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Title: Crop and Tree Response to Planting Patterns in Alley Cropping Systems

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Growing trees as a green manure crop together with an annual food crop is a new technology for farmers in Oregon. To promote farmer participation and to acquire a broad knowledge of the processes involved in species interactions, three feasible alley cropping and two sweet corn monocrop planting patterns were studied in a replicated factorial experiment. Each alley cropping pattern was planted twice, with either red alder (*Alnus rubra* Bong) or black locust (*Robinia pseudoacacia* L.). The annual crop component used was sweet corn (*Zea mays* L.). Sweet corn population was the same in all plant arrangements, except one alley cropping pattern.

The monocrop control, planted at 63.5 cm row spacing, yielded highest while the lowest corn yield was produced in the alley cropping system that involved alternate corn and black locust rows. The highest corn yield produced among alley cropping patterns surpassed the control planted at 89 cm row spacing. Corn yield in planting patterns was dependent on the relative space occupied by each species. A high ratio of tree occupation was negatively correlated with corn yield.

Greatest pruning biomass was produced in alley cropping systems with highest tree population and greatest percentage of tree space occupation. Compared to black locust, biomass produced by red alder trees was minimal. Within alley

cropping patterns of the same tree species, lower crop yield coincided with highest pruning biomass implicating trade-offs between potential soil improving effects and crop yield. Tree biomass was more strongly affected by changes in relative space occupation than corn yield.

Yield of individual corn rows within treatments varied considerably. In alley cropping systems where several corn rows were separated by double rows of trees, corn rows adjacent to trees yielded significantly more than those neighboring corn rows on either side. Corn row position had no significant effect in monocrop or patterns where tree and corn alternated. Mean yield of individual corn plants decreased when both neighboring corn rows and neighboring tree row were in close proximity.

The approach of using a few planting patterns as experimental treatments did not permit to precisely model the relationships between single proximity factors and yield components. However, the approach permitted identification of factors contributing the most to changes in tree and crop yield and demonstrated basic trends.

Crop and Tree Response to Planting Patterns in Alley Cropping Systems

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CROP AND TREE RESPONSE TO PLANTING PATTERNS IN ALLEY CROPPING SYSTEMS

CHAPTER 1

INTRODUCTION

'Alley cropping' involves planting of annual crops between rows of trees or shrubs, which are periodically cut to prevent shading and to provide green manure and mulch to the annual crop. This system was developed by scientists at the International Institute of Tropical Agriculture (IITA) in Nigeria, in search of alternatives to shifting cultivation. Human population pressures were resulting in ever shorter fallow periods in shifting cultivation while soil fertility levels were declining rapidly (FAO/SIDA, 1974). A technology was needed that could provide high levels of food production while maintaining soil health. Alley cropping was developed by integrating the biological and soil-enriching processes of forest ecosystems into an agricultural system.

Farmers from parts of the world have recognized the vital role of trees for soil productivity and conservation. For example, in Indonesia and the Philippines, there is a long tradition of planting hedgerows along the contours of sloping crop fields to control soil erosion (Nair, 1984). The tree rows provide a physical barrier to runoff while vegetative cover limits the impact of raindrops. Litter on the soil surface provides mulch that reduces erosion and runoff. Organic material from litter and roots can improve soil physical properties such as water infiltration, bulk density, and particle distribution (Hulugalle and Kang, 1989; Lal, 1991). Generally, the magnitude of erosion and runoff increases from forest cover to agricultural crop cover to bare soil (Charreau, 1972). Several studies in alley cropping systems have shown a drastic reduction of erosion (IITA, 1986; Lal, 1989).

Soil fertility in natural and agricultural ecosystems is improved by inclusion of trees that fix atmospheric nitrogen. Farmers in Central America traditionally use N-fixing alder trees in their agricultural practice. They recognized that the presence of alder in the field improves their corn yield (Dawson, 1986). Stands of *Leuceana leucocephala*, a widely used alley cropping species, fix an estimated 575 kg N / ha (Hutton and Bonner, 1960). Such amounts however, might not be realized in alley cropping systems, because of lower stand densities, but 60 to 200 kg / ha N yield are commonly reported in alley cropping stems in tropical climates (Kang et al., 1990).

In an 'ideal' forest ecosystem, there is nearly a closed nutrient cycle; relatively few losses occur (Nair, 1984). Most nutrients reaching deep soil layers through chemical and biological processes such as soil animal interactions, and infiltration are absorbed by tree roots. The nutrients are translocated into vegetative parts and returned to the soil surface through litter fall. This understanding is applied in alley cropping systems although it may not be possible to achieve a closed nutrient cycle in crop systems. However, some nutrients that would be lost in annual cropping systems might be captured by the deeper rooted perennials, and the addition of leaf litter, if incorporated into the soil, might increase soil organic matter levels and thus aid nutrient retention.

Multiple layers of vegetation make optimal use of incoming light in forest ecosystems. In alley cropping, optimal light use is achieved by pruning trees during crop growth, but allowing tree growth in the remaining time.

In any alley cropping system, trees utilize space both above- and below-ground that is not available for crop production. However, by designing a system in which resources are effectively captured and recycled, crop yield losses in alley cropping systems compared to monocrop systems might be far less than the proportional reduction of cropping space. Intercrops that utilize resources more efficiently when grown together than when grown separately make use of what Vandemeer (1981) calls the competitive production principle.

A second principle which might reduce crop yield losses is the facilitation production principle (Vandemeer, 1984). This principle applies when the environment of one species is modified by a second species in a beneficial manner. In alley cropping, for example, nitrogen fixing trees can provide nutrient rich green manure to the annual crop. Direct nutrient transfer between roots of N-fixing trees and the food crop in an alley cropping system has not been established, although it has been demonstrated in other agricultural plant associations (van Kessel et al., 1985).

A growing body of scientific knowledge about the role and benefits of nitrogen fixing trees in natural ecosystems exists for the temperate zone. This knowledge suggests the possibility of including nitrogen fixing trees in agricultural systems. Alley cropping, which was generally perceived as being appropriate only on marginal land with low soil fertility and limited mineral fertilizer accessibility (Torres, 1983), is now studied under various climatic and environmental conditions.

Concern about long-term land productivity unites farmers around the world. Farmers in Oregon are worried about impacts of their farming methods on their children's resource base. In meetings with farmers, I heard farmers repeatedly express their concern about declining soil and water quality. They are aware of the potential hazards that are posed by continuous monocropping and the use of high rates of pesticides and fertilizer. They now are exploring a wide range of alternative cropping strategies. Maintaining and improving soil quality is of great importance to farmers. At a meeting between farmers, extensionists, and researchers, one farmer commented that soil organic matter content in his fields is constantly declining even though he grows green manure crops annually. At the same meeting, farmers expressed the need for cooperation between farmers and researchers to develop long-term land management strategies that promote resource conservation.

The motivation to explore alley cropping in Oregon stems from these concerns and from the benefits alley cropping has demonstrated in other parts of the world. Integration of trees as green manure crops with agricultural crops could be an alternative that would reduce external inputs while conserving natural resources.

Alley cropping systems cannot simply be transferred from one location to another. To facilitate farmers' design of alley cropping systems, interdisciplinary approaches are required. Unfortunately, scientists working in institutions that support agriculture in the developed countries are accustomed to an intra-disciplinary approach where expertise is focused on one particular aspect of a cropping system. Alley cropping as an agroforestry technology, is an interdisciplinary approach to land-use (Gold and Hanover, 1987). It draws from knowledge of both applied and basic research disciplines such as forestry, agronomy, horticulture, soil science, ecology, microbiology, economics, sociology, engineering, and others.

The introduction of alley cropping into modern agriculture of temperate climates generates many research questions. Tree species have to be identified that demonstrate desired characteristics such as rapid growth and resprouting ability after repeated prunings. There is a need to explore the amount of tree biomass needed to have long-term effects on soil productivity. Also, machinery has to be adapted to new systems.

While I was exploring the possibility of alley cropping with farmers, they were mostly concerned with yield losses due to reduced cropping space and tree-crop competition. Spatial arrangements of two species has an important influence on the outcome of tree-crop interaction. For example, in alley cropping, the effectiveness of biological processes, such as nutrient cycling, depend on spatial arrangement of the two species (Nair, 1984). For these reasons, the present study will be concerned with identification of suitable tree species and the response of trees and crops to various planting patterns.

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

In the design of alley cropping systems, decisions about spatial arrangement, management, and combination of crop and tree component have to be integrated. Tree-crop interactions are important to consider in each of these decisions. The design process for these cropping systems might be facilitated by synthesizing the existing knowledge of tree-crop interactions while developing some conceptual models that communicate the basic relationships.

In an alley cropping system, complex interactions occur between trees, crops, and the environment (Figure 2.1). Trees may improve the environment of the annual crop by contributing nutrients, or improving soil physical and chemical properties (Nair, 1984). In contrast, the trees may be detrimental for the annual crop due to light interception or soil moisture depletion (Lawson and Kang, 1990).

Knowledge of the plant-environment interactions is critical to adapt cropping systems such as alley cropping to a different environment. This knowledge is the basis for diagnosis and decisions on factors such as selection of species, spacing, timing, and management (Loomis and Whitman, 1983). New methods of analysis have emerged that deal with complex systems. Holistic approaches such as 'systems analysis' can enable prediction of the net results from different interacting processes. 'Systems analysis' describes cause-effect pathways in a complex system (Watt, 1966). Large state variable models or simple conceptual models might be employed to describe these pathways. Simple models might include qualitative hypotheses and/or easy mathematical statements, which deal with one or two processes at a time (Nair, 1984). These models can improve our limited ability to integrate the processes involved (Wilson and Morren, 1990).

In the first part of this paper, I will review studies conducted in the traditional alley cropping areas as they relate to aspects of tree-crop interaction. An attempt is made to synthesize the information in simple conceptual models. I will follow the course of designing and managing an alley cropping system and focus on the tree component: selection of tree species, tree density, and spatial arrangement of tree and crop component, and considerations of tree management. Finally, changes in tree-crop interactions over time will be discussed.

The second part of this paper will concentrate on models and experimental designs that seek to predict plant interaction. First, I will review the models proposed by plant ecologists and then examine how these models were applied by alley cropping researchers. Finally, discussion will be concerned with implications of this review on the study and design of alley cropping in modern agriculture of the temperate zone.

FACTORS OF TREE-CROP INTERACTION

Tree species

Selection of tree species is an important consideration in the success or failure of alley cropping systems (Figure 2.2). Choices are limited to tree species that will grow under the particular soil and climatic conditions (Hughes and Styles, 1987). In tropical food crop systems, the most widely used woody green manure species are *Gliricidia, Leuceana, and Sesbania* (Brewbacker and Glover, 1988). Common alley cropping species in other agroecological zones are *Acioa, Alchornea, Cassia, Calliandra, Erythrina, and Flemingia* (Kang et al. 1990). These tree species depict the desired characteristics for alley cropping systems outlined by Kang (1985): rapid growth, good coppicing and resprouting abilities, and nitrogen fixing capability.

Rapid growth is important because significant amounts of tree biomass are needed to accomplish major alley cropping objectives such as adequate nutrient supply to the annual crop, erosion control, and/or weed suppression. Early successional tree species are most suitable for maximizing biomass production under the high light regime conditions encountered in alley cropping. Their architectural organization involving multilayered organization of leaves, low branches on the trunk, rapid extension of the leader axis and deep crowns allow them to use light efficiently (Ramakrishnan, 1987).

Variation among tree species in their growth habit and their resource needs are reflected in their influence on the annual crop. Lawson and Kang (1990) studied four species of shrubs and their effect on maize and cowpea (*Vigna sinensis* T.) yields at the International Institute of Tropical Agriculture (IITA) in Nigeria. Shrubs were pruned at the same time and to the same height, but percent incident solar radiation reaching the annual crops varied among species. *Leuceana leucocephala*, which produced the highest amount of above-ground biomass of all the shrubs, decreased maize and cowpea yield the most.

Not only above-ground growth, but also below-ground growth affects tree-crop interactions. Unfortunately, we know very little about patterns of below-ground resource depletion by different species (Goldberg, 1990). However, comparative studies might provide a better understanding of the factors involved. Research in Nigeria showed that if soil moisture is the limiting factor, the extensive root system of *Leuceana* competed more aggressively with maize than *Gliricidia*, resulting in a 17 percent versus 8 percent yield reduction compared to monocropping systems (Lal, 1991). Extreme conditions, such as severe drought stress usually accentuate the differences between tree species.

Prunings of different tree species vary in chemical composition as well as physical structure (Buck, 1986). This will influence the rate of decomposition, impact on soil chemical status (Yamoah et al., 1986), soil physical properties (Hullungale and Kang, 1989), and potential for weed control (Kuo et al. 1982). A slow rate of decomposition is preferred for erosion control and weed control (IITA, 1986). Slow decomposing leaves such as those from *Acioa barterii* or *Cassia siamea* will provide weed shading and a physical barrier for a longer time period compared to those of *Leuceana* species (IITA, 1982). Rapid breakdown and nitrogen mineralization rate is desired in situations where fertilizer substitution is the major goal. *Leuceana* species are among the most suitable in the tropical lowlands for this particular purpose (Guevara, 1976).

Another aspect to consider when selecting a tree species is that some are more likely to grow and reproduce in an uncontrolled fashion than others. This might occur when seed production progresses rapidly or if shoots from root suckers grow outside the hedgerow. However, these problems can be countered effectively by pruning before seed formation and appropriate tillage methods (Vegara, 1982).

Decisions on which tree species to choose depend also on the desired annual crop because both tree and crop have unique tolerances to various forms of resource competition. While one tree species might be grown successfully with a certain crop, growth characteristics of another one might severely limit its use in mixture with this crop. An example is given by Buddelman (1987), who reports that only the *Gliricidia*-Yam association produced acceptable yields compared to other tree-Yam associations. Some crops are more susceptible to competition for a certain resource than others. For example corn, a plant with a C_4 photosynthetic pathway, will compete for light more strongly than a C_3 plant (Trenbath, 1976). This theory was supported by Yamoah (1991) who tested several intercrops grown between rows of *Sesbania sesban*. He found that pole bean was the most appropriate intercrop while corn was least preferred. Generally, a tree-crop system is successful when plant associations can be selected in which each component's access to resources such as water, nutrients, and light is partitoned in space and time (e.g. different rooting depth) (Buck, 1986; Vandermeer, 1989).

