Intercropping for Food, Fiber, and Fuel on Pine Plantations in Virginia and North Carolina.

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INTERCROPPING FOR FOOD, FIBER, AND FUEL

ON PINE PLANTATIONS IN THE SOUTH.

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(ABSTRACT)

Intercropping is defined as a management approach where two or more crops are planted on the same forested site simultaneously. The advantages of applying this concept on young pine plantations in the South can increase site utilization, reduce weed competition, provide annual or semi-annual revenues early in the timber rotation, ameliorate the soil, and diversify production.

Research was initiated to determine the feasibility of using various plants as intercrops on pine plantations in Virginia and North Carolina. Regional crops were categorized into four groups based on management intensity, end use, and crop value. These crop groups included:

1. Field Crops: Corn, Sorghum, Cotton, Small Grains,
2. High Value Crops: Tobacco, Peanuts, Snap Beans, Tomatoes, Cucurbits,
3. Forage Crops: Grasses and Legumes,

4. Biomass Crops: Sycamore, Sweet Gum, European Black Alder, Cottonwood.

The ecological and management characteristics of these crops were examined to determine their compatability with pine plantation management. In every case, three significant constraints were noted; intercropping on plantations reduced the number of trees carried to maturity by 50 to 60 percent; intercrop production was highly sensitive to row spacings and required seedling row widths of 4 to 8 m; and great emphasis was placed on site preparation, with per hectare costs increasing by approximately 250 percent.

Investment analysis of several hypothetical intercrop scenarios suggested that forest intercropping can be financially rewarding under a variety of crop combinations. Intensively managed intercrops provided substantially greater returns than a conventional plantation investment. A field crop-pine combination was the most attractive intercrop scenario for large scale plantation intercropping, due to consistently high profit margins, low total investment costs, and fewer marketing constraints. Vegetable-pine combinations were typically high cost alternatives which generated equally attractive net revenues. However, the high costs and intensive management requirements restricted the introduction of vegetable crops to small plantation acreages where adequate attention would be available. Forage and biomass intercrops were relatively inferior investments relative to the more intensive vegetable and field crop combinations.

Wide intercrop spacings dramatically inreased average DBH of simulated pine stands configured for intercrop management, resulting in greater sawlog and veneer size log production and lower yields of pulpwood sized timber. Although the difference in net revenue from the pine component marginally favored the intercropped plantation, the difference in product mix suggests that companies or individuals interested in diverse timber products may wish to consider plantation intercropping as one means of diversifying plantation timber yields.

Further study is suggested to quantify the biological effects of forest intercropping on component crops, with emphasis on intensively managed crops. Practical application is restricted to fertile, highly productive plantation sites capable of supporting both agricultural and forest crops.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Intensive forest management in the South is evolving along lines closely paralleling those found in modern agricultural management. For example, forest sites are often subjected to intensive preparation, such as disking and bedding. Seedlings are planted in a pattern that allows ready access to all parts of the stand. The site is fertilized to increase growth and yield. Competing vegetation is controlled with herbicides to reduce seedling losses and increase the timber crop yield. In all, many parallels are evident between forest and agricultural management practices.

Demand for greater productivity in future years will encourage the adoption of even more innovative management. Current methods that result in under-utilization of the site during the first five to ten years of stand life will be unacceptable. Alternative land use patterns will continue to encroach upon the forest land base, forcing more intensive use of the land available to industry. Increased land taxes will necessitate greater productivity from the forest site. Finally, population pressures could encourage production of food and fuel crops, in addition to current fiber crops, on forested sites.

One way to achieve greater returns and diversify production is through intercropping, a method by which two or more crops are grown simultaneously on the same site. The advantages of intercropping on forested sites can include increased site utilization during the early years of stand rotation, increased financial returns over the life of the stand, and diversified production. Potential products include vegetables, field crops, forage, and fiber in combination with timber and pulpwood crops.

Certain Third World countries, such as Nigeria, India, and Burma, use forest intercropping to alleviate problems associated with increased population and limited land availability. By combining forest and agricultural practices on the same site, these countries obtain both food and timber crops from forest sites. Under this technique, known as 'taungya,' agricultural crops are interplanted with tropical hardwoods on cut-over forest sites. Generally, the first food crop is harvested before establishing the plantation seedlings. Agricultural crops are then 'intercropped' or grown simultaneously with the timber until the two crops become incompatible. Taungya originally evolved as a means of providing more productive farm land in underdeveloped countries and can be used to diversify and increase the yield of tropical hardwood plantations.

While forest intercropping techniques extend throughout Asia and Africa the concept has gained little acceptance in the United States. However, intercropping appears to be a viable alternative to standard forestry practices, particularly when greater site utilization is desired.

Applied forest intercropping is generally restricted to sites configured in a plantation pattern, where other crops can be planted and harvested between the rows of trees. For this reason, intercropping is particularly suited to the southeastern United States which contains over 5.34 million hectares of plantation pine. Plantation establishment in the South is expected to continue into the 21st century, providing an even larger land base with which to work (Shartle, 1977).

Southern plantations possess two other qualities that make them suitable for forest intercropping. The intensive management required for intercropping can be introduced on southern plantations, particularly because these locations are usually subjected to similar management for timber production. In addition, plantation sites are accessible to equipment used for both agricultural and forest production.

