield (maize and wheat straw) was estimated to increase initially by planting Leucaena in 20% area, then decline by further increasing the area under tree. Assuming that loss due reduction in grain yield would be compensated by fuel production, alley cropping with 20-30% area under hedges seems to be a viable alternative to traditional farming system.

5.0 CONCLUSIONS

We found little tree-crop competition between Leucaena hedge-rows and maize crops grown in alleys. In spite of quick recovery by hedges during the rainy season after pruning at maize sowing, the suppressive effect of hedges was restricted to the nearest maize row only. This effect of trees was further minimized at lower cutting heights suggesting some above ground competition between Leucaena and maize. During the maize season root barriers did not show any effect on maize yields therefore there was no indication for below ground tree-crop competition.

Although Leucaena maintained relatively little foliage during the wheat season, crop yields were reduced up to 2m distance from hedges, which was primarily due to competition for soil moisture at tree-crop interface. Cutting height did not show any effect on wheat yields. Polythene root barriers were partially effective and marginally improved crop yields. Pruning the hedges before the end of the rainy season may minimize tree-crop competition for soil water.

Crops were highly responsive to mulching. Because of increased nutrient supplementation through prunings and weed suppression, maize and wheat yields sharply increased with increasing rates of mulch application. At high mulch rates with added production and increased crop harvest, nutrient export in grain and straw from the system exceeded the input through fertilizers. In order to maintain long-term productivity of the system, nutrient management needs to be re-examined in view of contribution through biological N_2 fixation and efficient nutrient mobilization within the system.

Estimates based on tree-crop interactions observed in this study show that an alley cropping system with 20% area under Leucaena hedge-rows would provide about 12% lower grain yield and 15% higher fodder yield from crops as compared to sole cropping system.

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CHAPTER III

PREDICTING LONG-TERM CHANGES IN SOIL ORGANIC MATTER IN RESPONSE TO LEUCAENA FOLIAGE RECYCLING

ABSTRACT

In tropical systems soil organic matter (SOM) levels are typically low ($<$ 2%) and lack of organic matter input is a common problem. The level and rate of change of soil organic matter are key indicators for assessing the sustainabilty of land use systems. Generally these changes are very slow and difficult to quantify with short-term experiments. Problems associated with accurate measurement of the size and decay rates of different fractions of soil organic matter restrict the use of carbon models for predicting long-term effects of land use treatments. Earlier studies suggested that for a given climate, the soil microbial biomass : organic carbon ratio remains constant. Any short-term deviation from this equilibrium would indicate that soil is either loosing or accumulating carbon as it tends to return to the climate induced equilibrium. The present study examines the possibility of using short-term changes in microbial biomass induced by increased Leucaena mulching for predicting future changes in soil organic matter in a low input maize-wheat cropping system in the sub-humid subtropical climate of northern India. Observed changes in biomass carbon (Bc) are compared with changes in organic carbon (Oc) predicted by SCUAF (Soil Changes Under Agro-Forestry) model.

The low organic matter soil typical of this region (0.515% in 0-20 cm depth) responded quickly to increased rates of carbon addition through mulches. Leucaena foliage recycling at the rate of greater than 6 Mg ha^{-1} yr^{-1} resulted in a

significant increase in total Oc and Bc within three years. Bc, as measured 8 months after mulch application, increased approximately five times relative to Oc suggesting a preferential growth of this pool. The shifts in Bc from equilibria in response to all mulch levels were of the same magnitude as SCUAF predicted changes in Oc at the end of 25 years under similar mulch treatments. Thus, it may be possible to make quantitative projections for expected long-term changes in Oc based on observed early changes in Bc.

1.0 INTRODUCTION

Soil organic matter (SOM) is known to be a key factor in maintaining soil productivity. It regulates plant nutrients (Singh et al., 1989; Sanchez et al., 1989; Tiessen et al.,1992; Woomer and Ingram, 1990), and promotes soil aggregation (Oades, 1984; Yadav and Singh, 1976); leading to increased water holding capacity, reduced erosion (Lal, 1986), and greater infiltration (Lavelle, 1988). Singh et al. (1989) working in dry tropical forest and savanna ecosystems of northern India suggested that microbial immobilization of nutrients may be a major nutrient conservation mechanism; storing nutrients during dry summers and releasing them during the rainy season when plant growth is activated. Tiessen et al. (1992) evaluated the effect of cultivation and regrowth of bush fallow on soil organic carbon (Oc) and P fertility in semi-arid northeastern Brazil (rainfall 830 mm yr^{-1}, pH 5.2-6.07, Oc 0.6-1.8%, total P 123-155 $\mu g\ g^{-1}$). They observed a 30% reduction in C, N and organic P after 6 years of cultivation. The P fractionation indicated that the decline in P fertility was not a result of net export of P in the crop, but resulted from the mineralization of organic P and subsequent transformation of the surplus inorganic P to unavailable forms. Yadav and Singh (1976) observed that large water-stable aggregates were positively correlated with Oc whereas smaller aggregates were related to clay content. Additionally, labile carbon compounds complex toxic aluminum and manganese, resulting in a more productive rooting environment (Hargrove and Thomas, 1981; Hue et al., 1986).

Rapid loss in SOM in cultivated lands is an almost universal event. Plowing of virgin soil leads to rapid oxidation of SOM through increased aeration. Because little or no crop residue is returned to soil in most tropical cropping systems, a negative carbon budget sets a degradation spiral in motion resulting in lower and lower crop yields. Incorporation of fast growing perennials in these low-input farming systems has emerged as a viable option for reversing the trend of land degradation. Because SOM management is viewed as central to the finest scale approaches used to assess the sustainability of soil systems (Swift and Woomer, 1993), there is a need to link management options with their long-term influence on SOM. Earlier efforts in this direction can broadly be put under two categories: **1)** estimating long-term changes through simulation models (Jansson, 1958; Jenkinson and Raynor, 1977; Paul and van Veen, 1978; van Veen et al., 1984; Parton et al., 1987; Young et al., 1987) and **2)** using bioindicators to detect long-term changes in soil health, such as **a)** microbial biomass (Carter, 1986; Powlson et al., 1987), **b)** soil organism biodiversity (Paoletti et al.,1992), **c)** potentially mineralizable C and N (Campbell et al. 1989; Woods and Edwards,1992) and **d)** soil enzymes (Klein and Koths, 1980; Doran, 1980; Dick, 1984; Bolton, et al., 1985). Generally these indicators have been used for qualitative comparisons among land treatments and to understand their implications on soil processes. Efforts to use these indicators for quantifying the future changes in soil have been lacking.

In the present study, I used both of the above approaches to determine long-term effects of different levels of Leucaena foliage recycling on SOM in a Leucaena-based agroforestry system under sub-humid sub-tropical climate of northern India. Predictions made for changes in SOM using a model SCUAF (Soil Changes Under Agro-Forestry, Young and Muarya, 1990) were compared with the observed changes in microbial biomass carbon (Bc). The observed preferential changes in Bc were then used to make predictions for long-term effects on SOM.

1.1 Objectives and hypotheses

This study was conducted with following specific objectives:

1) To determine the initializing parameters for SCUAF, and validate the model for the crops, soil and climatic situation of the experimental site.
2) To quantify changes in total organic carbon (Oc) and biomass carbon (Bc) in response to different levels of Leucaena mulching in a maize-wheat cropping system.

3) To relate observed early changes in Bc with long-term changes in Oc as predicted by SCUAF and make predictions for future changes in Oc on the basis of observed early changes in Bc.

It was hypothesized that there is a preferential short-term increase of Bc over Oc in response to recycling of Leucaena prunings and that this can be related to long-term changes in SOM for different rates of mulch application.

2.0 METHODS AND MATERIAL

The experimental site was located 18 km west of Dehradun city in the northwestern hill region of India. The udic haplustalf soil had pH 5.7 and silty clay loam surface texture with silty loam subsoil. Under the sub-humid sub-tropical climate of this region 80% of total annual rainfall (1700 mm) occurs during mid-June to mid-September. Agro-ecological and socio-economic details of the region were given in Chapter 1.

2.1 Field Layout of the Experiment

The experiment was laid out as per the field plan given in **Fig. 1.1**. Five levels (0, 3.0, 6.0, 9.0 and 12.0 Mg ha^{-1} yr^{-1} dry weight basis) of mulching with Leucaena prunings were maintained with six replications in a complete randomized block design. Each of these 5x5 m size plots was cropped with a maize-wheat rotation. Mulch treatments were applied twice a year at sowing of both the crops. During both cropping seasons all the plots were uniformly fertilized with recommended rates of P and K while half of recommended N was applied. Agronomic details for both crops are given in Chapter 2.

2.2 Soil and Plant Analysis

2.2.1 *Soil sampling*

Soil samples from the plow layer (0-20 cm) of fallow and cropped plots were sampled with a surface core sampler (diameter 7 mm) prior to each mulching in the month of May and October. Within each replicated treatment plot ten sub-samples collected from randomly selected spots were mixed to prepare one composite sample for each plot. Samples were screened a 2-mm sieve without further air drying and refrigerated at 4°C in polyethylene bags until processed. Analysis for biomass C and organic C were completed within two weeks after sampling.

2.2.2 *Biomass carbon estimation*

Estimation of soil microbial biomass carbon (Bc) was done using the chloroform fumigation-extraction (FE) method (Voroney et al., 1993). Besides being rapid, this method is suitable for soils with low initial water content (Sparling et al. 1990; Sparling and West, 1989). Soil water content at sampling varied from 4-6 % w/w (% weight/weight) during May and from 11-14 % w/w during October. Prior to each analysis soil water content was determined and two sets of 50 g oven dry equivalent of soil were rewetted to 50 % w/w immediately before the fumigation. Unfumigated controls were also rewetted prior to extraction with 0.5 *M* K_2SO_4. One set of samples was fumigated with ethanol-free $CHCl_3$ and placed in the dark for 24 hours at 25°C. After 24 hours $CHCl_3$ vapors were evacuated. For extracting microbial C, 150 ml of 0.5 *M* K_2SO_4 was added to fumigated and unfumigated sub-samples and were shaken for one hour on an oscillating shaker. The soil suspension was then passed through Whatman # 5 filter paper. The organic C in 0.5 *M* K_2SO_4 extract was determined with dichromate oxidation method. The K_2SO_4 extract is added to a mixture of 66.7 m*M* $K_2Cr_2O_7$ (2 ml), 18 *M* H_2SO_4 (10 ml), 14.7 *M* H_3PO_4 (5 ml) and HgO (70 mg) and boiled under refluxing condition for 30 min. The excess dichromate remaining is determined by titration with 33.3 m*M* ferrous ammonium sulfate using ferroin as an indicator. Biomass C is then estimated as:

$$\text{Biomass C} = (OC_F - OC_{UF}) / k_{EC}$$

where OC_F and OC_{UF} are extractable carbon in fumigated and unfumigated samples respectively and k_{EC} represents extraction efficiency of the method. In this study a k_{EC} of 0.25 was used (Voroney et al., 1993).