Tree density and spatial arrangement

After an appropriate tree species is selected, the question arises as to how many trees should be planted per unit area. Tree density might depend on the objective and the environmental conditions of the particular system. If the objective is to rapidly produce large amount of tree biomass, then obviously tree density has to be relatively high. Willey and Heath (1967) described the relationship between density and above-ground biomass as a rectangular hyperbola where yield per unit area increases until a critical density is reached and is independent thereafter, when competition is severe. In the traditional alley cropping systems, increasing tree biomass production can be expected with increasing tree density since the critical density will not be reached. This relationship has been confirmed in both monotree crop and alley cropping experiments. Ferraris (1979) reported increasing biomass yield per area with increasing tree density in tree-only plots in Queensland, Australia, where tree population was controlled by changing inter-row spacing from 0.3 m to 0.9 m. Kang et al. (1990) reported similar results in *Leuceana* studies in Nigeria. High density planting of trees (0.5 m inter-row spacing) produced 41 tons of dry matter per hectare, while a lower density planting (1.0 - 2.0 m inter-row spacing) produced only 30 tons per hectare.

Unfortunately, tree density is commonly not reported in alley cropping experiments. The actual number of trees per unit area in a tree-crop mixture should depend on the species under consideration (Huxley, 1983). Rachie (1983) in Colombia estimated that prunings from 10,000 to 20,000 *L. leucocephala* per hectare were sufficient to cover the soil and provide significant amounts of nutrients to intercropped maize.

In a strictly competitive situation, any increase in tree density would depress crop yield (Vandemeer, 1989). However, in many intercropping situations, a facilitative effect of one species is encountered until a certain density is reached. For example, in an experiment that tested the effect of different tree densities, corn yield was generally 10% higher at low *Leuceana* densities of 13,000 trees per hectare than in no-tree treatments or at tree densities of 20,000 trees per hectare. An increase of tree density to 40,000 per hectare suppressed corn yield further (Raiche, 1983).

Tree and crop density are not independent of spatial arrangement (Figure 2.3). Generally, tree density is higher in systems with narrow alleys (ITTA, 1983). Alley width might be the most studied spatial arrangement factor in alley cropping research. In a review on various aspects of alley cropping, Sseskabembe (1985) presents a list of studies that involve different alley widths. Higher yield of the agricultural crop in wider alleys can be observed in all seven studies. In contrast, tree biomass per unit area commonly is increased in narrow alleys (Escalada, 1980).

However, alley cropping systems with wider alleys do not always increase food crop yield. Especially when fertilizer input is low, narrow alleys might be advantageous. For example, Jama et al. (1991) studied effects of *L. leucocephala* on corn yield in Kenya involving several alley widths. They found that narrow spacings of 2 and 4 meters yielded higher than 8 meter spacing or controls. Yamoah and Burleigh (1990) found that the level of fertilizer input was important in crop yield response to the spatial arrangement. At a nitrogen fertilization rate of 30 kg per hectare, bean yield was more than 35 % higher in 6 meter alleys than 8 meter alleys and 98 % higher than in the 2 meter alleys.

Spatial arrangement of the tree component influences quantity and quality of the pruning biomass. Trees in close spacing can be expected to produce maximum biomass yield with small sized stems (Cameroon et al., 1989). This was confirmed by Guevara (1976), who reported that *L. leucocephala* produced thinner stems at a narrower within-row spacing. Thus, within-row tree spacing determines the ratio of herbaceous and woody material. A wide within-row spacing resulting in a high percentage of woody material would be chosen if the mulch material has to persist for an extended period of time to control erosion or to increase soil organic matter. For nutrient contribution purposes, a closer within-row spacing, producing a high percentage of herbaceous material might be more appropriate.

In the traditional alley cropping systems, several crop rows are planted in the interspaces between the tree rows. Several studies report that position of the crop relative to the trees had a significant effect on crop yield. This was observed in a study in Peru involving corn and *Erythrina sp.* (Salzar and Palm, 1987). Corn yield increased steadily with increasing distance from the trees. In the row next to the trees, corn yield was reduced by 40 percent compared to the corn rows furthest away. In Hawaii, Rosecrance et al. (1992) studied maize yields affected by different species and crop row position. They planted the closest corn rows 40 cm from the hedge. This reduced corn row yield 34 % relative to rows planted 110 cm away. When closest row distance was increased to 60 cm and combined with an earlier pruning, yields were reduced only 10 %.

Yield reduction close to the trees is observed under various climatic conditions. Increased shading from the fast growing trees is the major limiting factor in tropical climates while competition for soil moisture is responsible for the reduction in semi-arid regions (Singh et al., 1988). However, fertility levels can alter this response. Yamoah et al. (1986) reports decreasing yield close to trees when plots were fertilized but increasing yield of corn next to tree rows of *Gliricidia, Fleminga*, and *Cassia* in plots where no nitrogen was added and prunings were removed. They concluded that this was due to litter accumulation near the hedgerow. Beneficial effect from the tree roots might have played a role too. Fine root "turnover " can contribute significant amount of nutrients to the soil (Bowen, 1984).

As might be expected, distance between the crop and the hedgerow also influences tree biomass production. Rao et al. (1990) observed an increase of tree biomass with an increasing distance between the first crop row and trees. They calculated total system outputs of their treatments on the basis of crop yield and tree fodder yield. Although crop yields increased, total outputs declined with increasing distance between trees and first crop row.

Tree management

After the trees are established in the desired spatial arrangement, they require management to provide the desired benefits. Some tree management options and effects on crop production are listed in figure 2.4. Coppicing is a common tree management practice in alley cropping systems. Coppicing refers to cutting the whole tree close to ground level, usually at 30 to 50 centimeters. Shoots then resprout from the resulting stump. Decisions are required about the timing, frequency and height of coppicing. The optimum time to start cutting for green manure purposes depends on tree species and climate. Initial harvesting in tropical climates can start as early as 4 months after tree establishment (Sseskabembe, 1985). In dryer climates however, trees may take much longer to establish and withstand coppicing. A well developed root system ensures fast regrowth after cuttings and resistance to adverse conditions.

Optimum coppice height depends on tree species. Dugma et al. (1988) reported that biomass yield of *Gliricidia, Leuceana, and S. grandiflora* increased with increasing height up to 1 meter because more dormant buds along the stem developed into new shoots. However, Sseskabembe (1985) reports yield of *Leuceana glauca* was highest at the lowest cutting height of 7.5 cm. He postulates that this method is preferable for green manure production, since shading of the annual crop is reduced, especially in the crop seedling stage. A more severe cutting will provoke more roots to die back, further reducing competition between the trees and the agricultural crop (Pawlick, 1987). However, the limited number of dormant buds reduces the chance of regrowth. In addition, if the short stems are split they are an easy target for pest attack (Vonk, 1983).

Coppicing frequency determines the degree of competition with the annual crop. Frequently cut hedgerows will reduce shading and favor crop productivity (Kang, 1984). Frequent cutting also will affect the ratio of leaf to wood biomass, with frequent pruning favoring leaf biomass (Russo and Budowski, 1986). This might be desirable for green manuring purposes. However, too frequent pruning has a negative effect on long term tree yield, since vigor and shoot growth decline after repeated pruning (Chavangi, 1986).

The below-ground portion of the trees is managed through soil tillage within the alley. This can reduce competition for water and nutrients, since the bulk of the fine root biomass of both trees and crops is located in the same soil layer (Jonson et al., 1988). However, growth of tree roots into the alleys may be desirable, since part of the nitrogen fixed by the bacteria associated with the tree roots can be used by the intercrop (Sseskabembe and Henderlong, 1991). This may be important in situations where fertilizer substitution is desired and soil moisture is not limiting.

Changes over time

Now that the consequences of management options have been described, it might be important to know what changes can be expected after several years of alley cropping. Size of root systems and stumps increases as the trees age. Extensive root systems compete strongly with the agricultural crop if soil moisture is limiting. For example, in the semi-arid regions of India, it was observed that *L. leucocephala* became progressively more competitive over time with both sorghum (*Sorghum bicolor* L.) and pigeonpea (*Cajanus cajan* L.) intercrops due to moisture competition (Rao et al., 1990).

In contrast, competition from trees might decline over time because of reduced resprouting ability. As I mentioned earlier, resprouting ability is determined by tree species and management. Certain species, such as *Markhamia lutea* in Western Kenya have been coppiced for more then 100 years (Pawlick, 1987). However, most popular agroforestry species can be coppiced through three rotations, after which vigor declines.

PREDICTIVE MODELS AND EXPERIMENTAL DESIGNS TO STUDY PLANT INTERACTIONS

Nair (1984) pointed out that, through synthesis of existing knowledge, we might arrive at meaningful predictions of the performance of tree-crop mixtures. Another approach to achieve this goal is to conduct experiments that allow predictions by observing responses to systematically changing factors of tree-crop interaction. Key proximity factors that influence the interaction are total density, proportion of species, and spatial arrangement (Harper, 1977; Radosevich, 1987). The next section will evaluate these approaches and then review the methods used in alley cropping research.

Four basic types of experiments have been developed to study the involved proximity factors: substitutive, additive, systematic and neighborhood. In "replacement series", a type of substitutive design, total plant density is held constant, while the proportion (i.e. ratio of tree density to crop density) between two species is changed systematically (deWitt,1960). Thus, the two factors are not confounded. Relative competitiveness of either species can be analyzed readily by calculating yield ratios. This model has been applied extensively by weed scientists to study interactions between weeds and cultivated plants. However, there are two major criticisms. First, the method does not account for the fact that competition between the species is dependent on the chosen total plant density (Remanjek, 1989; Connolly, 1986). Second, the degree of competitive interaction depends on the intrinsic properties of the competing species. Also, the approach appeared to be artificial because of a very limited range of densities for the crop (Radosevich, 1987).

A model that addresses the concern of total plant density dependence in replacement series was suggested by Joliffe et al. (1984). They proposed experiments which included several monoculture densities in addition to the replacement series. Alternatively, several complete replacement series are conducted at a range of total densities. This approach allows differentiation between intra- and interspecific competition. Unfortunately, this model's main value is in greenhouse studies where many treatments can be tested simultaneously on a small scale. In the field, the number of treatments required exceed the number that can be executed (Remanjek, 1989).

All of the above mentioned criticisms limit the replacement series approach in its suitability to examine interspecific competition in alley cropping. Both annual crops and trees have limited ranges of possible plant densities. Species of very different life forms are grown together so that the use of plant counts (i.e density, proportion) as predictors of species interaction appears arbitrary. Proportions of biomass or leaf area indices may be more appropriate.

Additive designs are the second major type of experiment. In this approach, the density of one species is held constant while density of the other species is varied. Both total plant density and proportion of each plant species changes. The simultaneous change of the two factors make the interpretation of either factor difficult and differentiation between intra- and interspecific competition is therefore limited. Spitters (1983) proposed a model to analyze these competition effects in additive experiments. He used a single regression model to quantify intra- and interspecific competition. It is assumed that relative influences of the addition of a certain number of plants of species one is equivalent to the effect of the addition of a certain number of plants of species two for all densities. In comparative studies, Joliffe's model, however, suggested that this assumption cannot be generalized for all situations and that the influence of inter- and intra-specific competition varies with relative density (Roush et al., 1989).

Based on additive and substitutive experiments, more extensive models emerged to gain a higher precision in predicting the response to changing proximity factors. Additive series consist of several replacement series, which are combined in additive fashion. Complete additive models cover the full range of possible density combinations (Remjanek et al.1989).

Despite possible difficulties in the analysis, simple additive experiments seem to correspond better to the practice of alley cropping than replacement and addition series. The latter two models have the prerequisite that monocultures of both species have to be included in the treatments as well as a range of species ratios (Spitters, 1983a).

A major limitation of all models mentioned so far is that spatial arrangement is not considered. Systematic designs, such as the fan design (Nelder, 1962) and the parallel-row design (Bleasdale, 1967) consider both plant density and spatial arrangement (Figure 2.6). Although they are used predominantly to study interference between individuals of a single species (Radosevich, 1987), they are potentially suitable to study competition between species in mixed cropping experiments. The main advantage of the systematic designs is that a wide range of spacings can be tested on a relatively small area and management treatments can be overlaid at the same time. In a fan design, the number of plants harvested is limited to those in any one arc and single plant data is used for the statistical analysis. This means that effects and yields have to be extrapolated to the whole stand

(Radosevich, 1987). However, measured individual plants grow next to other individuals, which have variable space available to them. Thus, the environmental conditions are different for each plant and extrapolation from individual plants to the entire stand might be risky. Further problems in the analysis arise when the land is not truly uniform. Site variability may be underestimated in these designs (Mead and Stern, 1979).

Systematic designs are potentially suitable for alley crop spacing experiments. The parallel-row design is probably a more flexible design than the fan design for alley cropping systems (Huxely, 1985a). Trees could be planted at various row and within-row spacings while crop spacing is held at a standard rate. The parallel row design has been further modified by Huxely (1985a) to what he calls a double superimposed parallel row design, in which systematic changes of crop and tree spacing are possible.

Another approach to study plant interactions are neighborhood experiments. The yield of a target individual is predicted by factors such as number, biomass, cover, aggregation, or distance to its neighbor (Goldberg and Werner, 1983; Mack and Harper, 1977). As in systematic designs, yield responses apply to individual plants and have to be extrapolated to stand yields. The advantage of this approach is that spatial arrangement can be incorporated into the analysis. Since position of the crop within the alley may affect its yield (Rosecrane et al. 1988; Salazar and Palm, 1987), it seems important to account for this factor.

METHODS APPLIED IN ALLEY CROPPING EXPERIMENTATION

A major limitation of all models reviewed is that only a limited number of factors can be included in each model and that the factors can't be varied independently (Mead and Riley, 1981). How do researchers in the field of alley cropping deal with this dilemma? Unfortunately, there are few studies that were designed to predict the effect of proximity factors. In this section, I will review some of these studies. I will focus on the authors' evaluation of their experimental approach.

Huxely (1985b) proposed tree-crop interface trials to study alley cropping in the initial phase of technology development. He expected that performance of any kind of zonal system can be predicted from a knowledge of the potential productivity of its three components: a) sole annual crop b) tree component c) tree-crop interface (i.e. area where trees and crops grow next to each other). To save resources, initial trials should focus on the interface of crop and tree. If there is a positive biological effect, then the amount of interface can be maximized. In case of a negative biological effect, the amount of interface can be minimized. Such a trial was conducted by Rao et al. (1991) from 1984 to 1987 in India, involving *L. leucocephala*, sorghum, and sunflower (*Helianthus annuus* L.). They expected that information generated at the interface could be extrapolated for different plant arrangements using the same tree and crop. However, they concluded that great care is needed in extrapolating the results to other arrangements.

A systematic design has been used in the subhumid tropical region of Australia to study a silvopastoral system. *Eucalyptus grandis* trees were planted in a Nelder fan design into a pasture (Cameroon et al., 1989). The effect of a wide range of tree densities on various yield components could be analyzed readily. They were able to describe functional relationships between tree density and yield. They found that the compact design was useful to assess the effect of the different tree densities visually.

Jama et al. (1991) planted *L. leucocephala* in a parallel-row design involving three between-tree-row spacings and four within-row spacings. They found that interpretation of the data was difficult, because there were significant interactions between main treatments. Huxely (1985a) noted that statistical problems are frequently encountered in these designs.