Pine plantations could be used to support a variety of crops. For instance, legumes have been successfully intercropped with loblolly pine to increase soil nitrogen levels (Jorgenson, 1980; Haines et al., 1978). Forages have been interplanted with Monterey pine (*Pinus radiata*) to produce hay and silage on plantations in New Zealand without affecting pine growth (Tustin et al., 1979). In addition, Gordon and Dawson (1979) suggest that interplanting suppresses certain fungal diseases, such as *Fomes anonsis*. In tropical countries, agricultural crops, such as rice and casava, are intercropped with teak (*Tectonia grandis*) and gmelina (*Gmelina arboria*) seedlings (Alexander et al., 1977). Atkinson and Hamilton (1978) suggested that intercropping red alder (*Alnus rubra*) in conifer plantations in the West could be an economically feasible alternative to more conventional management.

The production of two or more crops on forested sites essentially increases the land area in production. The need for more land, particularly for agricultural production, is argued by Pimentel et al. (1976), who note that, within the past 200 years, 96 million hectares of land have been removed from agricultural and forest production. The financial returns from intercrop production occur early in the stand life, a feature which can reduce investment length.

Plantations in the South generally provide one return on investment every 15 to 25 years, depending on rotation age. Conversely, intercropping can produce returns early in the rotation which continue for several years. These revenues augment those provided by the timber crop and could increase the investment value of an intercropped stand beyond that provided from conventionally managed stands.

The intent of this study was to determine whether forest intercropping is biologically, operationally, and financially feasible on loblolly plantations in the Southeast and, if so, examine the impact of this management under a range of conditions, crop types, and management alternatives. The objectives of this research were threefold:

1. To characterize and discuss the ecological conditions that might affect intercropping on southern plantations,
2. To identify and discuss the different crops that could provide an economic return when intercropped with loblolly pine in a plantation setting, and
3. To conduct an investment analysis of selected intercropping combinations to determine if intercropping can be a means of increasing revenues from pine lantations.

REVIEW OF PERTINENT LITERATURE

Forest Intercropping Terminology

Since forest and agricultural intercropping rely on the same precepts, many of the terms used in one discipline are applicable in the other. For example, the term intercropping is usually defined in such a manner that it can be applied to both agricultural and forest situations. Willey (1979) defined intercropping as growing two or more crops simultaneously on the same site. Alexander and Kassam (1976) suggested that the cropping process intensifies in both time and space under this approach. In addition, intercrop competition often develops at some point during the intercropping period.

Several authors have attempted to define intercropping in terms of forest application alone. King (1979) used the term taungya, or agri-silviculture, to describe forest intercropping systems in Africa and Asia. The process was defined as a land management technique where a single section of land is deliberately used for the concurrent production of agricultural and forest crops. This definition essentially restricts forest intercropping to forest and agricultural crop components.

While appropriate for many Third World countries, industrial forest intercropping cannot depend on agricultural crops alone. Biomass, fiber, and fuel crops may be better suited for industrial intercropping, especially on southern pine plantations. In addition, conventional intercropping methods fail to consider the intensive management and planning required at the industrial level. Operational planning and coordination would be of greater importance on intercropped plantation forests than implied by the conventional definition.

A more appropriate definition of forest intercropping is needed, based on these considerations. Under such conditions, forest intercropping can be best defined as a situation where forest land is managed for the concurrent production of forest crops with one or more other crops in some non-random spatial pattern.

Agricultural intercropping terminology can, in some cases, be applied to forest intercropping. Several agricultural terms relative to forest intercropping are presented below (Andrews and Kassam, 1976):

Monoculture: Where one crop is grown on the same site repetitively, ie; where the crop is never changed.

Cropping pattern: The sequence and spatial arrangement of a crop or crops on a given site.

Cropping system: The cropping patterns used on a farm (or plantation) and their interaction with

> the resources, other enterprises, and available technology that determine their formation.

In particular, the term cropping system suggests that a distinct series of relationships exist between the crops being grown, the resources available on the site, and the technology available for the production process. These relationships are currently undefined in relation to forest intercropping concepts.

Historical Background

Blanford (1958) described an intercropping approach known as 'taungya' which provided agricultural products from the forests of Burma as early as 1856. The term, literally meaning 'hilly cultivation', originally described shifting cultivation practices that evolved into the agri-silvicultural approach used today. Taungya spread from Burma throughout Asia and Africa as an important means of providing food in land-poor countries. In fact, much of the plantation acreage in Asia and Africa was planted using the taungya system (King, 1979). Taungya may be based on the German system of 'waldfeldbau', a method of cultivating agricultural crops in the forest (Alexander et al., 1980). However, it is more likely that the Burmese system followed a unique evolutionary path to meet the needs of that culture.

Past studies on the effects of intercropping in the forest are generally restricted to tropical regions. Coster (1939) noted the occurrence of root competition in relation to taungya. An earlier study by Adam (1923) suggested a need for more information regarding the effects of agricultural crops on tropical tree growth. Ojeniyi and Agbede (1980) interplanted agricultural crops with gmelina (Gmelina arborea) on forest sites in Nigeria and found that food crops, particularly yam and corn, can be planted in a young forest plantation with little effect on soil conditions. Measureable (but non-significant) increases in soil nitrogen and phosphorous were noted, with a slight increase in soil acidity (pH).

Some research has been conducted using Monterey pine (Pinus radiata) intercropped with forage crops on plantations in New Zealand (Tustin et al., 1979). Similar levels of production on these sites under different spacing patterns suggest that forage yields are generally unaffected by tree spacing patterns. Ensilage yields averaging 19 tons per hectare and hay yields of 130 bales (individual bales weighing 20 to 40 kg) per hectare were reported for pine row spacings of 5 and 7 meters. The intercropped sites were restricted to flat or slightly rolling terrain, due to the operating limits of the agricultural equipment. Borough

(1979), discussing the New Zealand research, stated that "the 6-7 m row spacing" was necessary for forage harvesting machinery access and to accommodate fertilization equipment. Only 8% of the plantation was left uncut to avoid damaging pine seedlings. The harvesting process is illustrated in Figure 1.