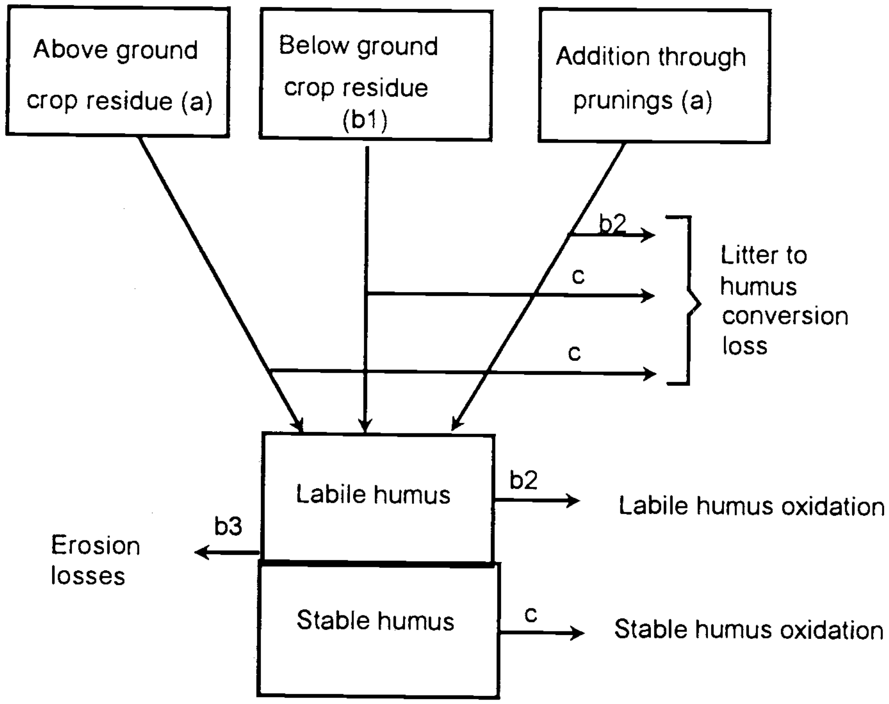
Presently no single method is available to provide measurements of Bc with unquestionable accuracy. Generally more than one method is used simultaneously to get reliable estimates of Bc pool size. Because the concern in this study was to determine relative deviations from the state of equilibrium, I did not attempt to verify the Bc values obtained by the FE method with any other method.

2.2.3 *Organic carbon*

Soil samples were air dried and finely ground and screened through a 0.2-mm sieve prior to analysis for organic carbon (Oc). The wet oxidation method without external heating (Anderson and Ingram, 1993) was used for Oc determination.

2.3 Input and Losses to SOM

Soil carbon balance in the surface 20 cm depth under a maize-wheat cropping system was determined using the SCUAF carbon model (section 2.4.1). Carbon inputs and losses, for which direct measurements were not feasible, used either the SCUAF default value or were estimated on the basis of available information (**Fig. 3.1**). Above ground crop residue were determined by sampling the residual phytomass after crop harvest in a 2x2-m quadrant for each of five mulch levels and six replications. C addition through weeds was determined at each manual weeding for each plot. Root biomass was estimated on the basis of soil core samples obtained at crop harvest. About 13 to 52 percent of annual root production is reportedly decayed by the end of growing season in cereals



a : addition through above ground crop residues were measured at harvest of crops and addition through weeds were measured at the time of manual weeding; measured amounts of Leucaena prunings were added;

b^1: root biomass were sampled at crop harvest and corrections made for root turnover during cropping periods;

b^2: litter-to-humus conversion loss for Leucaena prunings and oxidation losses of labile humus were estimated from observed changes in SOM under mulched fallow plots;

b^3: erosion losses were estimated using USLE (Wischmeier et al. 1978);

c : estimates based on default values of SCUAF.

Figure 3.1 Methods used for estimating components of soil carbon cycling

(Swinnen et al. 1995; van Noordwijk et al. 1994). I assumed that 30 percent of annual root production was decayed by the end of growing season for wheat crop and made corrections accordingly. Such a correction for maize crop was not done assuming carbon gained through rhizodeposition is leached during cropping season due to continuous monsoon rains. The annual C balance under different mulch rates were based on two-year (maize) and three-year (wheat) averages for C input through crops and weeds.

A three-part curve was considered to determine oxidation losses which include: **a**) rapid oxidation of fresh litter or crop residue, termed as litter-to-humus conversion loss or humification coefficients; **b**) relatively slow oxidation of labile humus and **c**) very slow oxidation of stable humus. I determined the conversion loss for Leucaena foliage which was the single largest source of C input in mulched plots. For estimating conversion loss of Leucaena foliage and decomposition rate for labile humus another set of fallow plots was maintained with five mulch levels e.g. 0, 3, 6, 9, 12 Mg ha^{-1} yr^{-1} applied with six replications in a randomized block design. Plots were maintained as weeded-free and mulch was applied in two equal amounts in the months of June and October at the time of mulching in cropped plots. Mulch was incorporated in soil in both sets of plots at the time of manual weeding. Depletion or accumulation of organic carbon in fallow plots were monitored during three years. As the stable humus fraction decomposes very slowly, it was assumed that net changes in Oc are the result of combined effect of oxidation of labile humus and losses or gains through humification of mulch material. Depletion in unmulched (control fallow) plots provided an estimate of oxidation loss of labile humus which was subtracted from the observed differences in SOM under mulched plots to determine litter to humus conversion loss for Leucaena foliage. In fallow plots erosion losses were restricted by creating collars around these plots with appropriate drainage for excess rain water. Leaching losses of SOM were not estimated separately. However, it might be possible that high intensity rains coinciding with vigorously decomposing Leucaena mulch could have resulted in significant losses of carbon through leaching. In the present study leaching losses were considered as part of conversion losses. Conversion loss for crop residues and oxidation of stable humus were not measured and estimates were based on default values of the SCUAF.

Loss of SOM through erosion was estimated using the Universal Soil Loss Equation (USLE) carbon enrichment ratios. USLE has been validated for this experimental site (Singh et al., 1981) and values for rainfall factor (EI_{30}) (Wischmeier et al., 1978), soil erodibility factor (K), and crop cover factor (C) were available (Narain et al. 1994). Topographic factor (LS) is determined using the slope-effect chart suggested by Wischmeier et al. (1978). Correction in cover factor C were made for mulch effects using the relationship between residue cover and surface cover sub-factor suggested for average crop conditions (Foster et al., 1981).

2.4 Using SCUAF for predicting changes in Oc

SCUAF (Soil Changes Under Agro-Forestry) is a prediction model developed at ICRAF by Young et al. (1987) for projecting long-term effects of various agroforestry land-use options on SOM and nitrogen. I used version 2 of this model (Young and Muraya, 1990) for predicting long-term effects of leucaena foliage recycling on SOM. The simplicity of the model, suitability to tropical farming systems (Vermeulen et al., 1993) and availability of required input data were the factors considered in selecting this model.

2.4.1 *Model structure*

SCUAF operates on one-year basis. The annual balance of soil carbon is calculated as:

$$C_{t+1} = C_t + \text{addition} - \text{oxidation} - \text{erosion} \quad \text{[Eq. 1]}$$

where C_t and C_{t+1} are soil carbon in successive years, additions are from humification of above and below ground tree and crop residues or organic additions, oxidation refers to the oxidation losses of labile and stable soil organic carbon by soil microorganisms, and erosion is loss of carbon in eroded soil.

In SCUAF, humification of litter (crop residue or mulch) is considered as first process of soil carbon cycle. It refers to breakdown of litter by meso- and micro-organisms and its conversion to soil organic matter. In the tropics this transformation takes about six months and more than half the carbon is lost through litter oxidation. Once litter is converted to soil humus, further oxidation takes place at slower rate and is calculated as:

$$C_{t+1} = C_t * (1\text{-}k) \qquad \text{[Eq. 2]}$$

where C_t is carbon in year t, C_{t+1} is carbon one year later, and k is the decomposition constant. Based on descriptive analysis made by Nye and Greenland (1960), SCUAF considers two humus fractions. A part of SOM, which is referred as stable carbon, oxidizes at a much slower rate than labile carbon. Losses and gain for these two pools are calculated separately.

Erosion removes the topsoil carbon contained in eroded sediment. Soil erosion is calculated from a simplified version of the universal soil loss equation (USLE) (Wischmeier and Smith, 1978).

The SCUAF is similar to the carbon section of CENTURY model of Parton et al. (1987), where CENTURY's plant carbon, active soil carbon, slow soil carbon and passive soil carbon are SCUAF's litter, soil microbes, labile humus and stable humus respectively. The model makes a major simplification by treating the size of microbial biomass as effectively constant.

2.4.2 *Initializing data files for SCUAF*

SCUAF is structured to deal with tree-crop mixtures rotated in space or time. In this study the model was used for predicting changes in soil Oc under cropped plots only. Leucaena foliage used for mulch was considered as part of organic additions. Input values for initializing SCUAF were determined as explained in section 2.2 and are presented in **Tables 3.1, 3.2** and **3.3**. SCUAF contains a set of default values which are best estimates for environmental conditions specified by the user to run the model.

2.4.3 *Model validation*

To validate SCUAF for agroclimatic conditions of the experimental site, observed changes in Oc under an on-going Long Term Fertility Trail (LTFT) plots were compared with SCUAF predictions. These plots were established in 1978 to compare the long-term effects of different methods of fertility management. Data from the following four treatments were used for this purpose:

1) Control (No fertilizer or manure),
2) Recommended levels of NPK (100:60:40 for maize and 100:50:40 for wheat),
3) Farmyard manure (FYM) 5 Mg ha^{-1} yr^{-1},
4) FYM 5 Mg ha^{-1} yr^{-1} + Recommended NPK.