A modified parallel row design was used by Rao et al. (1990). In this study sorghum and pigeonpea were grown in between L. *leucocephala* at various within- and between-tree row distances. The design allowed them to test a wide range of treatments on a much smaller area than would have been required in a conventional block design. They were able to draw predictive conclusions about the treatment effects. They also observed that systematic designs were not suited for sloping terrain and that systematic designs should be considered for preliminary exploration of a large number of treatments of newly proposed systems.

Non-systematic designs such as conventional block designs also are used to predict the relationships between yield and component characteristics. The disadvantage of these designs compared to the systematic designs is that they require a much larger area and that the range of possible factor levels is smaller. An example of a conventional block design is the study by Karim and Savill (1991). They tested the effect of three within-row and four between-row spacings of *Gliricidia sepium* on several tree parameters. Tree biomass production per unit area and per tree could be satisfactorily predicted with multiple regression involving the two spacing factors.

DISCUSSION

Although tree-crop interactions, positive or negative, are at the center of alley cropping, only a few studies are designed to predict the response to the factors involved. Conventional approaches used in such fields as weed science or plant population ecology seemed to be embraced only hesitantly by researchers in the field of alley cropping. One reason for this situation might be the feeling of researchers that not enough scientific information is available in agroforestry, which makes it difficult to choose the appropriate design and analyses for the experiment (Langton and Riley, 1989; Nair, 1984).

Another reason might be that conventional agricultural approaches are not suitable to study agroforestry systems. Several authors suggested that conventional approaches to agroforestry experimentation are difficult because of complexity (Rao et al. 1990, Huxley, 1985). Conventional approaches focus on individual system components or processes in isolation. These are integrated only as enough information become available. The premise is that by fully understanding each component we can achieve a total understanding of the whole system. All individual factors would have to be studied simultaneously and continuously over a long time. However, in each of the conventional models, one or more factors are assumed to be uniform or to have no effect; complex interactions are disregarded. Thus, any of these approaches are concerned with only part of the "real world situation" of a farmer who makes complex decisions of integrating planting pattern, combination of crop components, and density of these component species within the cropping system (Barker and Francis, 1986).

An unconventional approach was suggested by Huxley and Mead (1988). They proposed "Prototype System Trials" for areas in which certain agroforestry systems have not been tried before. While not directly aimed at tree crop interactions they are not restricted to any particular set of treatments. The trials are designed to explore possible "best bet" agroforestry factor combinations in an observational manner to acquire a broad understanding of whole systems functions , given that there is some knowledge of what the desired systems might look like. In contrast to the conventional approaches, this approach starts at a cropping systems level. Observations on this level might then lead to more detailed studies on individual system components.

The design of alley cropping systems in the temperate zone could be approached in a similar fashion. A vast body of research is available to guide the design of relevant "prototype systems". With a focus on monocropping systems, agricultural research has generated knowledge on optimum spatial arrangements of single plant species. Ecological research has established principles governing the interactions of species communities. General concepts of multi-dimensional resource sharing and utilization among and between components of a cropping system are well established (Buck, 1986). This knowledge could be used to design a systems model to evaluate optimal planting patterns of tree and crop. Trials using alternative planting pattern (i.e. whole systems) would then validate the suggested solution.

A whole cropping system consists of several integrated factors. Comparisons between whole systems appear more relevant to a farmer's situation (Huxely and Mead, 1988). Farmers might be invited to participate in refining the systems and identifying relevant research topics. Farmer's role in technology development becomes more critical and increasingly cost effective as the proposed technology becomes more complex (Sumberg and Okali, 1988). Whole systems comparison is a practical approach open for constant improvement and adaptation, and might generate a considerable amount of broad information in a short time. In depth information can be acquired in a later phase of the research process.

The treatment selection of the study described in the next chapter was guided by the belief that the selected whole systems (i.e. treatments) have to be feasible; They must integrate farmers concerns about crop yield reduction and adequate mechanization. I was expecting that by selecting an appropriate set of feasible treatments, extrapolation would be possible to answer the why and how of scientific inquiry. Treatment characteristics such as densities, and area occupied by each component were controlled to recognize basic yield relationships.

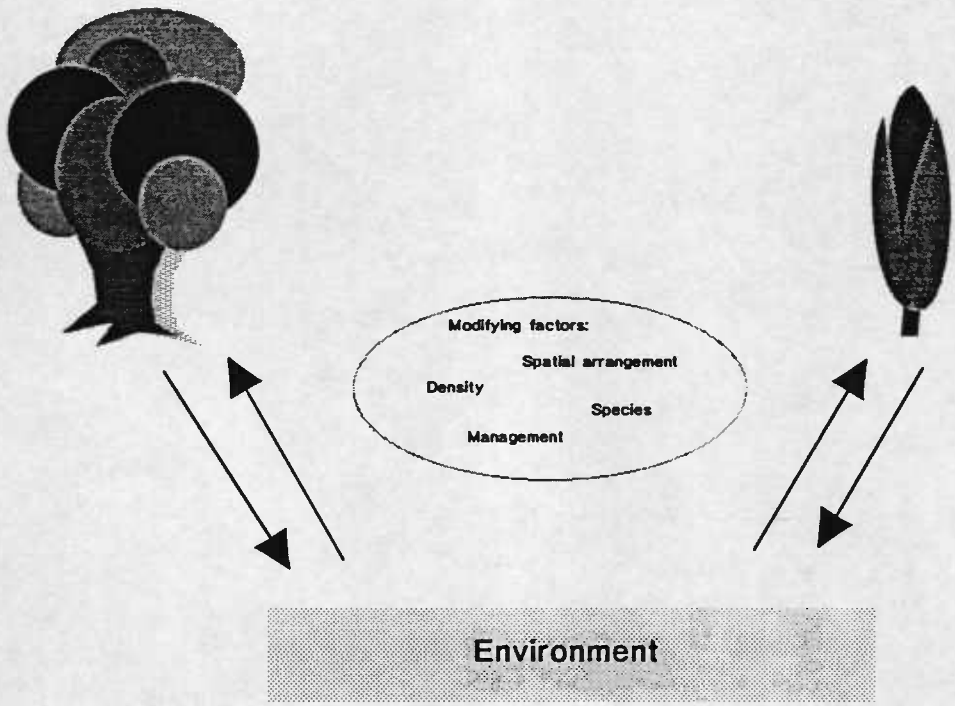


Figure 2.1. Interactions of trees, crops, and environment in alley cropping

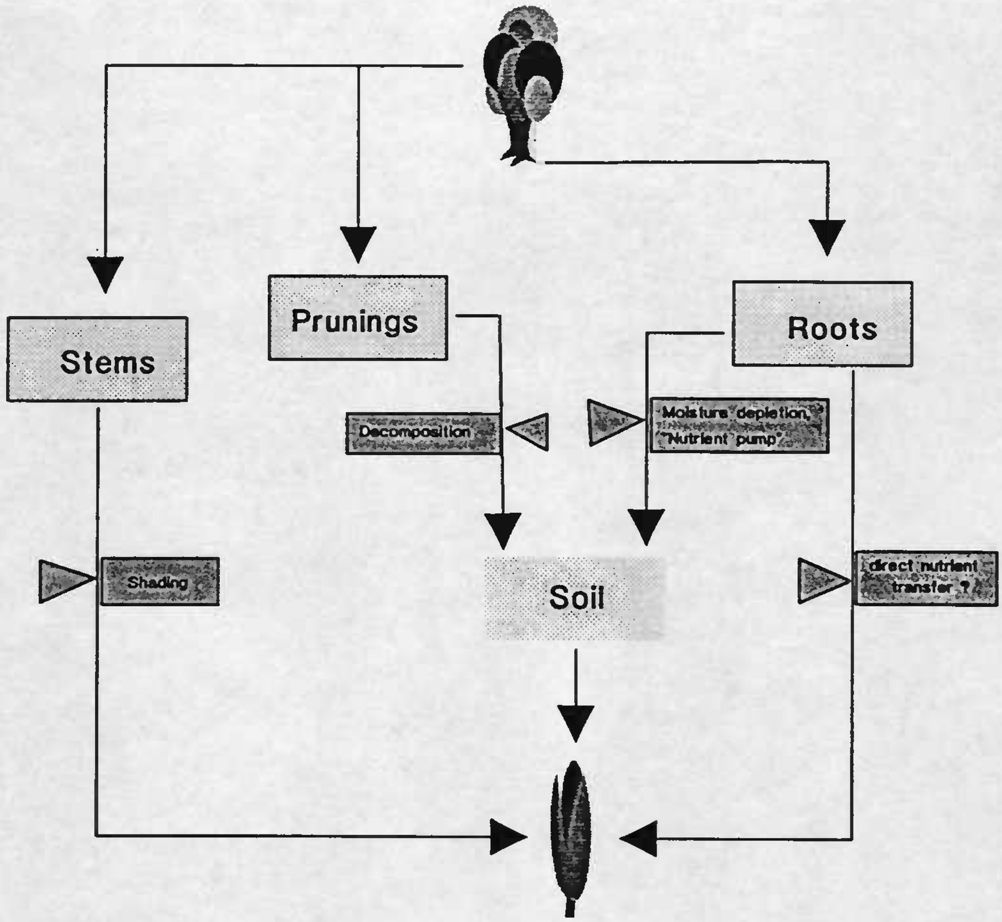


Figure 2.2. Effect of tree species characteristics on crop production. For simplification, only some examples of regulatory processes are shown.

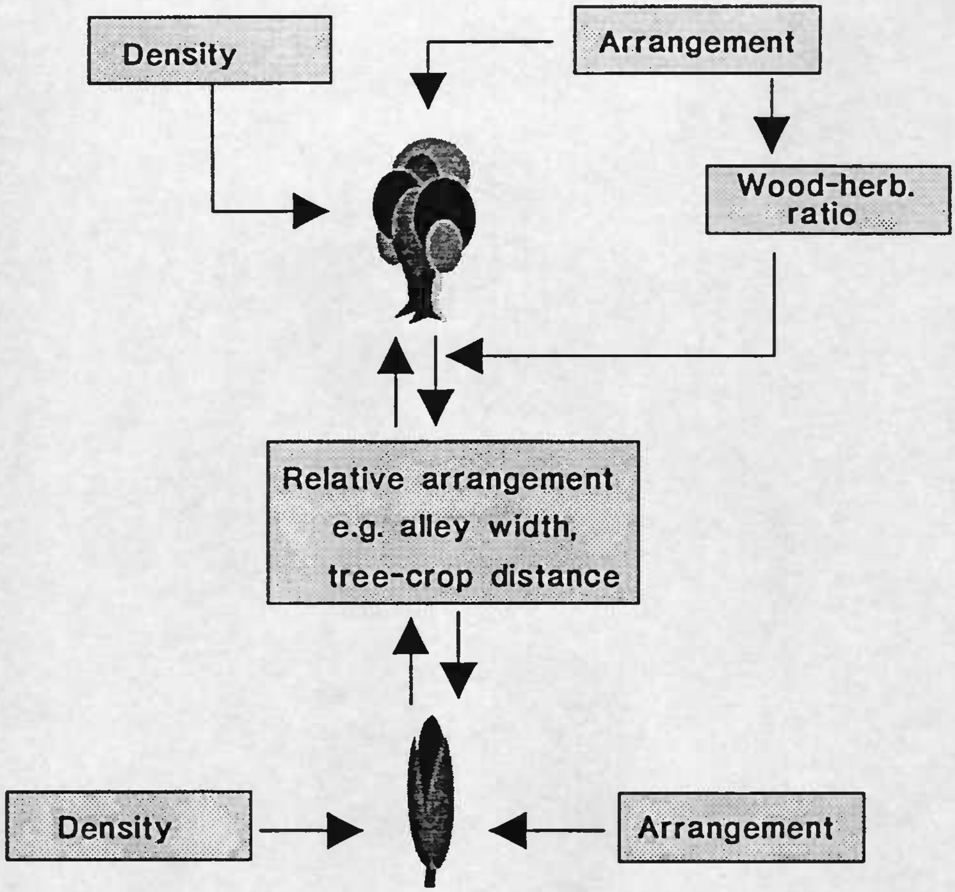


Figure 2.3. Effect of proximity factors on crop production

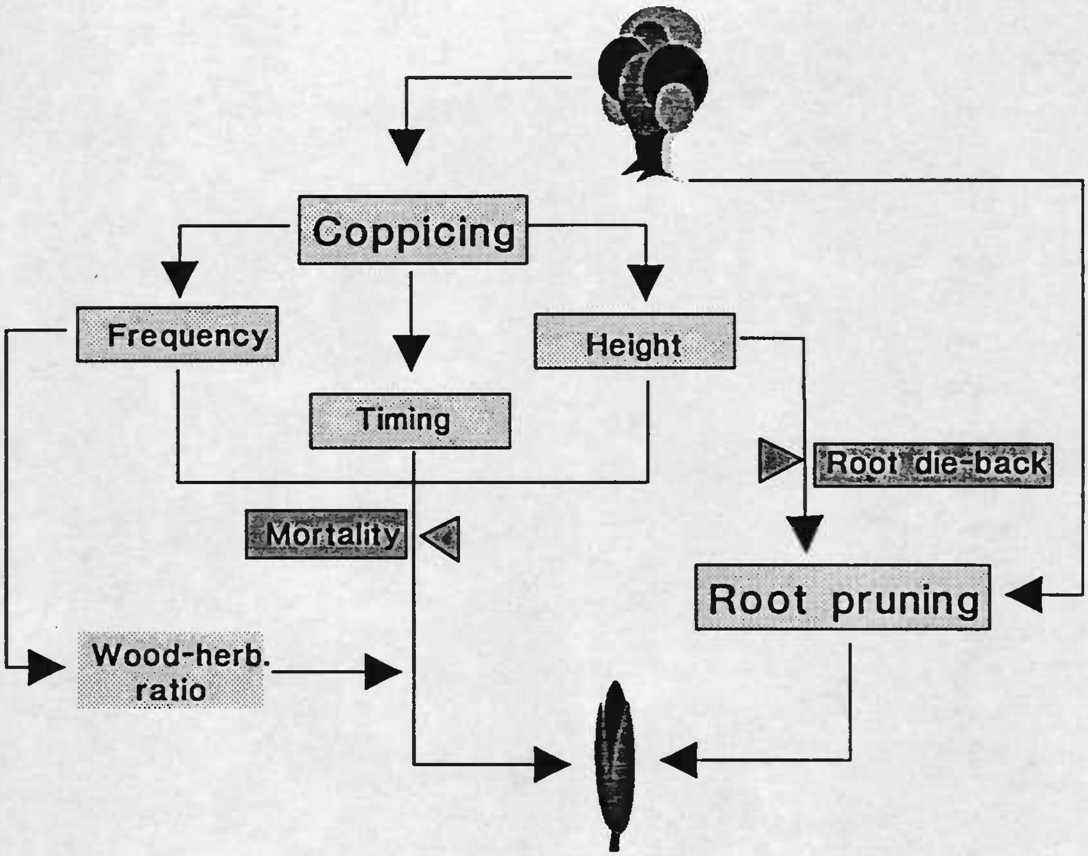


Figure 2.4. Effect of tree management on crop production. For simplification, only some regulatory processes are shown