Studies at the University of Missouri using an approach termed multicropping (where several crops are managed on the site over a single rotation) with black walnut (*Juglans nigra*) suggest that the principal benefit from integrating two or more crops on the same forest site simultaneously might be the earlier financial returns provided by the intermediate crops (Garret and Kurtz, 1980). Black walnut was grown in combination with one to four separate agricultural crops under four cropping alternatives. These alternatives included:

Alternative	Cropping System
A	Black Walnut and Grazing.
B	Black Walnut, Fescue Seed and Hay, and Grazing.
C	Black Walnut, Soybeans, Winter Wheat, Fescue Seed and Hay, and Grazing.
D	Black Walnut, Soybeans, Winter Wheat, Fescue Seed and Hay, and Fescue Hay.

Figure 1: Forage harvesting on an intercropped radiata pine plantation in New Zealand.

Nine different management options were considered for each alternative, based on variations in land quality, rotation length, timber growth rate, and thinning regime.

Wide spacing patterns, ranging from 3 x 12 to 12 x 12 m, were able to accommodate the operating equipment used for agricultural cropping. A direct correlation was detected between financial return and degree of management intensity for the systems studied. Thus, the more intensively managed systems (alternatives C & D) had higher rates of return than the less intensively managed systems. Another significant factor was site quality, with better sites providing greater returns, even though rent for these sites averaged $41 more per hectare.

Nurse Crops

A silvicultural technique known as nurse cropping parallels many of the principles incorporated in intercropping. Nurse crops are generally interplanted on pine or hardwood plantations to improve seedling survival and/or to increase seedling growth. Nurse crops, unlike intercrop plants, are not harvested and do not have a direct economic value. However, nurse cropping incorporates many of the techniques needed for successful intercropping. Site preparation, planting, and spacing considerations are all critical for the success of nurse crops, as they are for intercrops. Some common nurse crops, particularly alder (*Alnus spp.*) and clover (*Trifolium spp.*), have economic potential as intercrops.

Jorgenson (1980) interplanted legumes as nurse crops on forest sites in the Southern United States and found that some legumes, particularly lespedeza, can be established on forest sites with little site preparation. In addition, surviving plants were capable of fixing nitrogen from the atmosphere in quantities that could enhance tree growth. Studies in New Zealand with tree lupine (*Lupinus arboreus*) interplanted with Monterey pine (*Pinus radiata*) indicated that the lupines can fix nitrogen at rates up to 40 kg/ha/yr (Bengtson, 1978).

Newly established sycamore (*Platanus occidentalis*) plantations in Alabama were interplanted with two clover species, sub clover (*Trifolium subterraneum*) and crimson clover (*Trifolium incarnatum*). These legumes provided some measure of weed control, improved the foliar N level of the sycamore, and generally improved tree growth on the site (Haines et al., 1976). Loblolly pine seedlings intercropped with three clover species on a well drained site in the Upper Coastal Plain of Georgia did not respond as well. The clovers were established on the site one year prior to planting the pines. Using total pine height as a measurement criterion, no significant difference was detected between the interplanted and control sites. Foliar nitrogen levels for the interplanted pines were significantly lower than those for pines in the control plots (Haines et al., 1978). Clover yield from the intercropped sites was promising, particularly on fertilized plots. Crimson clover yield averaged 6000 kg/ha/yr, while subterranean clover provided 3300 kg/ha/yr on well established sites. Arrowleaf clover (*Trifolium vesiculosum*) overtopped pine seedlings for an extensive part of the growing season, resulting in a pine seedling survival rate of 63%. Seedlings interplanted with crimson clover had a survival rate of 89.8%, greater than any of the other interplantings. The results suggest that crimson clover and subterranean clover are particularly suited as intercrop plants for loblolly plantations.

Goncalves and Kellison (1980), reporting on the potential of European black alder (*Alnus glutinosa*) as a nitrogen-fixing nurse crop in the South, suggested that this species could be used as a short rotation crop in mixed stands. The advantage of this mixed species approach include increased soil nitrogen levels and additional revenues from harvested alder. However, recent studies in North Carolina indicate that black alder growth significantly declines after 4 or 5 years, particularly on tightly spaced stands (Frederick, 1984).

Gordon and Dawson (1979) stated that woody nitrogen fixing plants provide two commercially valuable products; high per hectare biomass yields and a nitrogen component provided through atmospheric fixation. Two systems were proposed for combining commercial forest plantations with nitrogen fixing woody plants:

1. A system using nitrogen fixing plants as the only or a major component of the final crop. This would include the practice of sequential cropping, as well as any situation where the nitrogen fixing crop could be sustained on the site until harvest with the timber crop.

2. A system where nitrogen fixers are planted as nurse crops and removed early in the rotation. This approach is oriented to a lower final yield from the site, but also to a lower level of management input during the rotation.

Woody-plant agrisystems were suggested for species like alder and poplar using completely mechanized harvesting, transport, and handling methods to produce fuel and fiber in commercial quantities. Studies by Tarrant and Trappe (1971) and DeBell (1975) support the conclusion that poplar-alder interplantings have great potential under this system.