Table 3.1 Selected SCUAF input parameters used for simulating maize-wheat cropping systems: Input values common to all mulch rates

Initializing Parameters		Input Values
Physical Environment	Climate	Highland sub-humid
	Soil texture	Medium textured
	Drainage	Free
	Slope class	Gentle (< 3 %)
Agroforestry System	Length (years)	1
	Fraction of land under tree	0
	Fraction of land under crop	1
Soil processes	Top soil depth (cm)	20
	Soil depth considered (cm)	20
	Total soil depth (cm)	300
	Initial carbon, top soil (%)	0.515
	No. of Humus fraction considered	2
	Labile:Stable humus	1:3[a]
	Labile humus decomposition	0.14 (14%)[c]
	Stable humus decomposition	0.005 (0.5%)[a]
Erosion USLE parameter	Climate factor	1048.2
	Soil erodibility factor	0.12
	Slope factor	0.14
	Crop cover factor	0.007-0.37 (Table 2b)
	C enrichment factor	1.9
Soil/Plant Feed back Factors[b]	Carbon (%)	0.5[a]
	Soil depth (%)	1[a]

[a]default values; [b]rise or fall in soil carbon or depth causes increase/decrease in rate of plant growth by 0.5 or 1 % respectively; [c]estimated as explained in **Table 3.9**.

Table 3.2 Selected SCUAF input parameters used for simulating maize-wheat cropping systems - Input values specific to the mulch rates

Initializing parameters	Land use systems				
	No Mulch	Mulch 3Mg ha^{-1}	Mulch 6Mg ha^{-1}	Mulch 9Mg ha^{-1}	Mulch 12Mg ha^{-1}
Growth allocation (kg ha^{-1} yr^{-1})					
Leaf	10600	12400	13200	14900	17600
Fruit	4600	5800	6400	7000	7700
Root	4500	5200	5600	6200	7000
Root fract. below 20 cm depth	0.3	0.3	0.3	0.3	0.3
Carbon fraction in dry mass	0.41	0.41	0.41	0.41	0.41
Biomass effect on erosion					
Crop cover factor (USLE)	0.37	0.11	0.04	0.007	0.007
Organic Additions (kg ha^{-1} yr^{-1})					
Leucaena Mulching	0	3000	6000	9000	12000
Carbon fraction	0	0.465	0.465	0.465	0.465
Nitrogen %	0	16:1	16:1	16:1	16:1
Harvest (fractions)					
Leaf	0.724	0.728	0.789	0.847	0.869
Fruit	1	1	1	1	1
Conversion losses					
Above ground parts[1]	0.85	0.85	0.85	0.85	0.85
Roots[1]	0.67	0.67	0.67	0.67	0.67
Organic additions[2]	--	0.82	0.82	0.78	0.76

[1]default values of SCUAF; [2]estimations made as explained in **Table 3.9**

Crop management details are presented in Chapter 2. and selected input parameters are presented in **Table 3.3**. Plant growth parameters used in the model are based on the yield data observed during initial five years of the trail.

2.4.4 *Sensitivity analyses*

Sensitivity of SCUAF was assessed for the input values estimated with assumptions. These input values were sequentially altered by 20% above and below the initial values. These alterations were not cumulative and only one variable was altered at a time.

2.4.5 *Prediction based on early changes in Bc*

I made the following assumptions for relating early changes in Bc with long-term changes in Oc:

1) For a given agroclimatic situation the Bc:Oc ratio will reach an equilibrium consistent with climate. Management induced early changes in Bc will lead to future changes in Oc, which are expected to occur in due course of time in order to return to the Bc:Oc ratio to the climatic equilibrium,
2) Changes in Bc pool size observed during the three years of study period will lead to the changes in Oc pool size expected over 25-year period.

Table 3.3 Selected SCUAF input parameters used for simulating maize-wheat cropping systems: Input values specific to LTFT plots

Initializing parameters	LTFT Treatments			
	Control	N:P:K	FYM 5Mg ha^{-1}	FYM+ NPK
Initial crop NPP (kg ha^{-1} yr^{-1})	14100	28000	22300	31800
Growth allocation (kg ha^{-1} yr^{-1})				
Leaf	7500	14900	11800	16800
Fruit	3300	6500	5100	7300
Root	3400	6700	5300	5300
Root fract. below 20 cm depth	0.3	0.3	0.3	0.3
Carbon fraction in dry mass	0.41	0.41	0.41	0.41
Oxidation losses[a]				
Above ground parts	0.85	0.85	0.85	0.85
Roots	0.67	0.67	0.67	0.67
Organic additions	--	--	0.47	0.47

[a]default values of SCUAF

These assumptions allow us to correlate early changes in Bc with expected changes in Oc during the period of 25 years with following equation:

$$C_t = C_i + (t/25) * \Delta Bc * C_i \quad \text{.......................................} \quad [Eq\ 3]$$

where C_t is predicted Oc at time t (yrs), C_i is initial Oc and Δ Bc is change in biomass carbon in fractions with respect to previous equilibrium stage. To have an estimate for the Bc at equilibria, I constructed a carbon budget for the

Table 3.4 Determining the deviation in Bc from equilibrium (ΔBc) in response to Leucaena mulching

Mulch (Mg ha^{-1})	Annual C input (kg ha^{-1} yr^{-1})	Carbon balance (Input-losses) (kg ha^{-1} yr^{-1})	Bc ($\mu g\ g^{-1}$)	ΔBc (fraction)[1]	Bc:Oc (% of Oc)
0	2500	-118	78	-0.049	1.53
Eq. point	3100[2]	0	82[3]	0.0	1.63
3	4300	214	97	0.183	1.83
6	5500	447	130	0.585	2.24
9	6900	799	158	0.927	2.51
12	8500	1258	220	1.683	3.36

[1] ΔBc=(Bc-82)/82;
[2]Estimated from the regression equation given in **Fig. 3.2**
[3]Estimated from regression equation between C balance and Bc
[Bc=82.45+0.104*C balance; R^2=98.2, P=0.001]

maize-wheat system with different mulch rates and control treatments. The point of equilibrium was estimated with regression equation (**Fig. 3.2**) and Δ Bc was calculated as explained in **Table 3.4**.

2.5 Statistical Analysis

To test the effect of mulch levels on Oc, Bc and Oc:Bc ratio, data were analyzed for each sampling date using complete randomized block design. Changes across the dates were compared using confidence limit of means (α=0.05).

3.0 RESULTS

3.1 Carbon budget of maize wheat system

The carbon budget of maize-wheat rotation with variable mulch rates is presented in **Table 3.5**. In the absence of organic additions annual carbon losses exceed the input through crop residues resulting in a net depletion of soil carbon reserves. Mulching at a rate of 3 Mg ha^{-1} yr^{-1} was able to reverse this trend. There were three sets of data available to relate annual C addition with annual C balance in this study. Observed Oc changes in cropped and fallow plots and SCUAF estimated annual C balance, show a linear relationship between C input and soil C balance **(Fig. 3.2)**. According to this relationship a minimum of 3 Mg ha^{-1} yr^{-1} of C incorporation is required to maintain present level of SOM.

3.2 Changes in Oc and Bc in response to mulching

Recycling of Leucaena foliage at variable rates resulted in significant changes in Oc, Bc and Bc:Oc ratio (**Tables 3.6, 3.7, 3.8**). Although Oc shows a consistent response to mulching over time, Bc has a seasonal pattern showing higher values for October than May samples. To determine treatment effects on Bc over time I have compared only May values as these are expected to represent annual minima because of maximum time interval (8 months) between mulching

Table 3.5 Annual carbon budget (C kg ha^{-1} yr^{-1}) of maize-wheat systems with different levels of Leucaena mulching

Source / Sink		Mulch levels				
		No Mulch	Mulch 3Mg ha^{-1}	Mulch 6Mg ha^{-1}	Mulch 9Mg ha^{-1}	Mulch 12Mg ha^{-1}
Inputs	Straw	314	386	458	578	721
	Weed	890	997	685	358	224
	Root	1284	1495	1593	1788	2006
	Leucaena Mulch	0	1395	2790	4185	5580
Total Input		2488	4273	5526	6909	8531
Litter to humus conversion losses	Above ground residues	1023	1176	972	796	803
	Crop roots	860	1002	1067	1198	1344
	Leucaena mulch	0	1158	2288	3306	4241
Humus oxidation	Labile humus	615	659	706	764	839
	Stable humus	45	45	45	45	45
Erosion Losses		63	19	7	1	1
Total Losses		2606	4059	5079	6110	7273
NET BALANCE		-188	214	447	799	1258

and soil sampling (**Fig. 3.3**). In spite of using all possible care in soil sampling and laboratory procedures the coefficient of variance for Bc data was high (25-30 %).