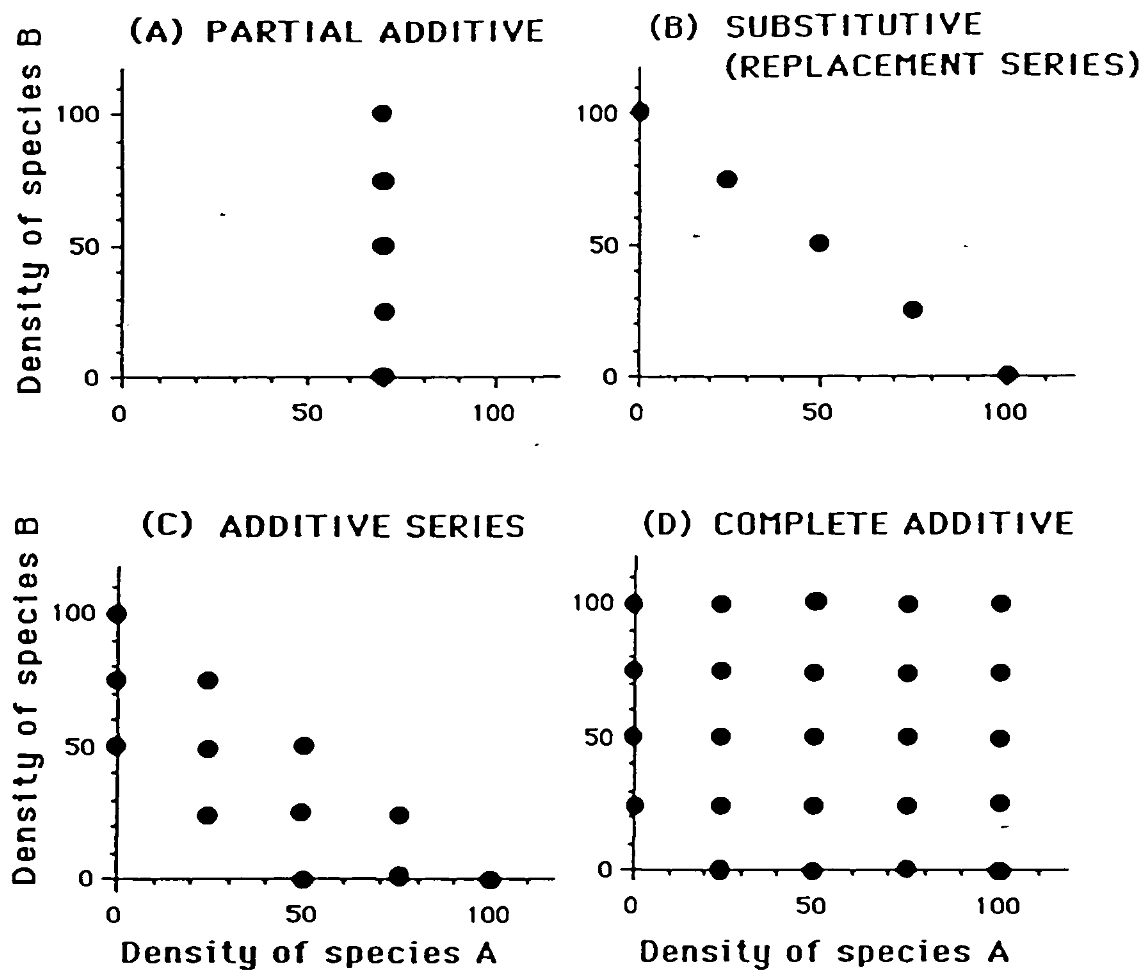


Figure 2.5. Four basic types of experimental design for competition experiments. Each point represents one possible combination of two species.

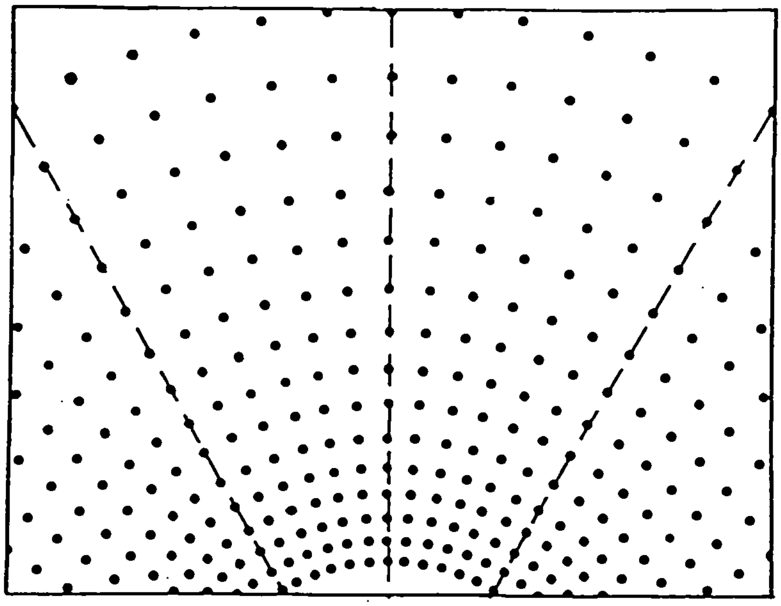


Figure 2.6. Fan design. Each dot represents position of one plant.

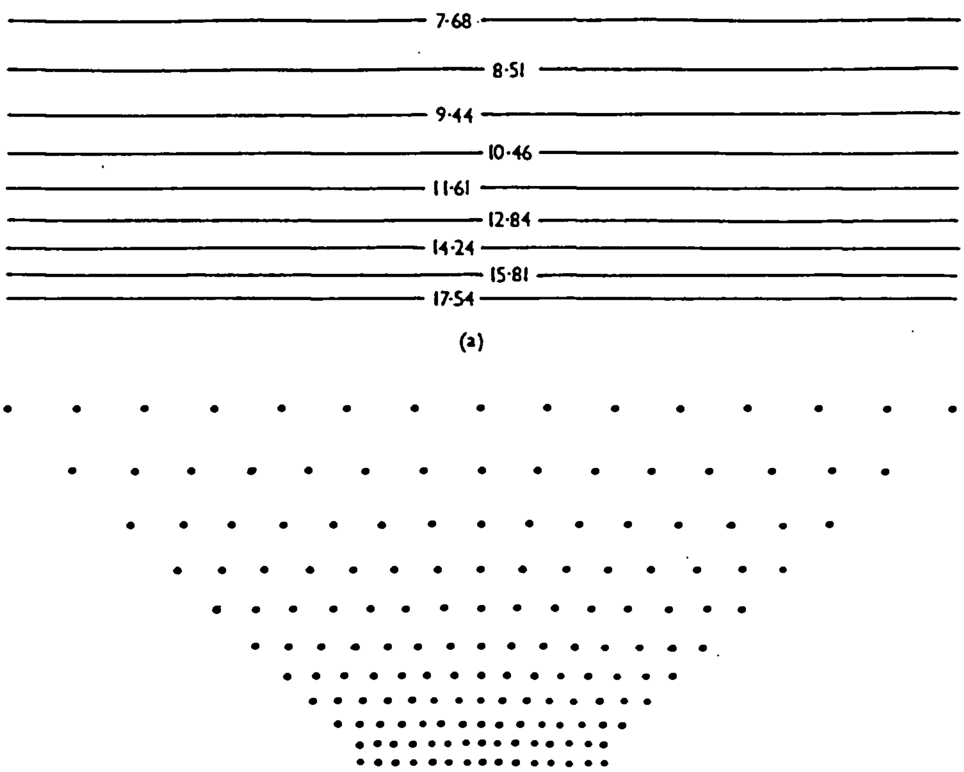


Figure 2.7. Two versions of the parallel row design. In (a) crop rows are represented as lines with number of plants shown on each line. In (b) each row has a constant number of plants represented by dots.

CHAPTER 3

CROP AND TREE RESPONSE TO PLANTING PATTERNS IN ALLEY CROPPING SYSTEMS

INTRODUCTION

Farmers around the world grow trees as green manure crops together with annual crops to improve crop and soil management. Crops are planted in-between tree hedgerows, which are periodically pruned, to function as a mulch and supply the crops with nutrients. Trees could serve the same function in agricultural systems of the temperate regions. As in other intercropping systems, there are concerns in alley cropping about yield reduction due to interspecific competition (Horwith, 1985). Given the close proximity of trees and crops in this system, they are likely to interact with each other. Approaches to study species interaction within a specific cropping system and environment may vary considerably. One approach is to study individual cropping system components or characteristics in isolation and integrate the information as it becomes available. In contrast, whole planting patterns might be observed and compared. The observations might then lead to more detailed study of certain system components. A predictive component can be included by comparing a set of whole systems, within which individual system components are controlled and structured.

In the present study, a set of several feasible alley cropping planting patterns and monocrop patterns were compared in a replicated factorial experiment. Proximity factors such as density, proportion, and spatial arrangement of trees and crops in these systems were controlled to study potential effects on crop and tree yield.

Most studies of plant interactions have focused on density to express relationships between plant performance and proximity (Harper, 1961, Weiner, 1984). In these studies, at least one of the interacting species was distributed irregularly. In alley cropping systems, however, the spatial arrangement of its components is structured. Since plants are opportunistic and fill the space (i.e. exploit resources) available to them (Mack and Harper, 1977), ultimately spatial arrangement and not density might be the major factor influencing tree and crop yield in these systems.

Objectives of this study were: to evaluate crop and tree performance in several alley cropping planting patterns; to describe relationships between spatial factors and yield of both trees and crop; and to evaluate the research methodology of using selected planting patterns.

MATERIALS AND METHODS

Study site

The study was conducted at the Oregon State University Vegetable Research farm in the Willamette Valley near Corvallis. The soil is a Chehalis sandy clay loam. The region is characterized by mediterranean climate. The bulk of the annual average 108 cm precipitation falls between October and May.

Experimental design

Plots measuring 9 by 4.5 m were established in a completely randomized block design, replicated in three blocks, each with eight treatments. The treatments included two corn monocrop and six alley cropping patterns (Figure 3.1). Three different alley cropping spatial arrangements were planted with either black locust (*Robinia pseudoacacia*) or red alder (*Alnus rubra* Bong.). Corn and tree rows were planted in an east-west direction. On the north and south side, plots were separated by one corn guard row.

Tree species

The two selected tree species in this experiment are both associated with nitrogen fixing bacteria. Black locust, as a member of the leguminosae family, is associated with rhizobium. Several hardwood species have shown increased growth in mixtures with black locust, attributed to its soil nitrogen contribution (Friedrich and Dawson, 1984). Black locust has been called "the temperate zone counterpart of leuceana" (Barrett and Hanover, 1991) because of its similarity in growth characteristics with some members of the *Leuceana*. Its rapid growth and the ability to resprout readily after repeated pruning (Hanover,1989) make it potentially suitable for alley cropping systems.

Red alder is an early successional species of the Pacific Northwest characterized by rapid growth, the ability to accumulate significant amounts of nitrogen, and to increase soil organic matter content in forest stands (Tarrant and Miller, 1963). The organism responsible for nitrogen fixation is a finely-hyphal bacteria (i.e.actinomyces) of the genus *Frankia*. Alder species, such as *A. glutinosa*, are known to supply adjacent plants, such as apple trees or timber trees, with atmospherically fixed nitrogen by increasing soil nitrogen concentration in the area close to the alder (Delver and Post, 1968; Dawson et al., 1983). Corn farmers in Central America use alder in their corn fields to improve soil fertility (Dawson, 1986).

Agricultural procedures

Black locust seeds were scarified by soaking in concentrated sulfuric acid for 50 minutes. Red alder seeds were soaked in water for 24 h, air-dried and placed in the freezer for 10 days. Treated tree seeds were sown directly into the experimental plots in May, 1991. Black locust seedlings were thinned to the final density (Figure 3.1) in August of the same year. Seedling emergence of red alder was erratic and insufficient for the experiment. One-year-old seedlings collected from wild stands in Oregon's coast range were planted in March, 1992. In May 1992, all trees were pruned to 30 cm, using a tractor-mounted flail. Prunings were incorporated into the top 15 cm of soil during seed bed preparation. 'Jubilee' sweet corn (Zea mays L.) was seeded May 14 with a hand pushed belt planter and hand-thinned to the final density (Figure 3.1) June 2. All plots were fertilized equally with mineral fertilizer at a rate of 170 kg N, 180 kg P, 100 kg K per hectare, representing the standard monocrop rate. Nitrogen, applied as ammonium, was split into two applications. No pesticides were applied. Weed control was achieved with mechanical cultivation. On June 20, black locust trees were pruned again to 30 cm, when the newly emerging tree shoots averaged 60 cm. These prunings were left on the soil surface next to the trees. Red alder seedlings were not pruned a second time because of limited regrowth. Water demand during the growing season was met by sprinkler irrigation.

Measurements

Sweet corn was hand-picked at a kernel moisture content of 72 % on September 2. Within each plot, individual rows were sampled. Row subsamples were combined for comparison of planting patterns and analyzed separately to determine possible row differences within the treatment. Whole planting pattern corn yield represents yield for the whole plot including area occupied by trees. Area harvested was 4.5 m (i.e. full plot width) by 4.5 m (i.e. half plot length) in all plots. Mean individual plant yield was not measured, but was determined by dividing row yield by the respective plant population.

At harvest, measured variables included: weight of mature ears (total harvestable yield), number of culls, weight of marketable ears (total harvestable yield minus weight of culled ears), average ear diameter and average ear length of ten randomly selected marketable ears. Culls were assessed visually and involved ears that were immature, misshaped, and attacked by pests.

Immediately prior to regular pruning to 30 cm, one meter row length in every tree row in each alley cropping plot was hand clipped to determine pruning biomass. Pruning biomass of each planting pattern represents area of the whole plot including area occupied by sweet corn. Prunings were oven-dried for one week and weighed. Beginning July 9, eight weeks after first pruning, tree growth was measured every four weeks. In each alley cropping plot, tree height was recorded from five randomly selected trees.

Statistical analysis

Data were analyzed by using 'General Linear Model' (GLM) procedure of SAS (SAS Institute, 1986). Data were checked for normality by comparing residuals and predicted values. Treatments were compared using Fisher's protected LSD at p = 0.05. Groups of treatments and row subsamples within treatments were contrasted using the contrast procedure (i.e. single degree of freedom comparison) of the GLM of SAS.