Black alder interplanted with pines and hardwoods on strip mine sites in Eastern Kentucky increased the average tree height from 4 to 50%. Mortality for all species was high, as evidenced by a 48% survival rate for loblolly seedlings (Dale, 1963). In a similar study, Plass (1977) interplanted black alder with loblolly pine using a 4.5 x 4.5 m spacing (for pines) on strip mine sites near London, Kentucky. Pine survival on these sites ranged from 52% for the first year to 35% for the tenth year). Non-significant diameter and height growth increases were also recorded for the intercropped loblolly pines.

The strip mine planting studies suggest that poor seedling survival of loblolly pine occurs when interplanted with alder. However, the low survival rates are better explained by the poor quality of the study sites. As noted by Brender (1973), loblolly pine is extremely sensitive to differences in site quality. Other studies that have intercropped loblolly pine with various types of clover report good survival rates on better plantation sites, suggesting that site quality is at least as important as the type of intercrop being considered (Haines et al., 1979; Jorgenson, 1980).

Economics of Intercropping

Industrial intercropping as an investment must be judged on the costs and returns associated with its use. Rottink et al. (1979) stressed this fact and proposed three criteria for measuring the financial potential of intercropping systems. First, the financial rate of return from interplanting must exceed the minimum level set by the company. Second, the necessary amount of investment funds must be available to fund the project. And, finally, the intercropping investment must compare favorably to other investment alternatives available to the company.

One of the few available financial analyses of an intercropping system was provided by Atkinson and Hamilton (1978), who compared three stands of harvestable timber on the Wind River experimental forest in Washington. Interplanted Douglas-fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) provided less net revenue than a pure stand of Douglas-fir fertilized at age 40 with a difference of $13.35 per hectare in net present value favoring the pure Douglas-fir stand. Planting costs of $56.66 per hectare for the red alder tended to bias the returns in favor of the fertilized stand.

Agricultural Intercropping

Agricultural intercropping experiments have been conducted in this and other countries with mixed results. Corn (*Zea maize*) soybeans (*Glycine max*), sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*), and sugarcane (*Saccharum officinarum*) are some of the more popular crop plants subjected to intercropping research. Crookston (1976) summarized some of the work being done in North America, particularly work on intercropping cotton for insect control. A Canadian study of sunflower-corn interplanting showed that intercropping sunflower with corn reduced the yield from these crops and, consequently, total expected per hectare production (Warren, 1980). Intercropped corn and sugarcane yields from plantations in Mauritius were generally unaffected by intercropping (Pillay and Mamet, 1978). Soybean nitrogen fixing rates, when intercropped with sorghum, were significantly reduced on intercropped sites (Wahua and Miller, 1978).

Several researchers have developed methods for quantifying the yield advantages from intercropping. Willey (1979) constructed an equation for comparing intercropped and monoculture yields to determine the efficiency of intercropping two (or more) crops. The equation uses a variable termed the 'land equivalent ratio' to quantify the yield advantage of one approach over the other. The land equivalent ratio, or LER, is defined as the relative land area required for sole crops to produce the same yield provided through intercropping. The mathematical expression of the LER is;

$$LER = La + Lb = (Ya/Sa) + (Yb/Sb)$$

where;
La,Lb = LER's for individual crops.
Ya,Yb = Individual crop yields from intercropping.
Sa,Sb = Individual crop yields from monoculture crops.

In a practical sense, the LER quantifies the relative advantages in yield of intercropped sites over monocropped sites. This is achieved in an uncomplicated, easy-to-understand manner by comparing yields using a simple ratio approach. If, for example, the LER for a corn-sorghum interplanting is equal to 1.20, the intercropped planting provides 20% more corn plus sorghum per land area than monoculture plantings of corn and sorghum. This concept, although developed for agricultural research, can be used in forest intercropping research with no modification.

The LER concept was discussed further by Mead and Willey (1980) who proposed the use of standardized sole crop yields to calculate the land equivalent ratio. Willey and Rao (1980) extended the utility of the LER concept by introducing the competition ratio (CR) value. The CR value is simply a ratio of the LER values for the intercropped plants, corrected for the initial planting proportions. The equational form of the CR value is;

CRa = (La/Lb) * (Zba/Zab)

where;
La,Lb = Land equiv. ratios for crop a or b.
Zba, Zab = Proportion of intercropped area initially allocated to crop a or b.

The CR value is useful as a means of quantifying the effects of intercrop competition on the yield of an individual crop. If the CR value for a crop is exactly equal to one, there is no apparent intercrop competition. This ratio, like the LER, is easily adapted for use in forest intercropping research.

Andrews and Kassam (1976) listed eight different multiple cropping[1] systems currently used in agriculture. Of these, four can be strictly defined as intercropping systems, including:

1. Mixed intercropping: Growing two or more crops simultaneously where no distinct row arrangement exits.

2. Relay intercropping: Growing two or more crops simultaneously during part of the life cycles of each crop. In this sense, a second crop might be planted after the first has reached its reproductive stage, but before it is ready for harvest.

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[1] Multiple cropping is defined as the intensification of cropping in time and space dimensions by growing two or more crops on the same site in a year. Multiple cropping incorporates both sequential (where crops are grown in a sequence over time) and intercropping methods.

3. Row intercropping: Growing two or more crops simultaneously with one or more of these crops planted in rows.

4. Strip intercropping: Growing two or more crops simultaneously in different strips wide enough to allow independent cultivation, but narrow enough to interact.

Mixed intercropping is not viable as a forest intercropping pattern, since the random pattern does not accommodate mechanized operations. In contrast, relay intercropping has no real parallel in forest intercropping terms. The tree crop, due to its extensive rotation period, precludes the concept of relayed planting.