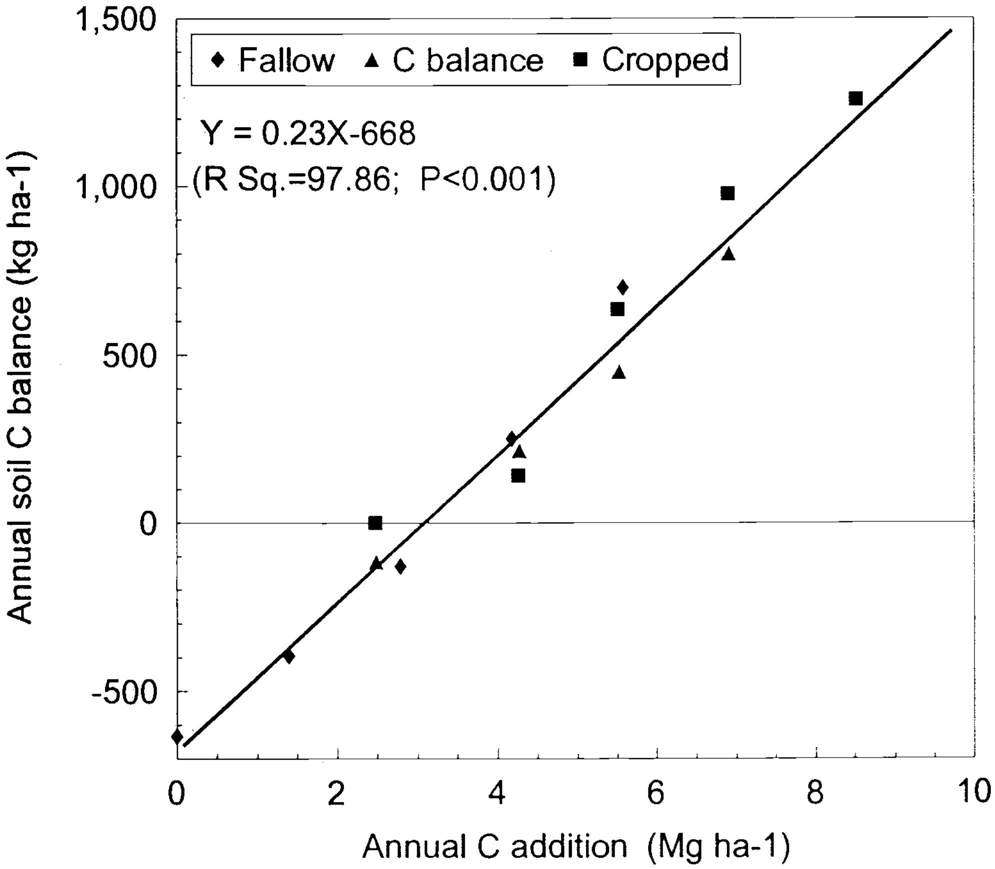


Figure 3.2 **Relationship between rate of Carbon addition and annual soil C balance as observed in fallow and cropped plots and estimated by C budget of maize-wheat system**

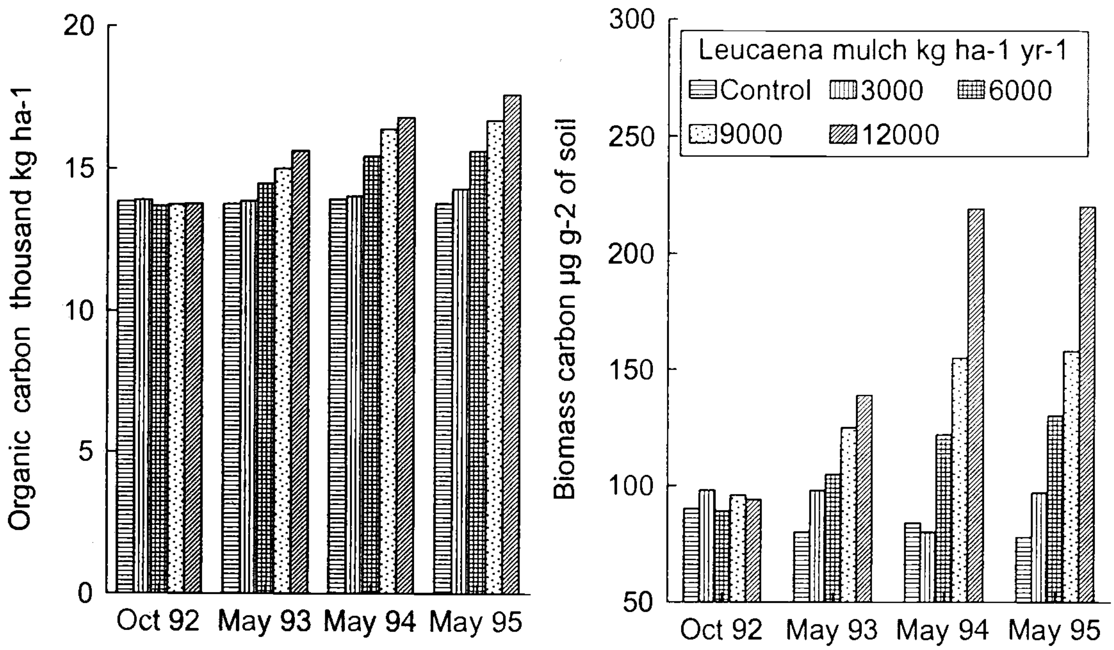


Figure 3.3 **Changes in Oc and Bc in response to mulch levels as observed during dry periods (May) of 1st, 2nd and 3rd year of study.**

Table 3.6 Soil organic carbon accumulation in 0-20 cm depth (± SE) during initial three years in response to mulching with Leucaena foliage

Mulch ($Mg\ ha^{-1}$)	Organic carbon (%)					
	October 1992[a]	May 1993[b]	October 1993	May 1994	October 1994	May 1995
0	0.513 (0.005)	0.51 (0.0055)	0.515 (0.0046)	0.516 (0.0056)	0.516 (0.0029)	0.511 (0.0048)
3	0.515 (0.0058)	0.514 (0.0097)	0.528 (0.0046)	0.52 (0.0072)	0.533 (0.0073)	0.53 (0.0053)
6	0.507 (0.0075)	0.536 (0.0071)	0.57 (0.0133)	0.572 (0.0071)	0.611 (0.0165)	0.579 (0.0128)
9	0.509 (0.0074)	0.556 (0.0064)	0.58 (0.0108)	0.607 (0.0123)	0.655 (0.0108)	0.62 (0.0223)
12	0.51 (0.0079)	0.579 (0.0082)	0.612 (0.0156)	0.623 (0.0086)	0.64 (0.0095)	0.653 (0.0271)
P value	0.89	<0.01	<0.01	<0.01	<0.01	<0.01
$LSD_{(0.05)}$	--	0.023	0.029	0.025	0.030	0.055

[a]soil samples taken just before first mulch application.
[b]samples on all subsequent dates were taken prior to mulch application.

Mulching at the rate of 6 $Mg\ ha^{-1}\ yr^{-1}$ or higher showed significant impact on both Oc and Bc in the first year itself. These effects were not significant under 3 $Mg\ ha^{-1}\ yr^{-1}$ mulching during the study period, however, a marginal increase was noticed in Oc and Bc pools. A gradual and consistent increase in Oc was observed in response to 6 $Mg\ ha^{-1}$ or higher mulching levels showing significant differences in the third year over first year. Although Bc, grew rapidly during first two years, within treatments differences over time were significant

Table 3.7 Soil biomass carbon accumulation in 0-20 cm depth (± SE) during initial three years in response to mulching with Leucaena foliage

Mulch rate ($Mg\ ha^{-1}$)	Biomass carbon ($\mu g\ g^{-1}$ of soil)					
	October 1992	May 1993	October 1993	May 1994	October 1994	May 1995
0	90 (5.7)	80 (5.4)	95 (3.5)	84 (3.6)	98 (4.2)	78 (5.1)
3	98 (7.5)	98 (5.7)	104 (9.6)	80 (6.6)	111 (9.9)	97 (16.1)
6	89 (12.6)	105 (11.5)	145 (10.0)	122 (18.9)	166 (10.5)	130 (5.9)
9	96 (6.1)	125 (13.8)	163 (13.0)	155 (15.9)	214 (23.1)	158 (21.6)
12	94 (8.6)	139 (16.2)	149 (26.1)	219 (20.3)	240 (20.5)	220 (22.4)
P value	0.92	0.011	0.012	<0.01	<0.01	<0.01
$LSD_{(0.05)}$	--	38.6	50.4	54.6	57	56.9

only with mulch applied at 9 $Mg\ ha^{-1}$ or higher. After three years of continuous application of Leucaena mulch, Oc increased by 4, 13, 21 and 27 percent over control with increasing mulch rates of 3, 6, 9 and 12 $Mg\ ha^{-1}\ yr^{-1}$, whereas Bc increased by 21, 63, 98 and 175 percent over control in corresponding mulch treatments. Thus Bc pool size expanded approximately five times relative to Oc during same period of time resulting in a significant increase in Bc:Oc ratio.

Table 3.8 Changes in Bc:Oc ratio in 0-20 cm depth (± SE) response to Leucaena mulching

Mulch rate (Mg ha^{-1})	Biomass carbon (% of Organic carbon)					
	October 1992	May 1993	October 1993	May 1994	October 1994	May 1995
0	1.76 (0.098)	1.55 (0.093)	1.85 (0.055)	1.63 (0.063)	1.89 (0.080)	1.53 (0.093)
3	1.90 (0.130)	1.90 (0.088)	1.96 (0.174)	1.54 (1.129)	2.08 (0.187)	1.83 (0.297)
6	1.74 (0.222)	1.95 (0.193)	2.54 (0.124)	2.11 (0.308)	2.71 (0.107)	2.24 (0.093)
9	1.88 (0.094)	2.25 (0.242)	2.79 (0.175)	2.54 (0.222)	3.25 (0.320)	2.51 (0.266)
12	1.83 (0.145)	2.39 (0.254)	2.42 (0.411)	3.50 (0.3 00)	3.75 (0.336)	3.36 (0.282)
P value	0.89	0.039	0.041	<0.01	<0.01	<0.01
$LSD_{(0.05)}$	--	0.638	0.787	0.847	0.845	0.757

3.3 Predicting long-term effects of mulching on SOM

3.3.1 *Model validation*

Estimated oxidation losses of labile humus and litter-to-humus conversion losses for Leucaena foliage is presented in **Table 3.9**. With the assumption that labile humus constitutes one-third of total SOM, the annual loss of this fraction is estimated to be 14 % (0.14 in fraction, see **Table 3.9**). SCUAF predictions for

Table 3.9 Oxidation losses of labile humus and Leucaena mulch estimated from annual changes in soil organic carbon under mulched fallow plots

Mulch carbon (kg ha^{-1})	Organic carbon (kg ha^{-1}) in surface layer (0-20 cm)			Average annual difference (*a*) (kg ha yr-1)	Total gain due to mulch (*a* + 633.5)	Annual loss in fractions of additions
	May 1993	May 1994	May 1995			
0	13600	12900	12300	-650	0	0.140[b]
1395	13900	13500	13100	-400	250	0.82[c]
2790	14000	13900	13700	-150	500	0.82[c]
4185	14000	14200	14500	250	900	0.78[c]
5580	14100	14800	15500	700	1350	0.76[c]

[a]combined effect of humus oxidation loss and gain through mulching;
[b]annual oxidation loss of labile humus;
[c]conversion loss of Leucaena mulch.