RESULTS AND DISCUSSION

First, results from the whole planting pattern are considered, followed by individual row yield within each cropping system, and finally individual plant yield within the row. Words are symbols. Rather than describe each treatment with several words, visual symbols are used for clarity (Figure 3.1).

Comparison of alley cropping patterns

The highest total and marketable corn yield among all alley cropping systems was produced in alder / corn | | |⁞⁞⁞ | | | averaging 20.4 and 18.4 tons per hectare total and marketable yield, respectively (Figure 3.2). Significantly lower yield was produced in |█ |█ |█ |█ |, where black locust and corn alternated (Table 3.1). Black locust / corn | | █ | | usually yielded values intermediate to the two other alley cropping patterns.

Alley cropping systems differ in the proportion of cropping space that tree and crop occupy (Figure 3.1). Alley cropping farmers who use the trees for green manure are primarily interested in maximizing their food crop yield. One can expect that when trees occupy less area, food crop yield will be greater. Therefore, corn yield was regressed against the proportion of tree area occupation (Figure 3.3). As expected, in the black locust treatments when trees occupied a high proportion of the total cropping space, corn yield was reduced. The same result occurred in the red alder treatments (Figure 3.4).

Compared to black locust, biomass pruned from red alder trees was minimal. Seedlings did not produce much growth in the short time after tree establishment. However, both tree species responded to increased space. Biomass production was highest in alternate black locust / corn  followed by narrow-spaced black locust  and wide-spaced black locust / corn  (Figure 3.5). Similar trends were evident in the respective red alder treatments (Figure 3.6). The difference in pruning biomass between close-spaced  and wide-spaced  of either species was statistically insignificant.

Since both components, trees and crop, took advantage of increased available space, high tree biomass production coincided with low corn yield. However, there was a difference in the magnitude of reduction of either yield component. Corn yield was 24 % lower in the alternate black locust / corn  compared to the narrow-spaced black locust / corn . Tree biomass production in the latter was reduced by 74 % compared to the former (Figure 3.7). Thus, an increase in tree density had proportionally less effect on corn yield.

Increased amounts of tree biomass often are correlated with decreasing crop yield (Lawson and Kang; 1990; Rosecrane et al., 1992). The crop yield response may depend on input levels and environmental conditions. Under low fertilizer input conditions, crop yield might not be reduced since the green manure provides nutrients to the crop. Under extreme environmental conditions where soil erosion is a major factor affecting crop yield or when the green manure is the only form of fertilizer, higher tree biomass may increase crop yield (Yamoha and Burleigh, 1990). However, when soil fertility is high, the general trend is the same as the one observed in the present study: decreasing crop yield with increasing tree biomass production. This points to tradeoffs between potential soil improving effects of high green manure production and crop yield.

Alley cropping patterns versus monocrop patterns

Since the objective of this trial was to compare treatments feasible for farmers, it is appropriate to compare the alley cropping systems to the presently practiced sole crop systems. Corn yield varied only slightly between conventional monocrop | | | | | and wide-spaced corn with red alder or black locust | | ⁞⁞⁞ | | and | | █ | |, although corn population was reduced by 20 percent in the latter two. Generally, crop yield is lower in alley cropping systems than in sole crop systems when trees replace corn and crop population is reduced (Sseskabembe, 1985). However, yield reduction in alley cropping systems might be avoided by manipulating plant rectangularity (i.e. inter-row spacing times intra-row spacing) to retain a crop population comparable to that in sole cropping (Huxely, 1983; Sseskambembe, 1985). In the present study, this idea is reflected in the comparison between narrow-spaced corn with trees | | | ⁞⁞⁞ | | |, | | | █ | | |, and narrow-spaced monocrop | | | | | | |. Crop yield differences between these treatments were higher than in the former comparison, but not significant statistically ($p = 0.05$) (Table 3.1).

Sweet corn in alternate corn / black locust |█ |█ |█ |█ | yielded 2.4 t/ha total yield less than in monocrop | | | | | and was significantly different from all other treatments. Almost equal to the control was the yield produced in alternate corn / red alder |⁞⁞⁞ |⁞⁞⁞ |⁞⁞⁞ |⁞⁞⁞ |. This suggests that either the red alder trees and corn did not interact or that beneficial interactions compensated for any competition. Considering the age of the seedlings and the high fertilization rate which was uniformly applied to all treatments, it is more likely that competition was lacking. Corn production in this treatment was as if trees were absent.

Individual alley cropping systems in this study were compared to sole crop systems. A knowledge of the optimum sole crop spatial configuration is important when sole crop systems and mixed cropping systems are compared (Trenbath, 1976, Huxley and Maingu, 1978, Vandemeer, 1989). The relative performance of mixtures, grown at different densities is easily misinterpreted, without the certainty that sole crop density and row arrangement is optimal. For example, if only conventional monocrop | | | | | had been included in the present study, it could have been concluded that several alley cropping systems yielded higher than mono cropping systems. However, yield produced by narrow spaced monocrop | | | | | | | averaged 2.8 t/ha more than the wide spaced monocrop | | | | |. At a narrow inter-row spacing, the planting geometry is closer to a square. This favors more efficient resource use (Sojaka et al., 1988), which resulted in higher yield according to Mack (1975). Both spatial arrangement and plant population influence yield. Research on the same sweet corn variety suggests that yield increases can be obtained beyond 70,000 plants per hectare (Moss and Mack, 1979). Thus, there is the possibility that the alley cropping systems were compared to monocrop systems which are now commonly practiced but which are not in a optimal spacing to achieve maximum yield. At the time, it can not be assumed that spacing of highest yielding alley cropping system was at an optimal level.

Influence of modifying treatment factors

In this trial, cropping systems were compared, in which several factors changed simultaneously. The proximity of trees has reduced the yield in alternate corn / black locust |█ |█ |█ |█ |. Contrasts (i.e. single degree of freedom comparisons) were used to evaluate the effect of common characteristics among the monocrop systems and the other alley cropping systems, which differed in corn density, row spacing, and presence of trees. No significant effects on corn yield were observed (Table 3.2). Additionally, similarity in the significance levels among the two species suggest that tree species was of minor importance. The results suggest some flexibility within these arrangements, where proximity factors can be changed within certain limits, without greatly influencing corn yield.

While it seemed that corn density had no significant effect on corn yield, tree yield differences among alley cropping systems were roughly proportional to their density. This was observed when the tree biomass of alternate corn / black locust |█ |█ |█ |█ | was compared to the biomass produced in narrow- and wide-spaced corn / black locust | | |█| | | and | | █ | |. The 35,000 plants per hectare in the former produced 5 tons and the 14,000 plants per hectare in the latter produced an average of 1.6 tons.

A wide array of responses to different levels of alley cropping system components can be found in the literature. Usually, an increase in tree population reduces crop yield. However, in some situations, crop yield increased with increasing tree population at first and decreased after a certain tree population was exceeded (Raiche, 1981). Alley width is another widely studied component in alley cropping research for which various crop responses can be observed. Usually crop yield declines with decreasing alley width due to increased inter-specific competition and reduced cropping space (Sseskambembe, 1985). However, some studies show that crop yield might increase with decreasing alley width (Jama et al.; 1991).

Effect of row position on yield

Yield of individual corn rows within the treatments varied considerably ranging from 21.5 to 28.4 t/ha total yield in narrow spaced corn / black locust | | | ■ | | |. The data suggested that corn rows adjacent to the tree double row yielded higher than all other rows.

Single degree of freedom comparisons were used to test for differences in row position (Table 3.3). Row position had no significant effect in alternate corn / tree | ■ | ■ | ■ | ■ | and | ⁞⁞ | ⁞⁞ | ⁞⁞ | ⁞⁞ |. There were only slight row yield variations in both monocrops and only one row within narrow spaced | | | | | | | was significantly different from any other row (Figures 3.8 and 3.9). Significant effects were detected in the double tree row treatments. Increased yield adjacent to the trees was observed in the treatments of both species, except in north rows of narrow spaced corn / black locust | | | ■ | | |. Generally, north or south position had no effect on row yield. The higher corn yield of the first row to the trees partially compensated for expected yield reduction from lost cropping space.

Increased yield of corn rows adjacent to trees was observed by Sseskambembe and Henderlong (1991), when they studied plant interactions in an alley cropping system involving black locust and corn. Higher yield along edges are found in other mixed cropping systems in the temperate zone as well. In strip cropping, where strips of grains, particularly corn, are frequently intercropped with strips of legumes such as soybeans, yield increases along the edges of the strips are attributed to a combination of above-ground and below-ground effects. At the interface of the two crops, the taller crop can take advantage of increased light interception (Allen et al., 1976). In these systems, legumes can contribute up to 50 kg/ha of nitrogen to the grain (Francis et al., 1986). When nodules senesce it is possible that part of the released nitrogen is used by the intercrop (Sseskambembe and Henderlong, 1991). Both alder and locust can contribute nitrogen to neighboring plants (Ike and Stone, 1958; Friedrich and Dawson, 1984). For example, in a system where rows of *A. glutinosa* were interplanted in hybrid poplar stands, Dawson et al. (1982) found that poplar growth increased with decreasing distance between the poplar and alder rows. They attributed the growth increase to higher levels of soil nitrogen concentration next to the alder rows.

The mechanisms of interference were not investigated in the present experiment. However, the higher corn yield adjacent to the hedges is most likely to be attributed to an increase in the amount of intercepted light. Competition for water and nutrients most likely played only minor roles because plots received a high rate of fertilization and water demand was met by frequent irrigation. Most studies in traditional alley cropping regions show reduced yield in the crop rows adjacent to the trees due to competition for soil moisture and/or light (Giruchu and Kang, 1988; Rosecrane, 1992; Salazar and Palm, 1987). In the semi-arid regions, the major limiting factor is soil moisture (Singh et al. 1988), while fast tree growth and the associated shading is the major limiting factors in the tropics. In the present study, however, the relatively slow tree growth in the temperate climate and optimum soil moisture appeared to favor higher row yields next to the hedges.

Mean plant performance

The analysis of row yields was limited to comparisons within each treatment. Comparisons among corn rows of different planting patterns were confounded by the difference in corn population. Although row corn yield adjacent to the trees was increased in two planting patterns it was not possible to determine relationships between yield and proximity factors. An analysis of individual plants would account for the different plant population and would enhance understanding of the relationship between yield influencing factors.

Measures of proximity for the following regression model were crop-crop distance and tree-crop distance. Crop-crop distance is the mean distance between two adjacent crop rows (Table 3.5). Tree-crop distance is the mean distance between the crop and next tree row. Mean plant yield was determined by adjusting row yield to the respective plant population.

Average individual plant yield decreased when both neighboring corn rows and neighboring tree rows were in close distance (Table 3.6). The relationship was highly significant for both tree species. Both crop-crop distance and tree-crop distance significantly contributed to the regression model. A quadratic factor of tree-crop distance improved the model estimate significantly.

The influence of neighbors on a plant decreases with distance (Firbank and Watkinson, 1987; Weiner 1984). Firbank and Watkinson (1987) suggested that it is possible to scale the intensity of interaction between two plants by the distance between them. The closest distance between corn plants is determined by their intra-row distance, which is not included in this model. However, since plants will make their greatest growth in the direction of least interference (Ross and Harper, 1972), it is reasonable to assume that corn will benefit from increased space in the direction of the next corn row. Thus, differences in intra-row distance among the treatments might play only a minor role. The proposed regression model suggests that there is a linear relationship between corn yield and the average distance to each species. However, when light is the major limiting factor, competition is "one-sided" or "asymmetric" (Weiner and Thomas; 1986). This means that plant growth at first is linearly correlated to the space they occupy. As they start to shade each other, plants with more space will grow taller and these plants will increase their share of the light resource. In the narrow range of distances tested in this study, corn responded in a linear fashion.

Competition studies usually rely on plant biomass as a yield criterion, because it is a more direct measure of the distribution of limiting resources among plants than yield of any plant part (Spitters, 1983b). At very high densities, marketable yield will decrease (Holliday, 1960) while biomass will remain constant (Willey and Heath, 1969) (i.e. parabolic versus asymptotic density-response curve). In the present study, biomass was not measured. Biomass rather than weight of ears as a response variable might improve the proportion of variation explained by proximity of trees and other corn plants.

SUMMARY AND CONCLUSION

First-year results from the present alley cropping study suggests that under the conditions chosen (e.g. soil type, climate, species), corn production in alley cropping is reduced compared to monocrop systems. Equally-spaced alley cropping systems and the monocrop system showed insignificant differences. Higher yield in rows next to the hedges partially compensated for expected yield loss due to reduced cropping space. Significant negative effects on corn yield were apparent when trees were grown in close proximity to the corn. Over time, competition from trees further away from the corn rows might become more severe as the tree roots grow further into the alleys. In this "young" alley cropping system, above-ground growth might have played a more important role in determining the degree of competition between the two species. Both corn and trees responded positively to increased space. The best predictor for species interaction was the spatial arrangement, and particularly, distance between crop rows and distance between crop and tree rows. Alley cropping is different from other mixed cropping systems in which density is usually the best predictor, because of its confined arrangement of the species in rows and alleys. Lowest crop yields coincided with the highest pruning biomass. This points at tradeoffs between potential soil improving effects by high pruning biomass and crop yield. Pruning biomass production was affected by changes in tree-crop area occupation ratio and changes in tree population.

Although, the exact outcome of interspecific plant competition may vary with the environmental conditions (Harper, 1977; Buck, 1986), knowledge of ecological principles can guide our design of feasible systems and eliminate many theoretical possibilities of species mixtures. The experimental design with only three tree-crop mixtures and two sole crop controls did not allow and was not intended to precisely model the relationship between single proximity factors and yield components. However, the structure and control of these factors allowed assessment of their relative importance to the output of the systems (i.e. tree and crop yield). It was possible to demonstrate basic trends in the relationship between planting patterns and yield of each component. Analysis on the cropping systems level provided an understanding and information about the general output capacity of the cropping systems. Analysis on row and individual plant level showed what factors contributed most to variation of corn and tree yield.

The present study focused on spatial arrangement factors in alley cropping systems. The major motivation to explore these systems in Oregon was potential soil improving effects of trees in annual cropping systems. To evaluate full capacity of alley cropping, long term studies are needed since full potential benefits are not realized in one growing season. The approach of comparing whole planting patterns that integrate several spacing factors was chosen to invite farmers to participate in the research process. The information gained in the first year of study could be presented to farmers and their evaluation could lead to other planting patterns. Also, experience from alley cropping around the world could be contributed which might stimulate the interest of Oregon farmers. Future research activities would then be planed collaboratively.