Row and strip intercropping patterns are oriented to a more structured management and can accommodate production operations. There are instances where strip cropping would be preferred over row cropping, as exemplified by corn (Zea mays) which requires a concentration of plants within a certain distance to achieve proper pollination. These two cropping patterns were used extensively in this study because of their adaptability to a variety of management and operational approaches.

Cultivation Studies

Cultivation on pine sites is generally limited to rough discing to remove herbaceous competition and loosen the soil. The practice is not common, although at least one study noted several advantages including early tree growth, increased weed control, and fewer fire hazards on the site (Hughes, 1965). Cultivating slash pine (*Pinus elliottii*) plantations in Georgia increased tree growth, but this growth was offset by insect infestation and disease. Specific problems with southern fusiform rust (*Cronartium fusiforme*) and pitch moth (*Dioryctria amatella*) were noted (Lewis et al., 1972). Cleaned and cultivated loblolly pine plantations have shown significantly greater juvenile growth when compared with stands intercropped with clover (Haines et al., 1978). These advantages would probably be evident on intercropped plantations where agricultural tillage and cultivation is required.

Prospects for Intercropping Systems

Three distinct management problems associated with forest intercropping were cited in a recent New Zealand study (Tustin and Knowles, 1974). Conservatism, lack of management expertise, and financial restrictions were considered major barriers to the acceptance of intercropping in New

Zealand. A concerted effort was suggested to educate managers and dispel prejudices associated with managing pine plantations for products other than timber. Financial and marketing constraints also hindered establishment of industrial intercropping systems in the country.

Similar attitudes and constraints will probably be encountered in this country. Only through education and proper development can forest intercropping be accepted as a valid approach to forest management in the United States.

SITE AND PLANT CHARACTERISTICS RELATIVE TO FOREST INTERCROPPING

Forest Site Considerations

The site factors to be considered prior to establishing an intercropped pine plantation range from the more obvious, like terrain conditions, to complex factors, such as the effect of site history on intercrop management. The more critical factors are detailed and discussed in this section to illustrate conditions that generally favor the establishment of intercropped forest sites in the South.

Site Type

A number of studies have discussed the differences between 'old field' and cut-over sites (Brender, 1973; Daniels and Burkhart, 1975; Wahlenberg, 1960). That these two site types provide distinctly different environments for tree growth is indisputable.

Most planting in the Georgia Piedmont prior to the mid-seventies occurred on old field sites. These sites were preferred because of the reduced interference from root obstructions, logging debris, and heavy litter often found on cut-over tracts. Old field sites characteristically had greater (pine) site index values than cut-over sites. Average pine site index differences of nearly 10 feet favoring old field sites were noted by Brender (1973) in Georgia. Old field locations generally require less intensive site preparation than cut-over sites, because of the cleaner site conditions and lack of harvesting debris. The lack of debris, few natural obstructions, and high growth rates on old fields would be ideal for intercropping purposes.

Cut-over forests, which includes cut-over plantations and natural stands, are often littered with slash and stumps that must be removed prior to stand establishment. Stands composed of hardwoods require site preparation to eradicate stump sprouts and clean up slash that can remain on the site for several years. Conversely, slash from pure pine stands will often decompose rapidly, while most southern pines fail to produce stump sprouts.

Site Preparation for Intercropped Plantations

The degree of site preparation required for agricultural purposes generally exceeds that required for forestry. The same pattern of operation is used initially, but more expensive preparation, like root raking and contouring, are often required for agricultural soils to minimize erosion and reduce subsurface debris that might hinder tillage operations.

Available preparation techniques. Similar preparation methods are used for both agricultural and forestry purposes. However, agricultural sites receive more preparation prior to seedbed establishment than do forested sites. Techniques used for reforestation or agricultural production can include any combination of chemical, controlled fire, or mechanical preparation methods.

Sprouts and other herbaceous growth that might compete with seedlings for light and nutrients can be eliminated with herbicides. Popular herbicides available for chemical site preparation include Round-up, Lasso, Garlon, Tordon, and 2,4-D. However, chemical application cannot be used for complete preparation, since debris and other impediments remain on the site.

Controlled burning, used primarily for reforestation, is seldom utilized for agricultural site preparation. Although slash and debris are degraded, sprouts and buried seeds can be relatively unaffected by fire which leaves the site open to early competition problems (Kluender, 1983).

Conversely, mechanical methods are expensive, but remove operating obstructions and create a prepared seedbed that promotes crop growth and yield. Debris can be completely removed or left on site in varying concentrations. Subsurface material can be removed, broken up, or simply left alone.

The critical factors associated with mechanical preparation include the cost of individual operations and the effect these operations have on the site. Mechanical preparation is the most plausible method of site preparation for intercrop management. Similar mechanical techniques are used for both reforestation and agricultural crops and can include any of the following (Kluender, 1983):

1. Shearing: Where existing material and slash are destroyed and incorporated with surface litter. This operation is a first step that will be followed by more intensive clearing operations, like discing or piling. Large crawler tractors with specially designed blades are commonly used.

2. Chopping: This operation uses the chopping drum attached to a large crawler tractor or skidder to chop up slash and surface debris. Chopping incorporates this material into the soil to increase organic matter content and reduce the size of any surface debris.

3. Raking: The raking process uses a special rake to remove slash, debris, and other subsurface debris prior to piling and discing operations. The root rake can not remove stumps from the soil, but does break up most of the root network in the soil.