LTFT plots are compared with the observed changes in Oc in **Fig. 3.4**. SCUAF prediction for changes in soil carbon correspond well with observed changes over a period of 15 years with reasonable accuracy (± 7%),. Although there seems to be a considerable departures of observed Oc values for a given year in some treatments, which increase with rate of nutrient input levels, the long-term trends of observed Oc changes closely follow the prediction curves.

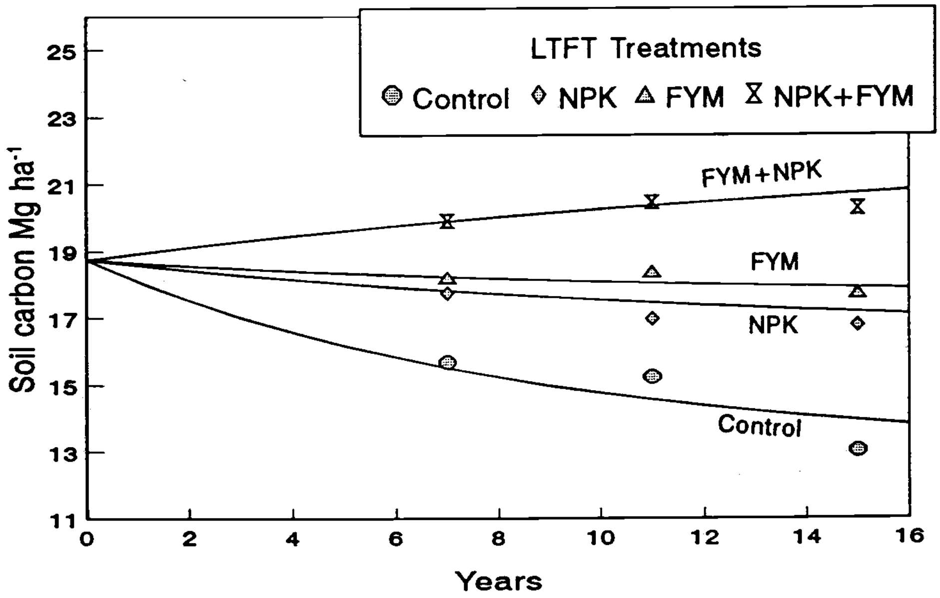


Figure 3.4 **SCUAF predicted (lines) vs observed changes (points) in soil carbon after 7, 11, and 15 years under LTFT plots.**

3.3.2 *Sensitivity analysis*

The model appeared less sensitive to carbon input rates as compared to oxidative losses and pool size of labile and stable humus components when sensitivity was tested for a period of 25 years (**Table 3.10**). A 20% alteration in input values for 'litter-to-humus conversion loss' changed the predicted value for soil carbon by 12 to 30 %. When ratio of stable humus was changed by 20%, SCUAF prediction for change in Oc after 25 years changed by 16 to 48%.

3.3.3 *SCUAF vs Δ Bc based predictions*

SCUAF provided realistic estimates for future changes in SOM in response to recycling of Leucaena foliage with different rates. Over a period of 25 years the model predicts decline in Oc by 12 percent under the no mulch treatment and mulching at the rates of 3, 6, 9, 12 Mg ha^{-1}, as projected by SCUAF, would result in an increase of Oc by 16, 50, 94 and 160 percent of present Oc level respectively (**Fig. 3.5**).

As the proportional increase in Bc pool observed during three years of experiment corresponds well with the SCUAF projected increase over a period of 25 years, it was reasonable to assume that observed changes in Bc pool size represent the expected accumulation of Oc in a time span of 25 years. Predictions

Table 3.10 SCUAF sensitivity to selected input parameters which were estimated with assumptions : percent change at 25 years in predicted SOM due to 20% increase or decrease in input values

Parameters		Sole cropping of maize			Maize-wheat with mulch (6 Mg/ha/yr)		
		Initial input	% change in SOM		Initial input	% change in SOM	
			Input + 20%	Input - 20%		Input + 20%	Input - 20%
INPUT	Fraction of above-ground NPP in roots	0.293	+ 7.8	- 6.7	0.283	+ 11.3	- 9.4
LOSSES	Above-ground residue oxidation[1]	0.85	- 12.9	+ 22.0	0.85	- 14.4	+ 22.6
	Below-ground residue oxidation[1]	0.67	- 12.4	+ 17.6	0.67	- 17.4	+ 25.3
	Mulch oxidation[1]	-	-	-	0.82	- 30	+ 30
	Labile humus oxidation	0.14	- 7.4	+ 10.2	0.14	-13.4	+ 20.5
POOL SIZE	Fraction of stable humus	0.667	+ 28.7	- 16.0	0.667	+ 47.7	- 17.2

[1]Litter to humus conversion loss

based on Equation 3 project a decline in Oc by 5 percent under no mulch plots. Mulching with 3, 6, 9 and 12 Mg ha^{-1} show respective increase of 18, 59, 93 and 168 percent over unmulched control (**Fig. 3.5**). Although net change at the end of 25 years projected by SCUAF and Δ Bc approach (Equation 3) are well in

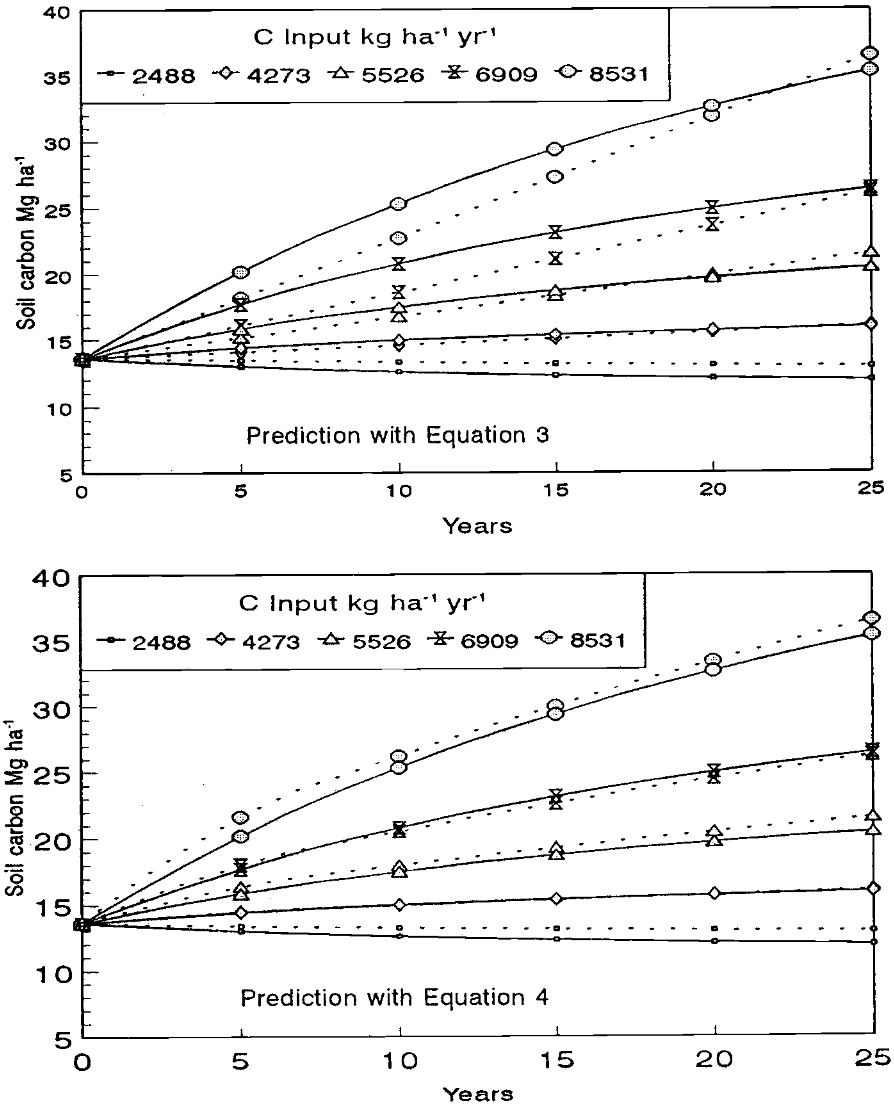


Figure 3.5 Changes in soil carbon under different rates of Leucaena mulching: SCUAF predicted (solid lines) vs prediction based on early changes in biomass carbon (broken lines)

agreement to each other, the rate of change projected by two methods differs. If constant C input levels are maintained, rate of change of soil organic matter is expected to decline as the increase or decrease in labile SOM will gradually approach to equilibrium where gain through humification equals oxidation of SOM. This is well represented by curvilinear progression in SCUAF predictions whereas Equation 3 predicts linear change over time. Using a coefficient for time function in Equation 1 eliminated this difference.

$$C_t = C_i + (t/25)^{0.65} * \Delta Bc * C_i \quad \text{.....................................[Eq. 4]}$$

Prediction curves suggested by this equation compared well with SCUAF predictions.

4.0 DISCUSSION

Soil organic matter under forest cover in the Doon Valley ranges from about 1% (under severe biotic interference, and erosion hazards) to 4% (under level conditions and protected sites) (Singhal et al., 1975 and 1986; Singh et al., 1990). Cultivation on these soils leads to a rapid decline in Oc levels. The negative carbon balance of the annual budget of low input farming with maize-wheat rotation indicates that this traditional land use is a degrading system. The annual carbon input to soil in this system is about 2.5 Mg ha^{-1}. Because maize and wheat straw are consumed as fodder, very little (about 13% of annual C input) of the crop residue is recycled to soil. Crop roots (50%) and weeds (36%)

are major contributors to soil organic matter. The soil has not reached a new equilibria where present C input is able to sustain the Oc level. Soil Oc has declined from 1.07% (under adjoining natural Sal forest) to 0.515% during 40 years of known cropping history of this experimental site, which confirmed the trend observed under the traditional cropping practice. Rate of loss in soil Oc projected by SCUAF and annual C budgeting compare well with each other due to procedural similarities in estimating annual losses. Under the favorable growing conditions of this region, recycling of nitrogen-rich foliage of Leucaena substantially increased crops yields (see Chapter 2). Because of increased carbon input through mulching and crop residues, mulching at the rate of only 3 Mg ha^{-1} was able to reverse the trend of SOM depletion.