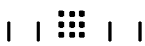
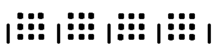
Cropping system	Crop population (plants/ha) Inter-row x intra-row spacing (cm)	Tree density (plants/ha) Species Arrangement	Cropping area Occupation by trees - corn (%)
	70000 89 x 16	0	0 - 100
	70000 63.5 x 22.5	0	0 - 100
	70000 63.5 x 19	14000 Red alder Double rows	14 - 86
	70000 63.5 x 19	14000 Black locust Double rows	14 - 86
	56000 89 x 16	14000 Red alder Double rows	20 - 80
	56000 89 x 16	14000 Black locust Double rows	20 - 80
	70000 89 x 16	35000 Red alder Single rows	50 - 50
	70000 89 x 16	35000 / ha Black locust Single rows	50 - 50

Figure 3.1. List of treatments

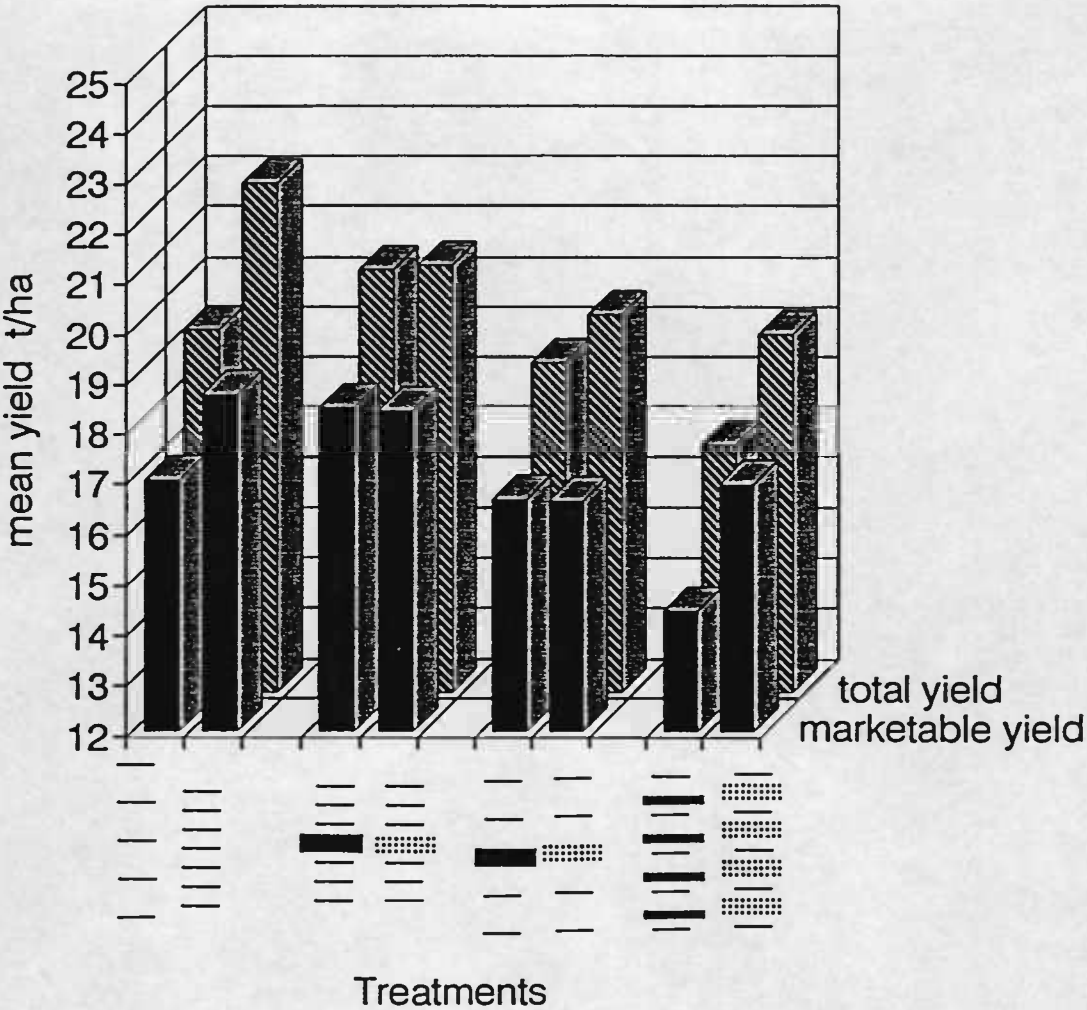


Figure 3.2. Treatment comparison of mean total and mean marketable corn yield (t/ha). Each bar is the average of three replications.

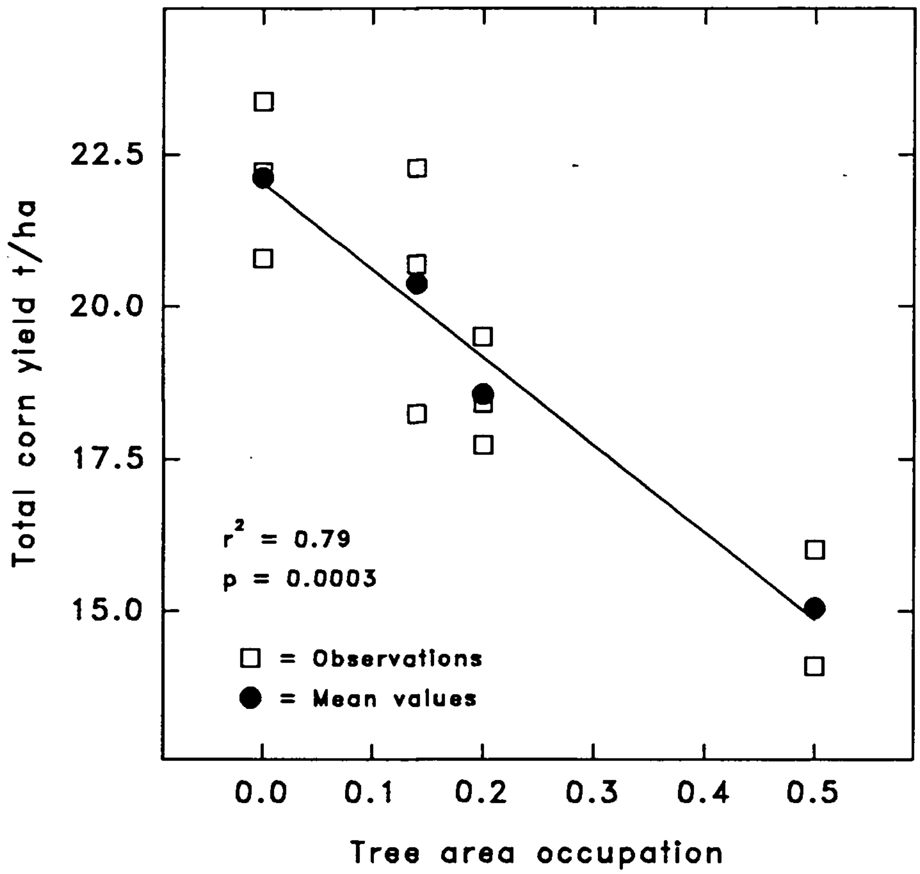


Figure 3.3. Corn yield response to **black locust** area occupation. Level 0 corresponds to treatment | | | | | | | . Level 0.14 corresponds to treatment | | | ▌| | | . Level 0.2 corresponds to treatment | | ▌ | | . Level 0.5 corresponds to treatment |▌ |▌ |▌ |▌ | .

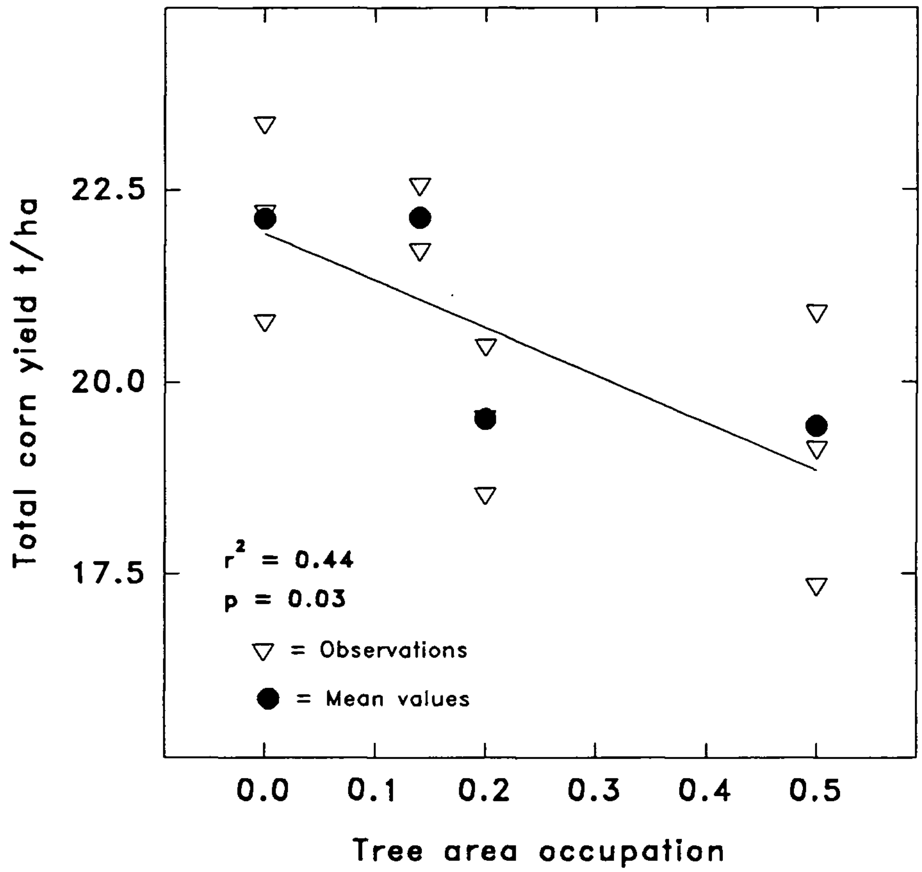


Figure 3.4. Corn yield response to **red alder** area occupation. Level 0 corresponds to treatment | | | | | | | . Level 0.14 corresponds to treatment | | |⁙| | | . Level 0.2 corresponds to treatment | | ⁙ | | . Level 0.5 corresponds to treatment |⁙|⁙|⁙|⁙| .

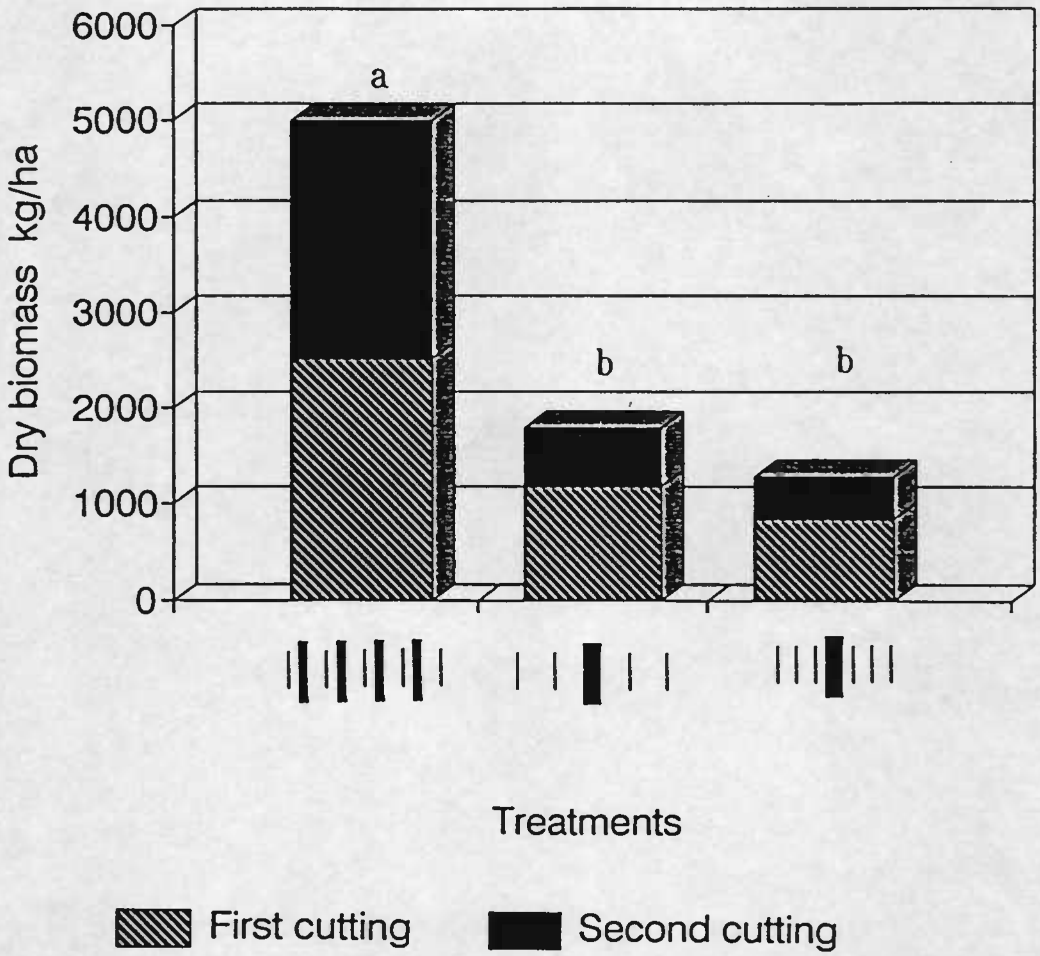


Figure 3.5. Black locust pruning biomass production (kg/ha) in three alley cropping planting patterns. Treatment means were separated using Fisher,s protected LSD. The same letter indicates no significant differences at $p = 0.05$.