4. Piling: This procedure uses a crawler tractor with another specially designed blade to remove debris, slash, and other material from the soil surface. Removed material is deposited in piles, or windrows, where it either remains or is destroyed by burning. Piling can be the last step in the preparation process for reforested sites, particularly where debris is light.

5. Discing: The discing process involves a skidder or crawler tractor pulling a specially designed disc-harrow to break up the soil and some subsurface debris. Discing is another last step procedure, but can be followed by even more intensive preparation techniques. The disc-harrow is a larger version of discs used in agriculture for tillage operations.

Agricultural preparation techniques include all of those discussed above in addition to other methods that prepare the site for agricultural operations. These preparation techniques are, in most cases, considered too expensive for reforestation work and are generally confined to sites being prepared for agricultural cropping.

1. Stump Removal: Tree stumps are removed from the soil by crawler tractors or, more commonly, by loaders capable of lifting the stump out of the ground. Removing stumps produces soil problems by mixing the B and C horizon soil with the more organic A horizon. The large depressions caused by stump removal can require further preparatory work, such as contouring.

2. Secondary Raking: A second raking operation is desired for many agricultural sites to remove surface and subsoil debris. Secondary raking can remove large amounts of organic material from the soil and actually reduce site quality.

3. Subsoiling: Subsoiling operations are not always restricted to agricultural site preparation. Where compaction or poor drainage is evident on forest soils, subsoiling can be used to ameliorate drainage conditions. Special subsoiling plows are used to penetrate deep into the soil to reduce problems from plow pans. The soil is furrowed rather than plowed, leaving the soil relatively intact around the opened furrow.

4. Sifting or Sieving: This operation is generally restricted to intensively tilled agricultural sites requiring complete removal of subsoil debris prior to tillage operations. Lower Coastal Plain sites having high organic matter content (muck soils) often re-

quire sifting to remove buried tree slash from below the soil surface. Sifting is perhaps the most intensive and expensive agricultural site preparation method.

5. Contouring: Contouring is one of the last operations performed prior to seedbed establishment. The soil is contoured to remove depressions or barriers to later operation. It is required where stump removal has seriously disturbed the soil contours. Standard crawler tractors with shaping blades are used to produce an even contour on the site.

Preparing plantations for intercropping. The goals of site preparation on forested sites are threefold (Crutchfield and Martin, 1982):

1. Remove obstructions to planting,
2. Control competing plants, and
3. Improve the micro-site for each seedling.

These goals can be expanded for intercropping purposes to include the removal of obstacles to crop tillage. For sites previously supporting timber, this added goal is expensive. The major deterents to cropping on previously forested sites are slash and stumps. Stumps, unlike slash, are difficult to remove, cause mixing among the soil horizons when removed, and create depressions that impede equipment operation. However, if the site is to be intercropped, stumps must be removed economically and without damaging the site.

Equipment that can remove stumps economically and with little soil damage have been designed by the Rockland Mfg. Company of Bedford, Pennsylvania. The unit, known as the

Rockland Roto-Lifter, was tested by the American Pulpwood Association for harvesting plantation-grown pine stumps. When pulled behind a 120 h.p. tractor, the unit can achieve production rates of 0.4 to 0.8 hectares per hour. Figure 2 shows the unit in field operations.

Stumps can be removed from harvested pine plantations using the Roto-lifter. However, natural stands of randomly located trees cannot be effectively treated with this unit and require more expensive, time consuming methods to clear the site of stumps.

The degree of preparation required for agricultural or reforestation purposes vary based on a number of factors. Site characteristics, such as prior vegetation and subsoil conditions, are important in defining the level of preparation required. So, too, is the end use of the site. Agricultural preparation is oriented to more intensive operations than reforestation. Cost restricts the degree of site preparation by limiting the number of operations that can be economically performed.

The economics of site preparation for intercropping differ from that for forestry. Added costs associated with cropping will be incurred when preparing a site for forest intercropping. This added cost must be recouped through the revenues provided by intercrop production. Otherwise, tim-

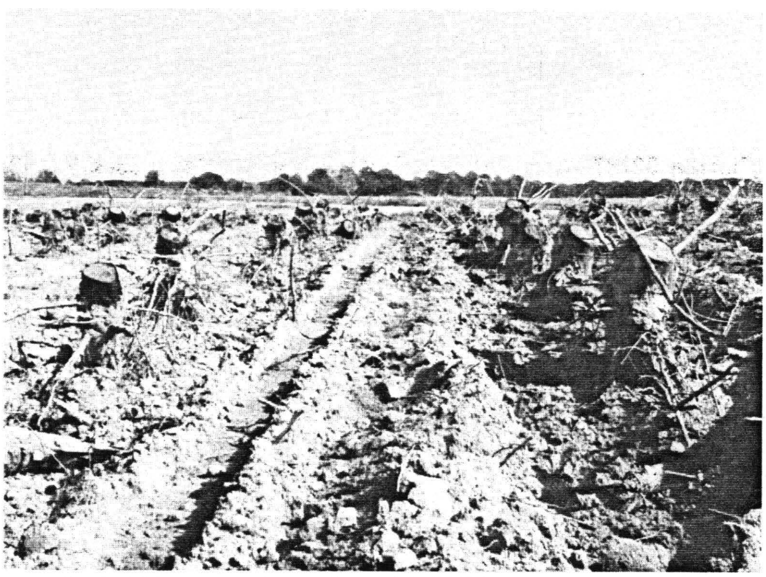


Figure 2: The Rockland Roto-Lifter removing stumps from a recently harvested plantation site.

ber revenues subsidize these costs and reduce the net gain from the site to a point lower than that provided by a monocrop of pine. A balance must be struck between the desire to intensively prepare the site and the cost associated with doing so. Several factors affect the cost and degree of site preparation for intercropped plantations, as illustrated in Figure 3.