Our estimate for humus oxidation was comparable with estimates obtained with isotope based studies conducted in tropical locations (Sauerbec and Gonzalez, 1977; Dalal, 1982) and are about ten times higher than the reported estimates for temperate climate (Jenkinson and Rayner, 1977). The litter to humus conversion loss for Leucaena mulch material presented in **Table 3.9** corresponds well with other estimates made in tropical situations. Nye and Greenland (1960) from west Africa suggested that between 80 and 90% of the above ground part and 50-80% of root residue are lost through oxidation as litter-to-humus conversion loss. Depending upon soil type and quality of substrate conversion loss of plant materials vary widely but fall within the range of 0.5 to

0.9 (Charreau and Fauck, 1970; Saurbeck and Gonzalez, 1977; Gonzalez and Saurbeck, 1982). Data presented in **Table 3.9** indicate that quantity of litter also influences the estimate of conversion loss as lower values are obtained with increasing rates of mulch application. This may be due to a layering effect of mulch with higher rate, leading to slower rate of decomposition.

As the SCUAF, along with its inherent assumptions and determined or selected default values for initializing parameters, was able to predict trends of depletion or accumulation of SOM, that were in agreement with the observed changes in LTFT plots, the model shows promise to provide reliable estimates for changes in SOM under different carbon input levels. The deviation in observed Oc from respective prediction values are most likely due to inconsistent weed management. Also the amount and distribution of rainfall and fertility buildup or depletion influence crop productivity and annual C input through crop residues. These effects are not simulated by SCUAF. However, the model considers feedback factors for calculating annual C input in response to the rise or fall in SOM or nitrogen.

As shown in **Fig. 3.2**, the annual C balance estimated using SCUAF correspond well with observed annual change in soil organic carbon in cropped and fallow plots. This lends support to the idea that the assumptions used for the SCUAF were reasonable. Also, SCUAF predictions for the highest mulch level (12 Mg ha^{-1} yr^{-1}) for SOM accumulation at 100 years was about 2%, which was similar to SOM in native forests of this valley where annual above-ground litter input is about 12 Mg ha^{-1} yr^{-1}.

Sensitivity analysis of SCUAF to input values, estimates for which were based on assumptions, show that the model is highly sensitive to humification coefficients and labile:stable carbon ratio, and unless accurate measurements for the pool sizes and decay rates of labile and stable humus fractions are made, the model predictions may not be completely reliable beyond a limited time frame for which it has been calibrated. However, since the model predictions were in agreement with observed changes in agricultural and forest soils, SCUAF predicted values were considered acceptable for assessing effect of mulch levels on SOM over a period of 25 years.

Our results confirmed the preferential growth of Bc pool in response to an increase in C input level which is in accordance with earlier findings of Carter (1986), Doran (1987) and Powlson et al. (1987). Microbial biomass quickly responded to C input levels and seemed to attain a new semi-equilibrium state within three years which is normal time span for most field experiments. Results of other studies conducted on tropical soils on the effect of change in land use on Oc and Bc are summarized in **Table 3.11**. Although rates of changes in Oc and Bc were variable, these studies confirm the preferential growth of Bc over Oc. Also, relatively more rapid changes in Bc and Oc were observed in tropics (Henrot and Robertson, 1994; Ayabana et al. 1976) than temperate soils

(Powlson et al. 1987; Angers et al. 1992). Henrot and Robertson (1993) observed a rapid decline in Bc as a result of removal of 20-year-old secondary vegetation in two soil types in Costa Rica. In both soils Bc was reduced to 50% of its initial value within the first six months and stabilized at 35% of its initial value within 15 months, whereas Oc was reduced by only 20% after 3 years. There results are in agreement with our trends as mulching showed rapid growth of Bc in first two years and then it seemed to stabilize. However, Bonde (1991) and Luizao et al. (1992) reported a much more gradual change in Bc after conversion of virgin

rainforest to pasture in an Amazonian oxisol as they observed no change in first year and 58% in eighth year. If C input rates are constant and large quantities of unhumified litter is not present, Bc is expected to stabilize quickly within the turn-over time required for decomposition of organic materials being recycled to soil. Earlier, Woods and Schuman (1988) also reported that the Bc pool quickly attains a new equilibrium in response to change in land use. They found that only 1 year of cultivation (wheat-fallow) of a native grassland soil resulted in reduction of Bc in the top 7.5 cm by approximately the same amount as did 25 years of cultivation.

Earlier findings indicated that early changes in Bc in response to any change in land management has potential to provide a quantitative estimate for medium to long-term changes in SOM. Anderson and Domsch (1986) proposed an equilibrium constant for Bc:Oc of 23 mg Bc per g Oc for monocultures in temperate conditions. This constant was further expended to an equilibrium function accounting influence of macroclimatic conditions by Insam et al. (1989). They concluded that Bc:Oc ratio is largely controlled by macroclimatic conditions and soil type or crop management have relatively less effect on the ratio. They proposed that it should be possible to find an equilibrium constant for Bc:Oc ratio for a given climatic region and deviation from this equilibrium constant would indicate that soil investigated is either loosing or accumulating carbon.

Soil microbial biomass, however, is a highly sensitive to changes in soil environment such as soil temperature, water content, aeration and quality and quantity of available C. As these conditions change within a year with season, crop management and crop growth stages, large seasonal fluctuations in Bc are expected and observed (Kaiser and Heinemeyer, 1993; Joergensen et al. 1994). Therefore, for determining relative deviation in Bc:Oc ratio it is important to measure Bc at the time of year when its size is relatively stable. May samples, which were taken 8 months after mulch application, were expected to represent the annual minima of microbial biomass and therefore it was possible to detect a definite trend of increase in Bc over a short time in response to mulching. If land management treatments being compared are not imposed on a system that has

Table 3.11 Observed changes in Oc and Bc in response to changes in the land management in tropical soils

Location	Soil Type	Land use / Treatment	Observed changes in Oc and Bc	References
South-west Nigeria	Alfisol, pH 6.8, Oc 1.1%, Bc 270 $\mu g\ g^{-1}$	Two years after conversion of bush regrowth to maize cultivation	Bc declined by 30% (unfertilized) and 15% (fertilized)	Ayabana et al., (1976)
Australia	Vertisols, pH 8, clay 41%, Oc 1.2%,	Retention of sorghum residue (4 Mg ha^{-1}dry wt) for 6 years	8% increase in Oc, 15% increase in Bc	Saffigna et al., (1989)
Vindhyan hill tract of north India	Ultisol, pH 6.4, clay 71%, Oc 2.18%, Bc 609 $\mu g\ g^{-1}$	15 to 40 years of cropping of a dry deciduous forest	50% decline in Oc and 60% decline in Bc	Srivastava and Singh (1991)
Central Amazon	Oxisol, pH 3.7, Oc 4.8% (3-10 cm), Bc 1463 $\mu g\ g^{-1}$	Conversion of virgin rain forest to pasture	No change in Bc after first year in 0-5 cm depth; Reduction in Bc (3-10 cm depth) by 30% after 2 yrs and 58% after 8 yrs	Luizao at al. (1992) Bonde (1992)
Costa Rica	a) Oxic humitropept, pH 5, Oc 4.5%; b) Fluventic Dystrandept, pH 6.4, Oc 2.6%	Removal of 20 yrs old secondary vegetation in both the soils	In both soil types Bc reduced by 50% in first six months and by 65% in 15 months; Oc reduced by only 20% in 3 yrs.	Henrot and Robertson (1993)
Central Zimbabwe	a)Haplustulf, pH 5.7- 6.1, clay 13-19%, b)Haplustulf, pH 5.5, clay 22%	a) Mamba savanna-wood land (spp. Brachystegia spiciformis, Julbernardia globiflora) b) Maize groundnut rotation for 15 years	a) Bc 816 $\mu g\ g^{-1}$ in 0-5cm surface layer 233 $\mu g\ g^{-1}$ in 25-50 cm subsoil, Oc 1.24%; b) Bc 397 $\mu g\ g^{-1}$ in plough layer, Oc 0.74%.	Kirchamann and Eklund (1994)

reached equilibrium or semi-equilibrium stage, as it was the case in the present study, it may be necessary to consider the initial Bc on the basis of Oc:Bc ratio at equilibrium for determining ΔBc values.

Results of the present study show that early response of Bc pool not only enables qualitative comparison of land management options but also can be potentially used to provide quantitative projections for change in Oc in response to any land management scheme influencing C input or mineralization rates. The approach may be especially useful for assessing long-term implications of various land use options under tropical conditions where it is difficult to meet input requirements of prediction models. Such projections however should be made for restricted time frames as early changes in Bc may not accurately represent long-term changes in overall soil fertility leading to changes in C input through plant residues. Another constraint experienced in this study was high variability in Bc measurements, which increased with increasing mulch levels. Increasing number of samples might be helpful to some extent to overcome this problem. Because accurate sizes for labile and stable C pools and their decomposition rates were not measured in this study and predictions are done with default values of SCUAF, the proposed relationship between early changes in Bc and long-term changes in Oc need further validation with long-term studies with different rates of organic additions.

5.0 CONCLUSION

SCUAF predicted a declining trend in soil organic matter under a maize-wheat cropping system without recycling of straw or stalks in the sub-tropical climate of northern India. SCUAF provided reasonable projections for changes in SOM in response to various levels of Leucaena foliage recycling. Soils with low organic matter content responded quickly to increased rates of carbon addition through mulches. Leucaena foliage mulching at rates greater than 6 Mg ha^{-1} yr^{-1} resulted in significant increases in total organic carbon and biomass carbon within three years. Biomass carbon, increased approximately five times more than organic carbon confirming a preferential growth of this pool. The shifts in Bc from equilibria in response to all mulch levels were of the same magnitude as SCUAF predicted changes in Oc at the end of 25 years under respective mulch treatments. Results of this study support the hypotheses that the Bc:Oc ratio tends to return to a climate induced equilibrium and early changes in Bc may be useful for making quantitative predictions for future changes in soil organic matter. Further testing with long-term studies should be used to validate proposed relationship between early changes in Bc and long-term changes in Oc.

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CHAPTER IV

SUMMARY AND OUTLOOK

In sub-humid sub-tropical India, both agricultural and forest ecosystems are increasingly under pressure for meeting food, fodder, fuel and timber needs of rapidly increasing human and animal populations. Continuous cultivation with low input management have resulted in loss of soil productivity due to high rates of water erosion and depletion in plant nutrients and soil organic matter. Because of fuel and fodder scarcity little or no crop residue is recycled to the soil. Integrating fast growing perennials with grain crops as hedge-rows on contours was considered as an alternative to monocropping system for controlling soil erosion and providing mulch material and fuel wood.