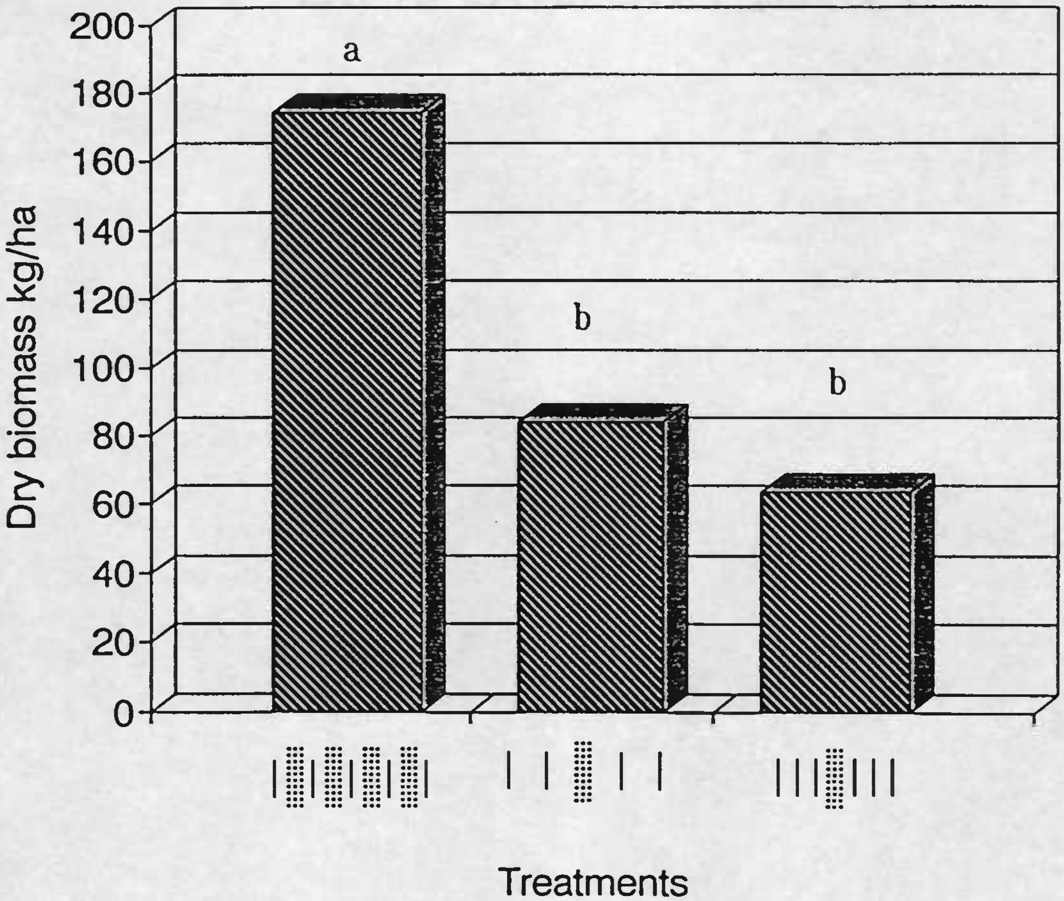


Figure 3.6. Red alder pruning biomass production in three alley cropping planting patterns. Treatment means were separated using Fisher's protected LSD. The same letter indicates no significant differences at p = 0.05.

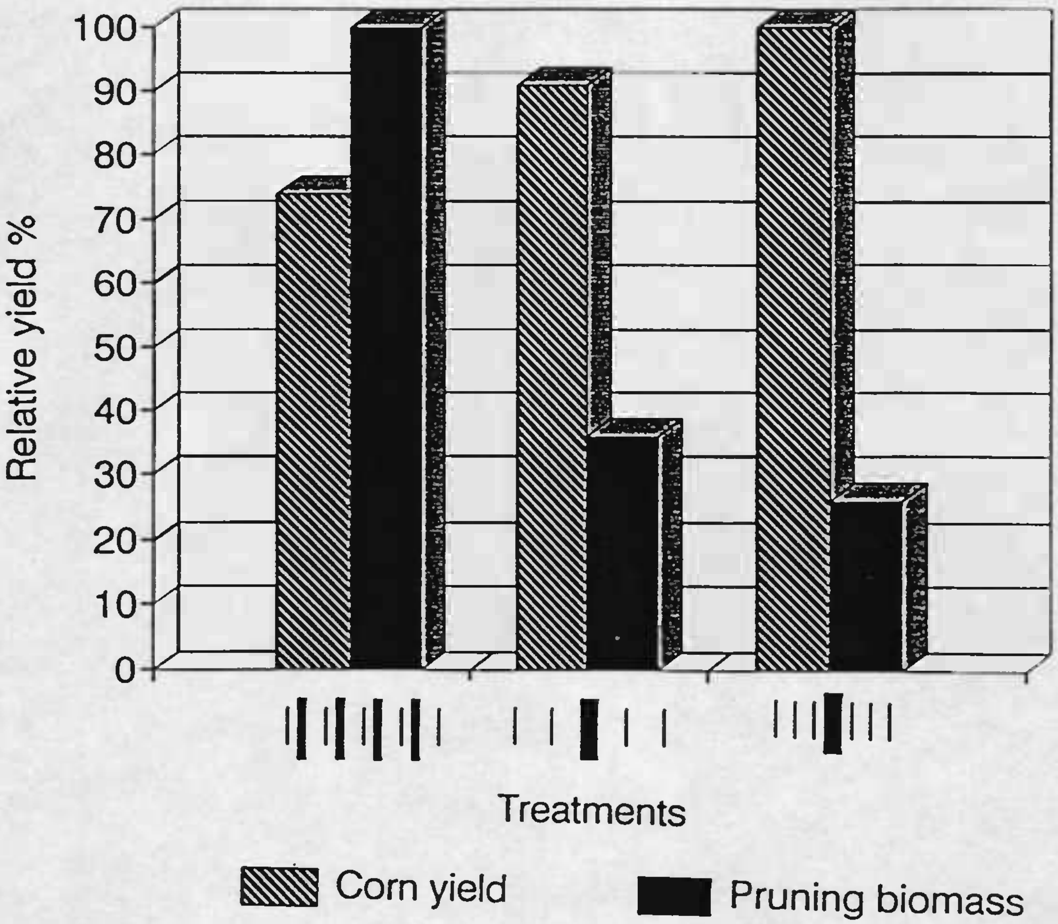


Figure 3.7. Comparison of relative corn yield and relative black locust yield in three alley cropping planting patterns. The highest component yield was denoted as 100 %.

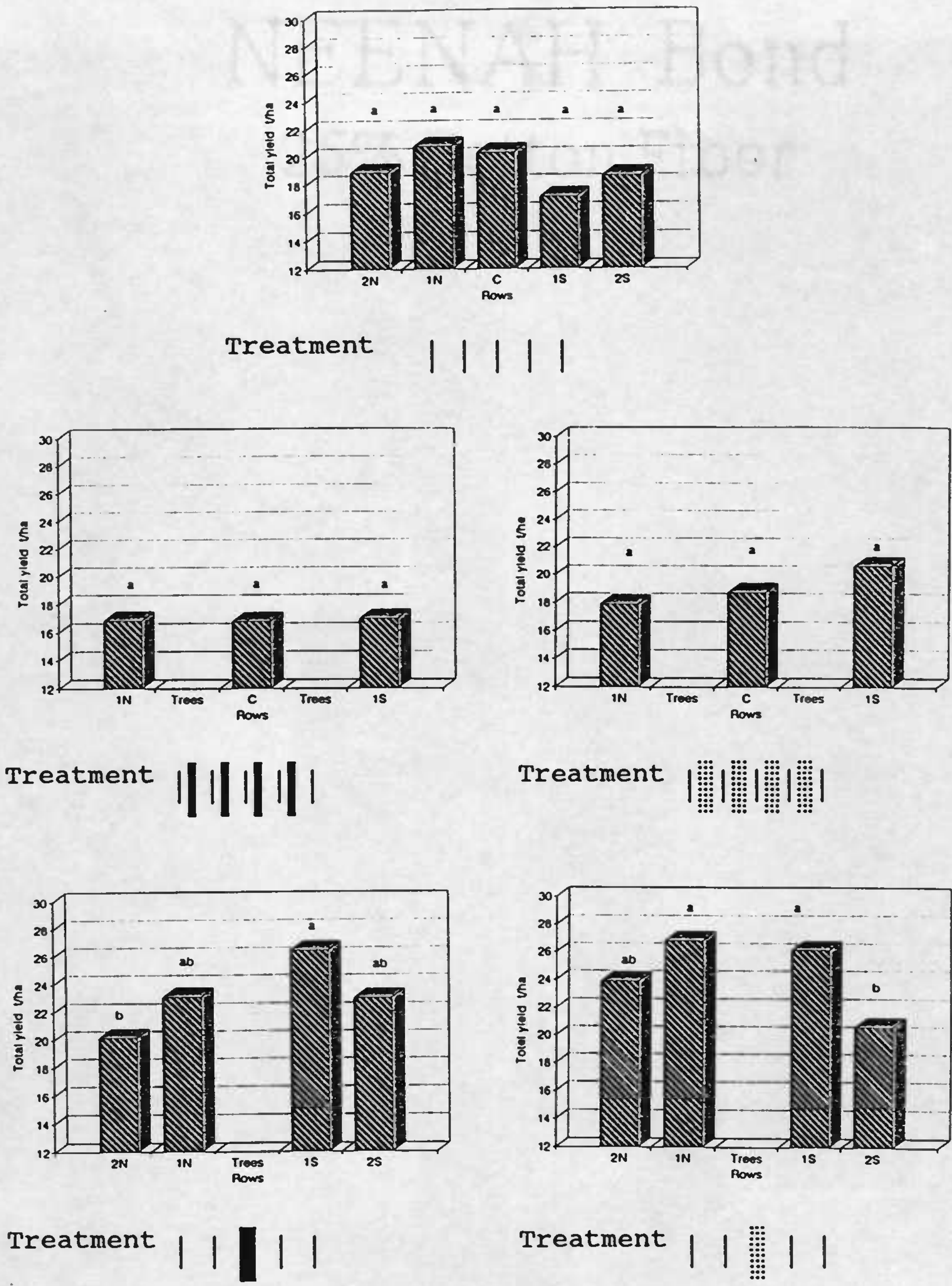


Figure 3.8. Comparison of mean row yield in monocrop and alley cropping planting patterns planted at 89 cm corn row spacing. Each bar is the average of three replications. Means were separated using Fisher's protected LSD. Same letter indicates no difference at $p = 0.05$.

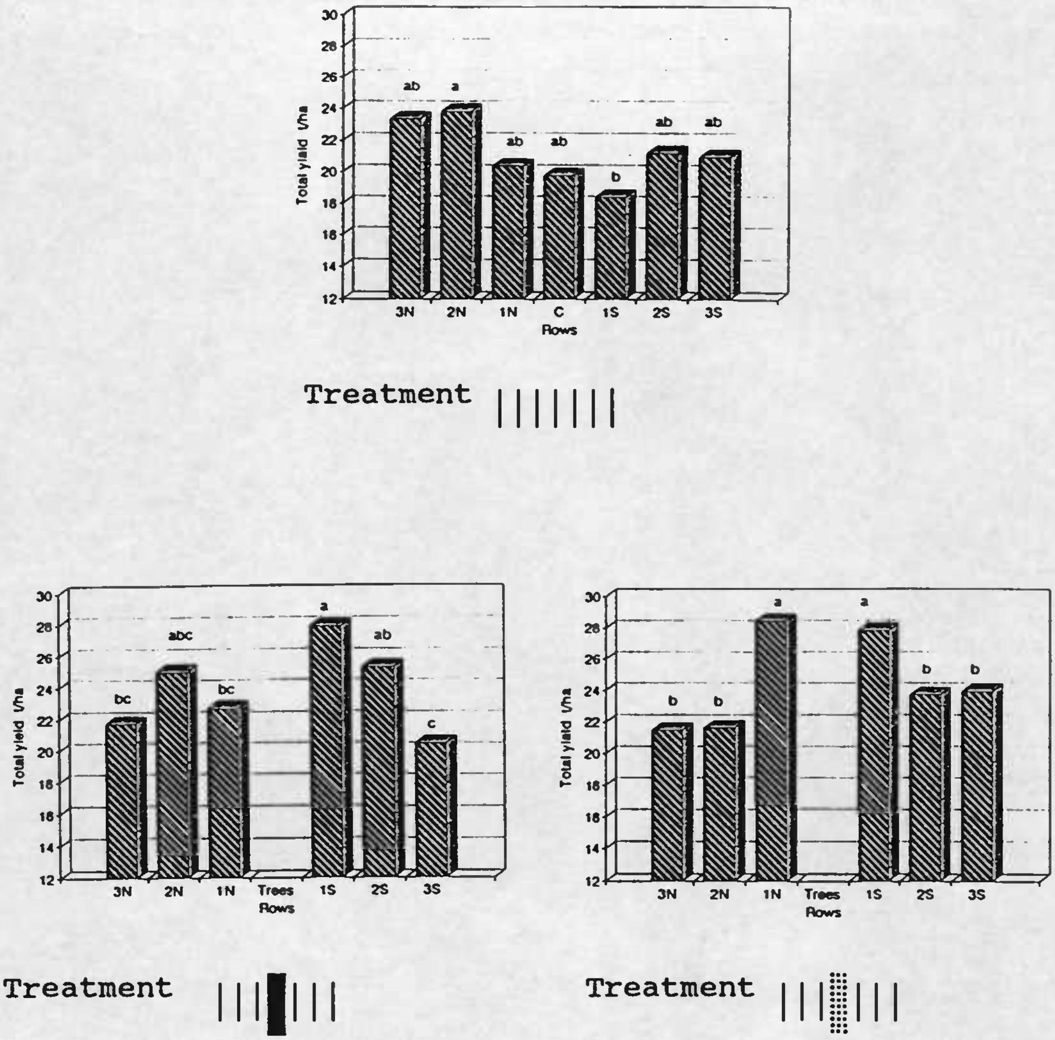


Figure 3.9. Comparison of mean row yield in monocrop and alley cropping planting patterns planted at 63.5 cm corn row spacing. Each bar is the average of three replications. Means were separated using Fisher's protected LSD. Same letter indicates no difference at p = 0.05.

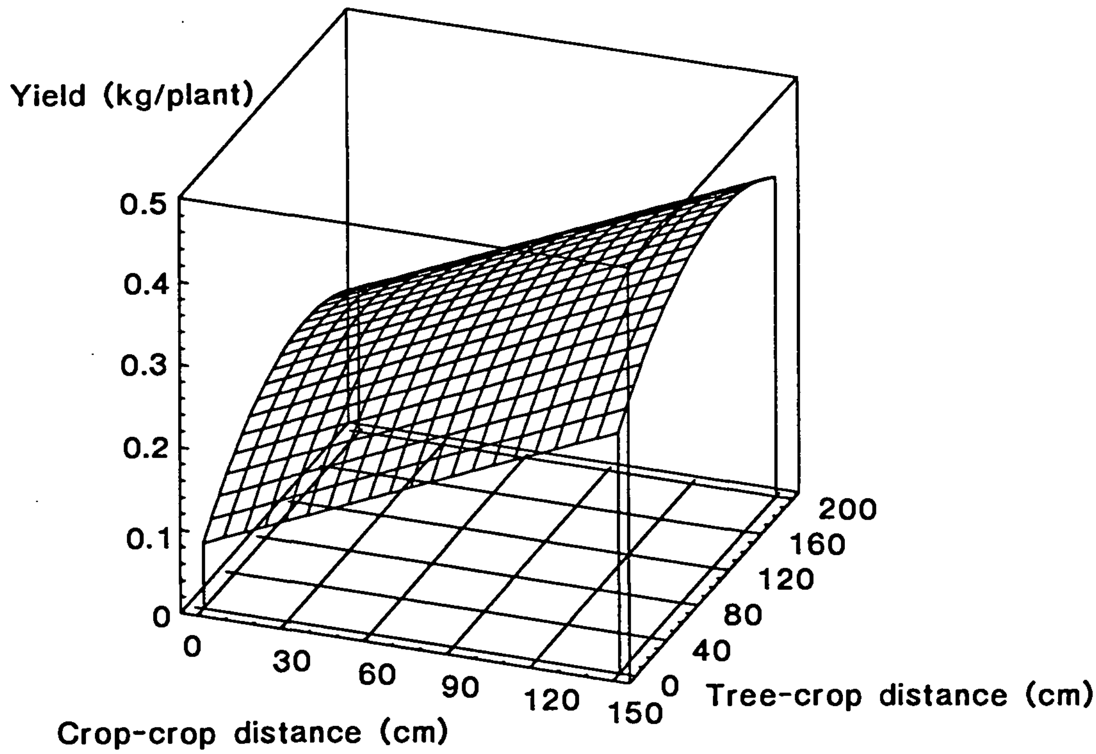


Figure 3.10. Predicted corn yield (kg/plant) in red alder planting patterns in response to crop-crop distance (cm) and tree-crop distance (cm).