Regeneration Methods

A stand can be regenerated naturally or through the use of artificial methods. Seedlings in a naturally regenerated stand have a relatively random placement that hinders intercropping. Artificial methods include both direct seeding and planting. Direct seeding produces a stand comparable to naturally regenerated stands in terms of seedling placement. Conversely, planting can produce oriented seedling rows that facilitate the intercropping process. In addition, planting restores the site to a productive capacity more rapidly, provides better control over the spatial pattern and more consistent stocking throughout the stand.

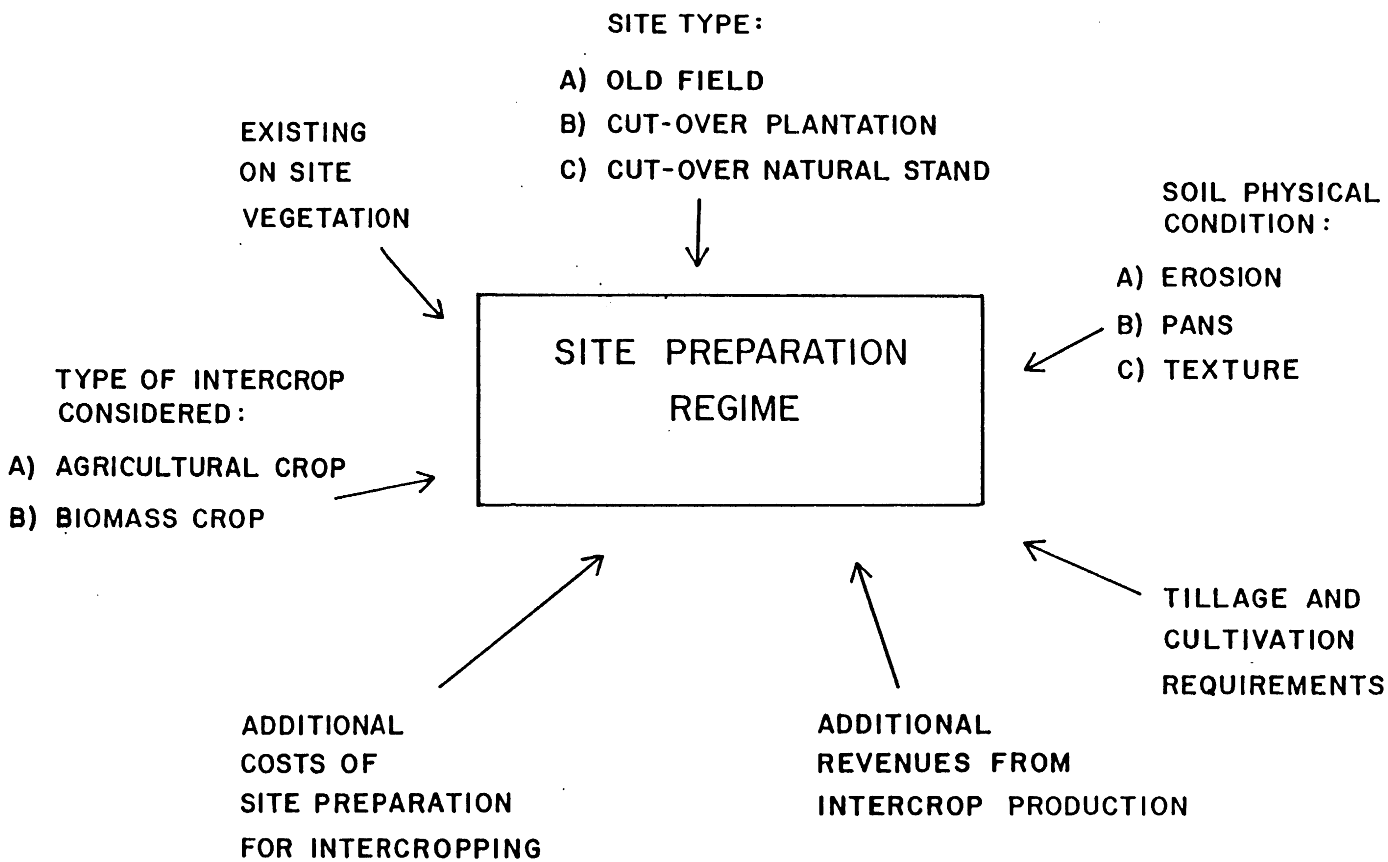


Figure 3: Factors that affect preparation intensity on intercropped forest sites.

Soil-Site Factors

Very little research exists identifying or discussing the critical soil-site factors relative to forest intercropping. Available studies identified factors relative to general forest productivity (Ralston, 1964; Broadfoot et al., 1971; Carmean, 1975). Soil variables considered important in these studies include:

1. Physical condition of the soil: influenced by parent material, past use, preparation, and soil texture.

2. Nutrient availability: influenced by past use and parent material.

3. Moisture availability: influenced by soil physiography, water table depth, and past use.

4. Soil aeration: influenced by past use and internal drainage.

Soil physical conditions. Soil conditions such as compaction, erosion, poor soil structure, poor texture, and pans reduce site productivity by affecting plant rooting habits and soil permeability. These conditions can sometimes be altered through site manipulation, but only at great expense. Old agricultural fields, while preferred from a management standpoint, often contain a plowpan that reduces productivity. Specific preparation (plowing, subsoiling, discing, etc.) is needed to alleviate these problems before intercropping.