This study aimed to investigate tree-crop interactions and the effect of different hedge-row management options on soil organic matter. I examined the effect of cutting height of Leucaena and root barriers between trees and crop rows on biomass production of tree and crops. Recycling of Leucaena prunings was evaluated for its effect on crop yields and soil organic matter accumulation.

Biomass production of Leucaena increased with increasing cutting height up to 120 cm. Leaf and twig biomass at each pruning from 3 year old trees was 6 and 8 Mg ha^{-1} of area under Leucaena. Higher cutting height also favored biomass accumulation as bole growth. Since cutting height had little effect on maize and no effect on wheat grain and straw yields, pruning the Leucaena at the height of 120 cm can be recommended. An exponential relationship between root collar diameter and biomass production of Leucaena was observed. Appropriate nursery techniques and seedling selection based on collar diameter and root:shoot ratio may have a potential of improving biomass production from trees in alley farming systems.

After each pruning, a decline in live root biomass of Leucaena with a small increase in dead root biomass was observed suggesting a possibility of pruning induced shedding of fine roots. Thus in an alley cropping system where trees are repeatedly pruned, a substantial contribution to the soil organic matter may occur through root litter.

Root barriers had little effect on Leucaena growth during initial 3 years and no effect on maize. Though the barriers were only partially effective in restricting lateral roots of trees, it influenced wheat grain and straw yields at the tree-crop interface. This reduction in yield was attributable to soil moisture depletion by trees during two months of post rainy season fallow period. Pruning the hedge-rows with the cessation of monsoon rains in September is expected to favor the wheat yield at tree-crop interface and will be examined.

Crops were highly responsive to increasing levels of mulching with Leucaena prunings, when crop yields were compared on a net cropped area basis. When yields were adjusted for loss of area under trees and reduction in yields at the tree-crop interface, the total grain yields declined with increasing mulch levels due to corresponding reduction in net cropped area. Estimates based on tree-crop interactions observed in this study, show that an alley cropping system with paired row of Leucaena hedges (1 X 0.5 m spacing) at every 8 m interval in maize-wheat rotation (2:8 tree:crop ratio) would produce about 12% lower grain yield and 15% higher fodder (straw of maize and wheat) yield as compared to sole cropping system. Additionally, trees would produce about 3 and 3.2 Mg ha^{-1} of leaf mulch and twig yields. With this amount of mulch only marginal increase in soil organic matter (from 0.52% of present level to 0.6% after 25 years) can be expected. Any further increase in the soil organic matter would be at the cost of crop yields. Using hedge-rows as a barrier to overland flow could be an effective soil conservation practice, as demonstrated by earlier studies, however, such a system does not show a great potential of ameliorating an already degraded site.

For assessing the ecological sustainability of different land management options, soil organic matter is an important indicator which relates well with most soil physical, chemical and biological properties influencing soil productivity. I compared two approaches for evaluating the effect of mulch levels on long-term (25 year) changes of soil organic matter. Predictions made by a simulation model SCUAF (Soil Changes Under AgroForestry) for expected changes in soil organic matter over a period of 25 years, were of about the same magnitude as the observed deviations of biomass carbon from equilibrium during the 3 year study period. Therefore it may be possible to make quantitative predictions for expected changes in soil organic matter based on observed early changes in biomass carbon. However, since the relationship suggested in this study was based on the SCUAF predictions, it needs further validation through long-term field data. Also, I found a high variability in soil microbial biomass carbon measurements, possibly due to seasonal fluctuations in the pool size of microbial biomass and potential of measurement error involved with sampling and laboratory procedures. There is need to examine pattern of seasonal variation in microbial biomass and to identify appropriate sample size and time of sampling.

In spite of above limitations, this study indicates that changes in microbial carbon within a 3 year time span of a short term field experiment can be used to assess longer-term (25 years) changes in total soil organic matter in response to a change in land management. This approach could be an alternative to data demanding simulation models, especially for resource limiting situations in developing countries of the Tropics.

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APPENDICES

Table A.1 ANOVA for root barrier effect on Leucaena leaf biomass*

Source	DF	20 months		24 months		32 months		36 months	
		Mean Square	P Value	Mean Square	P Value	Mean Square	P Value	Mean Square	P Value
Block	2	2.78	-	3.58	-	14.04	-	6.96	-
Cut height(H)	3	0.58	-	3.08	-	1.04	-	5.25	-
$Error_a$	6	0.47	-	0.75	-	0.56	-	0.85	-
Root barrier(R)	1	2.04	0.89	5.32	0.04	1.09	0.46	3.67	0.22
R*H	3	1.20	0.50	1.25	0.31	1.26	0.58	3.10	0.28
$Error_b$	8	1.38	-	0.90	-	1.81	-	2.04	-

Table A.2 ANOVA for root barrier effect on Leucaena twig biomass*

Source	DF	20 months		24 months		32 months		36 months	
		Mean Square	P Value	Mean Square	P Value	Mean Square	P Value	Mean Square	P Value
Block	2	11.72	-	45.14	-	54.02	-	35.88	-
Cut height(H)	3	1.60	-	2.93	-	3.42	-	30.52	-
$Error_a$	6	0.48	-	1.21	-	1.94	-	4.93	-
Root barrier(R)	1	2.12	0.16	2.37	0.22	4.59	0.48	29.61	0.093
R*H	3	0.80	0.48	2.24	0.25	3.62	0.73	15.59	0.21
$Error_b$	8	0.87	-	1.35	-	8.17	-	8.13	-

*ANOVA presented in Table A.1 and A.2 are for the biomass data from border rows only and were tested for the effect of root barrier only.

Table A.3 ANOVA for Repeated measure analysis of fine root data

Source	DF	Live root			Dead root			Total root		
		Mean Square	F Value	Pr > F	Mean Square	F Value	Pr > F	Mean Square	F Value	Pr > F
Block	2	129.26	41.97	<0.001	5.54	15.43	0.004	135.54	42.36	<0.001
Height	3	10.26	3.33	0.098	0.91	2.54	0.15	10.62	3.32	0.098
$Error_a$	6	3.08	-	-	0.36	-	-	3.20	-	-
Time	11	27.85	4.21	0.002	5.54	9.23	<0.001	27.74	4.2	0.002
$Error_b$	22	6.61	-	-	0.60	-	-	6.60	-	-
Height*Time	33	2.29	0.28	1.0	0.45	0.58	0.97	2.13	0.25	1.0
$Error_c$	330	8.24	-	-	0.79	-	-	8.41	-	-

Table A.4 ANOVA for linear polynomial contrasts for time effect on fine root biomass

Source	DF	Live root			Dead root			Total root		
		Mean Square	F Value	Pr > F	Mean Square	F Value	Pr > F	Mean Square	F Value	Pr > F
Mean	1	112.75	10.66	0.003	26.84	22.96	<0.001	136.73	12.52	0.0013
Block	2	25.26	2.39	0.109	0.58	0.50	0.61	24.69	2.26	0.12
Height	3	0.66	0.06	0.979	0.69	0.59	0.63	0.63	0.06	0.98
Error	30	10.58	-	-	1.169	-	-	10.92	-	-

Table B.1 ANOVA for cut-height and root barrier effects on wheat grain yield

Source	DF	Wheat grain 1994			Wheat grain 1995		
		Mean Square	F Value	Pr >F	Mean Square	F Value	Pr >F
Block (B)	2	69.69	1.22	0.36	19.05	0.78	0.5
Cut Height (H)	3	85.44	1.50	0.31	52.83	2.17	0.19
$Error_a$ (B*H)	6	56.94			24.38		
Root Barrier (R)	1	141.28	9.76	0.014	166.01	5.32	0.0499
H*R	3	26.73	1.85	0.22	34.7	1.11	0.40
$Error_b$ (B*H*R)	8	14.47			31.21		
Distance (D)	8	251.24	10.36	<0.001	416.02	50.06	<0.001
$Error_c$ (D*B)	16	24.24			8.31		
D*H	24	16.46	0.76	0.76	11.16	1.18	0.31
$Error_d$ (B*D*H)	48	21.45			9.42		
D*R	8	21.88	1.38	0.22	11.62	2.07	0.05
H*D*R	24	6.75	0.42	0.98	9.01	1.60	0.07
$Error_e$ (B*D*H*R)	64	15.89			5.62		

Table B.2 ANOVA for soil moisture at tree-crop interface (depth 7.5 cm)

Source	DF	Mean Square	F Value	Pr >F
Block (B)	5	10.437	3.74	
Cut Height (H)	1	2.266	0.81	0.41
$Error_a$ (B*H)	5	2.787		
Root Barrier (R)	1	17.005	5.766	0.037
H*R	1	0.207	0.07	0.797
$Error_b$ (B*H*R)	10	2.949		
Distance (D)	1	62.13	28.803	0.003
$Error_c$ (D*B)	5	2.157		
D*H	1	11.672	40.627	0.0014
$Error_d$ (B*D*H)	5	0.287		
D*R	1	12.907	5.087	0.048
H*D*R	1	0.017	0.007	0.94
$Error_e$ (B*D*H*R)	10	2.537		

Table B.3 ANOVA for mulch effect on crop yields : year 1993

Dependent Variable: Maize grain

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	292.9333	58.5866673	3.69	0.0158
MRATE	4	1150.421	287.6052000	18.12	0.0001
Error	20	317.4631.	15.8731540		
Corrected Total	29	1760.817			CV 11.29

Dependent Variable: Maize straw

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	1245.389897	249.077979	2.54	0.0619
MRATE	4	16178.350733	4044.587683	41.22	0.0001
Error	20	1962.433787	98.121689		
Corrected Total	29	19386.174417		CV 12.95	

Dependent Variable: Wheat grain

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	118.56041667	23.71208333	1.64	0.1942
MRATE	4	543.51250000	135.8781250	9.42	0.0002
Error	20	288.38750000	14.41937500		
Corrected Total	29	950.46041667		CV 12.19	

Dependent Variable: Wheat straw

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	582.8854167	116.5770833	1.68	0.1859
MRATE	4	1470.5958333	367.6489583	5.29	0.0045
Error	20	1389.6041667	69.4802083		
Corrected Total	29	3443.0854167		CV 19.03	