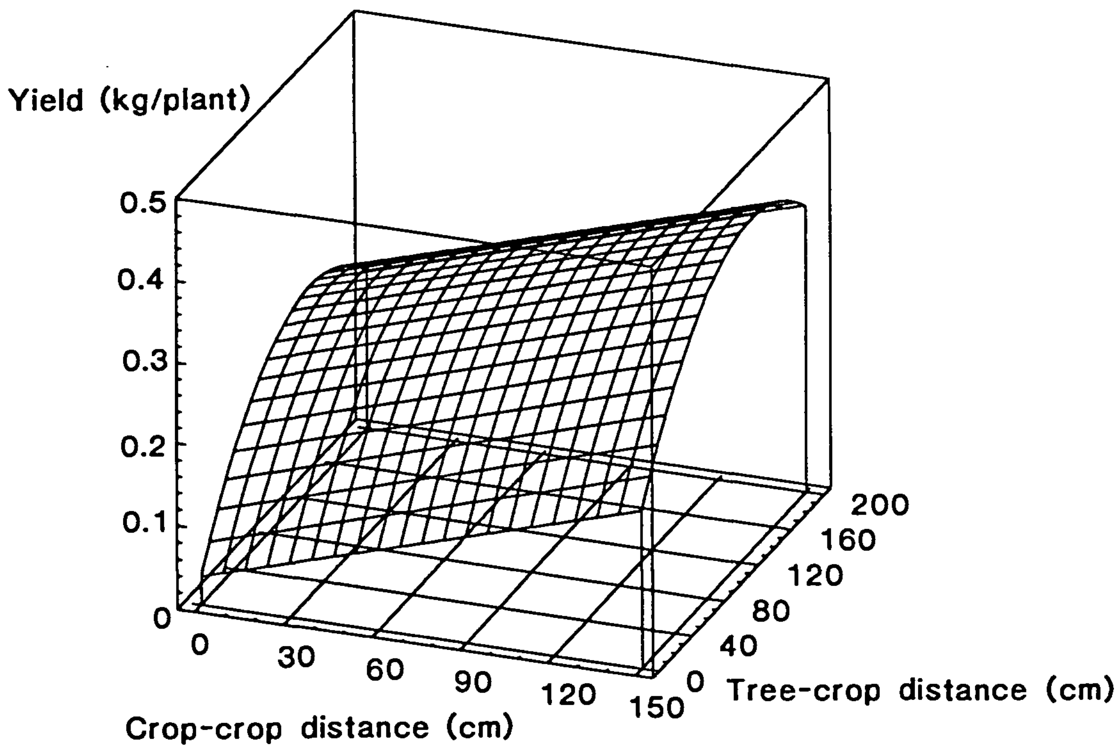


Figure 3.11. Predicted corn yield (kg/plant) in black locust planting patterns in response to crop-crop distance (cm) and tree-crop distance (cm).

Table 3.1. List of mean total and marketable corn yield (t/ha) produced in each planting pattern. Means were separated using Fisher's protected LSD. Same letter indicates no difference at p = 0.05.

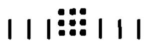
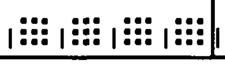
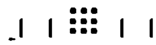
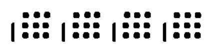
Treatment	Total Yield		Marketable yield	
	19.2	abc	17.0	ab
	22.1	a	18.7	a
	20.4	ab	18.4	a
	20.5	ab	18.4	a
	18.5	bc	16.6	ab
	19.5	abc	16.5	ab
	16.9	c	14.4	b
	19.1	abc	16.9	ab

Table 3.2. P-values for comparisons of corn yield between treatments.

Contrasted planting patterns:[Z]	Test for effect of:	p-value[Y]	
		Treatments	
		R. alder	B.locust
I I I I I I I I I I I I versus I I I ■ I I I I I ■ I I	Presence of trees	0.54 (0.73)[X]	0.28 (0.7)
I I ■ I I versus I I I ■ I I I I I I I I I I I I I I I	Corn population	0.38 (0.21)	0.12 (0.21)
I I I I I I I ■ I I versus I I I I I I I I I I ■ I I I	Corn inter-row spacing	0.39 (0.96)	0.64 (0.95)

[Y] P-value of 1 denotes probability that compared treatments are equal.
[X] Values in parenthesis show p-values for marketable yield.
[Z] Symbol used is symbol of planting patterns for both tree species.

Table 3.3. p-values[Y] for comparisons of corn row yield within treatments

Contrasted rows	Row position	Treatment	p - values
1N,1S vs. 2N,2S[X]	Outer rows vs.		0.01
	Inner rows		0.05
1N,1S vs. 3N,3S	Outer rows vs.		0.001
	Inner rows		0.003
1N,1S vs. 2N,2S	Outer rows vs.		0.002
	Middle rows		0.2
2N,2S vs. 3N,3S	Middle rows vs.		0.9
	Inner rows		0.02
C vs. 1N,1S	Center vs.		0.8
	Outer rows		0.9
C vs. 2N,2S	Center vs.		0.4
	Outer rows		
C vs 3N,3S	Center vs.		0.5
	Outer rows		

[X] N (North); S (South); 1 (1st row adjacent to trees); 2 (2nd row adjacent to trees); and 3 (3rd row adjacent to trees).

[Y] p - value of 1 denotes probability that the compared rows are equal.

Table 3.5. Average crop-crop and crop-tree distances (cm) in alley cropping patterns

Planting patterns[x]	Rows	Crop-crop distance	Tree-crop distance
	Inside North, South	133.5	89
	Outside North, South	89	178
	All	89	44.5
	Inside North, South	95.25	63.5
	Middle North, South	63.5	127
	Outside North, South	63.5	190.5

[x] Symbol used is symbol of planting pattern for both tree species

Table 3.6. Multiple regression to describe the effect of mean distance between two adjacent corn rows (crop-crop distance) (cm) and mean distance between trees and next corn row (tree-crop distance) (cm) on mean corn yield (kg/plant).

Tree species	Regression equation[x]	R^2
Red A.	$Y = 0.08 + 0.001 \times C + 0.0002 \times T - 0.00007 \times T^2$	0.50***
Black L.	$Y = 0.03 + 0.001 \times C + 0.0003 \times T - 0.000001 \times T^2$	0.54***

[x] Y (mean corn yield); C (crop-crop distance); and T (tree-crop distance).

*** Significant at P = 0.001

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APPENDIX

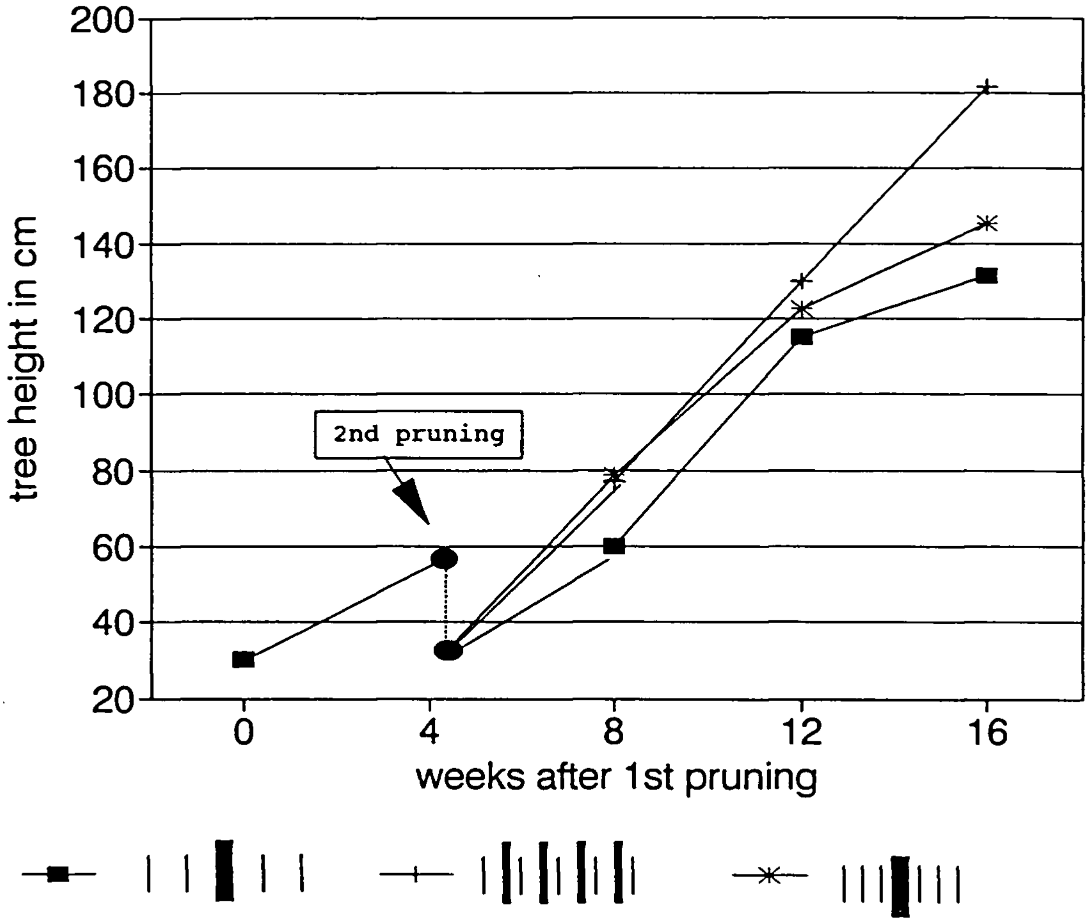

Figure A.1. Black locust growth after pruning. Each data point is the mean of 15 measurements.

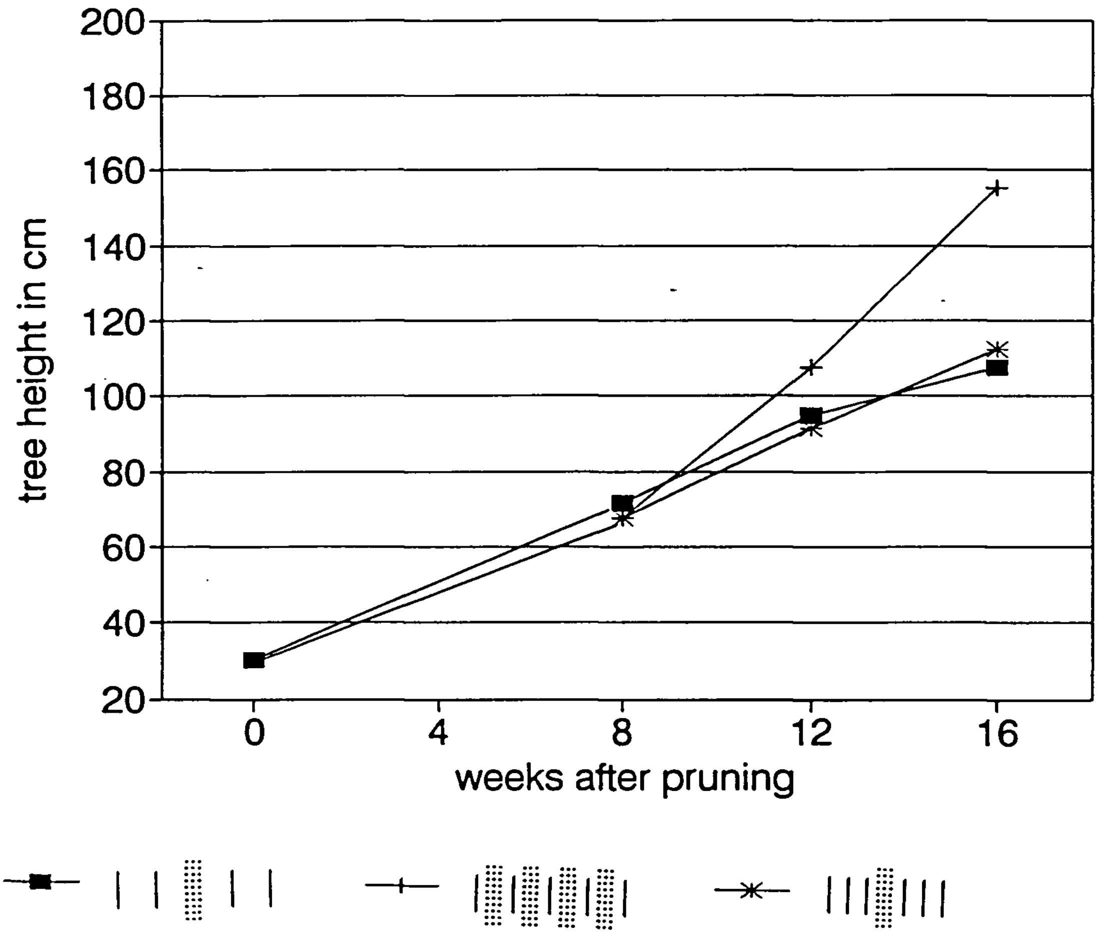

Figure A.2. Red alder growth after pruning. Each data point is the mean of 15 measurements.

Table A.1. Anova summary of multiple regression to describe the effect of mean distance between two adjacent corn rows (cm) and distance between **black locust** trees and next corn row (cm) on mean plant yield (kg/plant).

Source	DF	Mean Square	P-value
Model	3	0.0183140	0.0001
Error	33	0.00120304	

Standard error of est. = 0.0346849

R-squared (Adj. for d.f.) = 0.542388

Variable	P-value
Corn - Corn distance	0.0018
Tree - Corn distance	0.0001
$(\text{Tree - Corn dist})^2$	0.0002

Table A.2. Anova summary of multiple regression to describe the effect of mean distance between two adjacent corn rows (cm) and distance between **red alder** trees and next corn row (cm) on mean plant yield (kg/plant).

Source	DF	Mean Square	P-value
Model	3	0.0161229	0.0001
Error	30	0.00133747	

Standard error of est. = 0.0365715

R-squared (Adj. for d.f.) = 0.501241

Variable	P-value
Corn - corn distance	0.0002
Tree - corn distance	0.0229
$(\text{Tree - corn distance})^2$	0.0453