Dependent Variable: Maize weed

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	149.46666667	29.89333333	4.42	0.0071
MRATE	4	804.80000000	201.20000000	29.76	0.0001
Error	20	135.20000000	6.76000000		
Corrected Total	29	1089.46666667		CV 30.47	

Table B.4 ANOVA for mulch effect on crop yields : year 1994

Dependent Variable: Maize grain

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	148.6250400	29.7250080	1.18	0.3535
MRATE	4	1373.9510533	343.4877633	13.64	0.0001
Error	20	503.6204267	25.1810213		
Corrected Total	29	2026.1965200	CV 18.44		

Dependent Variable: Maize straw

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	662.645817	132.529163	1.12	0.3806
MRATE	4	12953.141367	3238.285342	27.41	0.0001
Error	20	2362.496233	118.124812		
Corrected Total	29	15978.283417	CV 18.80		

Dependent Variable: Wheat grain

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	15.55170667	3.11034133	0.63	0.6825
MRATE	4	341.76598000	85.44149500	17.17	0.0001
Error	20	99.51766000	4.97588300		
Corrected Total	29	456.83534667	CV 7.07		

Dependent Variable: Wheat straw

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	44.65517667	8.93103533	0.73	0.6083
MRATE	4	632.38864667	158.09716167	12.95	0.0001
Error	20	244.20167333	12.21008367		
Corrected Total	29	921.24549667	CV 7.40		

Dependent Variable: Maize weed

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	77.0666667	15.4133333	2.57	0.0595
MRATE	4	1198.4666667	299.6166667	49.96	0.0001
Error	20	119.9333333	5.9966667		
Corrected Total	29	1395.4666667	CV 17.66		

Dependent Variable: Wheat weed

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	14.45466667	2.89093333	4.74	0.0051
MRATE	4	55.69866667	13.92466667	22.82	0.0001
Error	20	12.20533333	0.61026667		
Corrected Total	29	82.35866667	CV 27.83		

Table B.5 ANOVA for mulch effect on crop yields : year 1995

Dependent Variable: Wheat grain

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	60.69600000	12.13920000	1.50	0.2357
MRATE	4	802.19000000	200.54750000	24.70	0.0001
Error	20	162.35400000	8.11770000		
Corrected Total	29	1025.24000000		CV 8.74	

Dependent Variable: Wheat straw

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	104.16666667	20.83333333	0.69	0.6340
MRATE	4	518.46666667	129.61666667	4.32	0.011
Error	20	600.33333333	30.01666667		
Corrected Total	29	1222.96666667		CV 14.43	

Dependent Variable: Wheat weed

Source	DF	Anova SS	Mean Square	F Value	Pr > F
BLOCK	5	17.19466667	3.43893333	1.46	0.2473
MRATE	4	99.02666667	24.75666667	10.50	0.0001
Error	20	47.16533333	2.35826667		
Corrected Total	29	163.38666667	CV 27.75		

Table B.6a ANOVA for mulch effect on wheat yields : pooled over years

Source	DF	Wheat grain			Wheat straw		
		Mean Square	F Value	Pr>F	Mean Square	F Value	Pr>F
Block	5	14.03	1.46	0.216	21.31	0.52	0.76
Mulch	4	405.23	42.03	<0.001	556.24	13.62	<0.001
Year	2	16.89	1.75	0.18	653.95	16.01	<0.001
Mulch*Year	8	8.32	0.86	0.55	49.56	1.21	0.304
Error	70	9.64	--	--	40.85	--	--

Table B.6b ANOVA for mulch effect on maize yields : pooled over years

Source	DF	Maize grain			Maize straw		
		Mean Square	F Value	Pr>F	Mean Square	F Value	Pr>F
Block	5	22.30	0.872	0.51	99.55	0.781	0.57
Mulch	4	616.54	24.10	<0.001	7199.33	56.49	<0.001
Year	1	979.86	38.30	<0.001	5250.96	41.20	<0.001
Mulch*Year	4	14.56	0.57	0.69	83.54	0.66	0.63
Error	45	25.58	--	--	127.45	--	--

Table B.7 Fuel, fodder and grain production under different tree:crop ratios in 3rd year of a alley farming system

Tree:Crop ratio	Mulch available[a] (kg ha^{-1} cropped area)	Maize grain yield (kg ha^{-1})	Maize straw yield (kg ha^{-1})	Wheat grain yield (kg ha^{-1})	Wheat straw yield (kg ha^{-1})	Wheat yield adjusted for reduction at TCI[d]		Total grain yield (kg ha^{-1})	Total fodder yield (kg ha^{-1})	Laucaena twigs (kg ha^{-1})	Total biomass (kg ha^{-1})
						grain (kg ha^{-1})	straw (kg ha^{-1})				
0:10	0	2230[b]x1[c] =1960	3660[b]x1[c] =3660	2480x1 =2480	3600x1 =3600	2480x1 =2480	3600x1 =3600	4710	7260	0	12000
1:9	670	2180x0.9 =1960	4340x0.9 =3910	2700x0.9 =2430	3760x0.9 =3380	2430x0.922 =2240	3380x0.9 =3040	4200	8110	1600	15100
2:8	1500	2470x0.8 =1980	5190x0.8 =4150	2940x0.8 =2650	4000x0.8 =3200	2650x0.825 =2190	3200x0.77 =2460	4170	8320	3200	18100
3:7	2570	2970x0.7 =2080	6280x0.7 =4400	3200x0.7 =2240	4200x0.7 =2940	2240x0.80 =1790	2940x0.73 =2150	3870	6550	4800	18800
4:6	4000	3430x0.6 =2060	7740x0.6 =4640	3460x0.6 =2080	4530x0.6 =2720	2080x0.767 =1600	2720x0.69 =1880	3660	6520	6400	21400
5:5	6000	4030x0.5 =2020	9770x0.5 =4890	3650x0.5 =1830	5000x0.5 =2500	1830x0.72 =1320	2500x0.62 =1550	3340	6440	8000	23780
6:4	9000	4930x0.04 =1970	12830x0.4 =5130	3560x0.4 =1420	5700x0.4 =2280	1420x0.65 =920	2280x0.53 =1210	2890	6340	9600	26030
10:0	12000	-	-	-	-	-	-	-	-	16000	28000

[a]Leucaena biomass production assumed to be leaf: 6 Mg ha^{-1}, twigs 8 Mg ha^{-1} at each pruning (Chapter 1); [b]Maize and wheat grain and straw yields in response to mulch levels estimated using equations 2.1, 2.2, 2.3 and 2.4; [c]yield correction for area reduced under crops; [d]see table B.8.

Table B.8 Reduction in wheat yield (%) due to tree-crop competition at TCI under different tree:crop ratios

Tree:Crop ratio	Tree:crop arrangement	% cropped area under tree-crop interface	% reduction in yield[1]	
			Grain	Straw
0:1	Crops only	0	0	0
1:9	Paired rows[2] of leucaena hedges every 18 m, total 5 strips of hedges per ha	22.2	7.8 (0.922)[3]	10.0 (0.9)
2:8	Paired rows every 8 m, total 10 strips	50	17.5 (0.825)	23.5 (0.77)
3:7	3 rows every 7 m, total 10 strips	57	20 (0.8)	26.8 (0.73)
4:6	4 rows every 6 m, total 10 strips	66	23.3 (0.767)	31.3 (0.69)
5:5	5 rows every 5m, total 10 strips	80	28.0 (0.72)	37.6 (0.62)
6:4	6 rows every 4 m, total 10 strips	100	35.0 (0.65)	47.0 (0.53)

[1]estimates based on assumption of 35% and 47% reduction in grain and straw yields respectively,
[2]intra-row spacing 0.5 m and inter-row spacing 1.0m,
[3]in parentheses reduced yield in fraction

Table C.1 ANOVA for mulch effect on soil organic carbon (Oc) at different dates

October 1992

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00224617	0.00044923	1.91	0.1384
MRATE	4	0.00025713	0.00006428	0.27	0.8921
Error	20	0.00471567	0.0002357	C.V 3.005135	

May 1993

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00133724	0.00026745	0.75	0.5962
MRATE	4	0.02018033	0.00504508	14.13	0.0001
Error	20	0.00713897	0.00035695	C.V. 3.505751	

October 1993

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00547834	0.00109567	1.83	0.1532
MRATE	4	0.03739530	0.00934882	15.59	0.0001
Error	20	0.01199420	0.00059971	C.V. 4.366923	

May 1994

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00153387	0.00030677	0.69	0.6356
MRATE	4	0.05700845	0.01425211	32.13	0.0001
Error	20	0.00887105	0.00044355	C.V. 3.71	

October 1994

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00393247	0.00078649	1.28	0.3096
MRATE	4	0.09516497	0.02379124	38.85	0.0001
Error	20	0.01224823	0.00061241	C.V. 4.19	

May 1995

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	0.00236727	0.00047345	0.23	0.9447
MRATE	4	0.08429705	0.02107426	10.26	0.0001
Error	20	0.04108865	0.00205443	C.V. =7.83	

Table C.2 ANOVA for mulch effect on soil microbial biomass carbon (Bc) at different dates

October 1992

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	3114.1666667	622.8333333	1.62	0.2015
MRATE	4	355.5333333	88.8833333	0.23	0.9179
Error	20	7707.6666667	385.3833333	CV 21.01	

May 1993

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	4419.100000	883.820000	1.18	0.3520
MRATE	4	13045.800000	3261.450000	4.37	0.0106
Error	20	14931.400000	746.570000	CV 25.00.	

October 1993

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	6235.866667	1247.173333	0.98	0.4521
MRATE	4	21442.133333	5360.533333	4.23	0.0122
Error	20	25363.466667	1268.173333	CV 27.16	

May 1994

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	2657.766667	531.553333	0.36	0.8714
MRATE	4	78567.800000	19641.950000	13.21	0.0001
Error	20	29747.400000	1487.370000	CV 29.22	

October 1994

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	2834.800000	566.960000	0.35	0.8767
MRATE	4	92318.866667	23079.716667	14.22	0.0001
Error	20	32467.533333	1623.376667	CV 24.33	

May 1995

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	5	6384.666667	1276.933333	0.79	0.5697
MRATE	4	74580.000000	18645.000000	11.52	0.0001
Error	20	32358.000000	1617.900000	CV 29.43	