Coile (1952) found that productivity on southern sites can be affected by soil texture. Studies in the Piedmont and Coastal Plains of Virginia, North Carolina, and South Carolina showed that sandy soils in these regions had a lower site index than other soils tested. In contrast, clayey textured soils consistently had higher site index values, even when poorly drained. This association is not confirmed for intercropped sites, but the findings do suggest a general correlation between plant productivity and soil texture.

Nutrient conditions. Pure pine stands in the South characteristically develop an organic horizon that holds nutrients in the fragmented layer. Studies by Metz et al. (1971) indicated the presence of high concentrations of nutrients in the fragmented organic layer of soils under loblolly pine stands in the Virginia Piedmont. A summary of these findings is presented below detailing the average weight of nutrients in the litter under 19 loblolly stands:

Litter Layer	*Nutrient Level (kg/ha)*				
	N	P	K	Ca	Mg
L (litter)	28	2	4	17	4
F (fragmented)	178	13	10	65	9
H (humus)	59	4	4	20	3

(From Metz et al., 1971)

Decomposition of pine litter slows appreciably in the F layer where nutrients accumulate reducing growth potential on the site. Conversely, hardwood litter reduces to a humus state more rapidly, making nutrients accessible to plants. For this reason, deciduous forests can provide more nutrients through litterfall than most coniferous forests, as much as two times the nitrogen and four times the calcium as pine litter over the same period (Broadfoot et al., 1971; Metz, 1952).

Regional nutrient problems are prevalent in the Coastal Plain w here sandy soils are subject to phosphorus deficiencies. caused by acid quartz sands too poor in phosphorus to support normal tree growth. Sandy Coastal Plain forest lands converted to agriculture often require more intensive phosphorus fertilization. Alley and Bertsch (1979) tested the hypothesis that large phosphorus applications could counter the slow mineralization rates characteristic of these soils and lead to increased agricultural yields. Tested sites responded most favorably to phosphorus applications ranging between 225 and 500 kg per hectare. At these rates, field corn yields averaged between 6.9 and 9.4 Mg per hectare in the first growing season, significantly greater than the 2.5 Mg per hectare yields from sites not fertilized with phosphorus. Phosphorus is definitely a major limiting soil nutrient that standard fertilization practices can not correct soil nutrient that takes proper applications and a long time to correct on some Coastal Plain forest soils.

Nitrogen, the other limiting nutrient in most southern forests, is usually available in enough quantity to ensure pine seedling growth. Intercropping on pine plantations will, in many cases, require additional nitrogen to stimulate crop production.

Because the forests and fields most available for intercropping are nutrient deficient, fertilization and soil amelioration may be standard operations during the intercropping period. For this reason, fertile sites are preferred for intercropping to reduce the cost and effort of enhancing soil nutrient conditions.

Moisture conditions. Tree growth is controlled more by moisture than any other site related factor (Pritchett, 1979). Soil moisture availability depends on topographic position, depth to water table, flooding frequency and duration, rainfall, and soil moisture characteristics of the site (Broadfoot et al., 1971). Management efforts to alter these conditions are generally confined to drainage and irrigation.

Drainage can produce growth response in pines at distances of 180 m from the drainage point. In one study, pines on well drained sites yielded over 1000 percent more wood than those on undrained locations. Results of the study are summarized below:

Distance from Canal (m)	Average DBH (cm)	Average Height (m)	Yield (m^3/Ha)
52.0	15.0	12.5	261.1
131.0	12.7	8.8	133.4
207.0	11.7	8.8	87.0
undrained	7.6	5.2	18.2

(From Miller and Maki, 1957)

Yield increases ranging from 84 to 696% have also been reported in three other Coastal Plain studies (Klawitter and Young, 1965; White and Pritchett, 1970; Brightwell, 1973). The adaptation of coastal wetland sites for intercropping purposes is possible through drainage. Close proximity of water table levels to the surface encourages flooding even on drained sites during wet periods, leading to possible damage and loss of intercropped plants. For this reason, drained sites involve greater financial risk and are viable only where the crops are relatively impervious to flood damage.

Irrigation is rarely used for forestry purposes, due to the great expense associated with the process. Most irrigation in forestry practice is limited to tree nurseries and seed orchards (Pritchett, 1979). Farm use of irrigation in the South is often restricted to high value crops like tobacco and then only when moisture stress threatens crop production.

Commonly irrigated crops are unsuited for intercropping, due to the cost associated with this process. However, irrigation may be unnecessary in the Southeast due to well distributed rainfall patterns.

Soil aeration. Soil aeration, predominantly affected by internal drainage characteristics of the soil and past use on the site, provides oxygen for plant roots and microorganisms in the soil. Poor aeration eliminates most of the gaseous oxygen in the soil and, as a result, encourages fermentation processes that can result in severe root damage.

Poor aeration, if not corrected, inhibits root growth and nutrient uptake while reducing plant vigor. Forest sites with poor aeration should not be used for intercropping unless the site can be improved through low cost management. Frequently flooded sites, like some found in the lower Coastal Plain, commonly exhibit poor growth as a result of aeration problems. Most of these soils can develop better aeration and increased growth capacity through drainage. As noted previously, yield increases of over 1000% have been recorded for newly drained sites.

Soil aeration difficulties can also develop from bad agricultural practices, particularly in the Piedmont region. Poor farming practices in this region have produced plow-

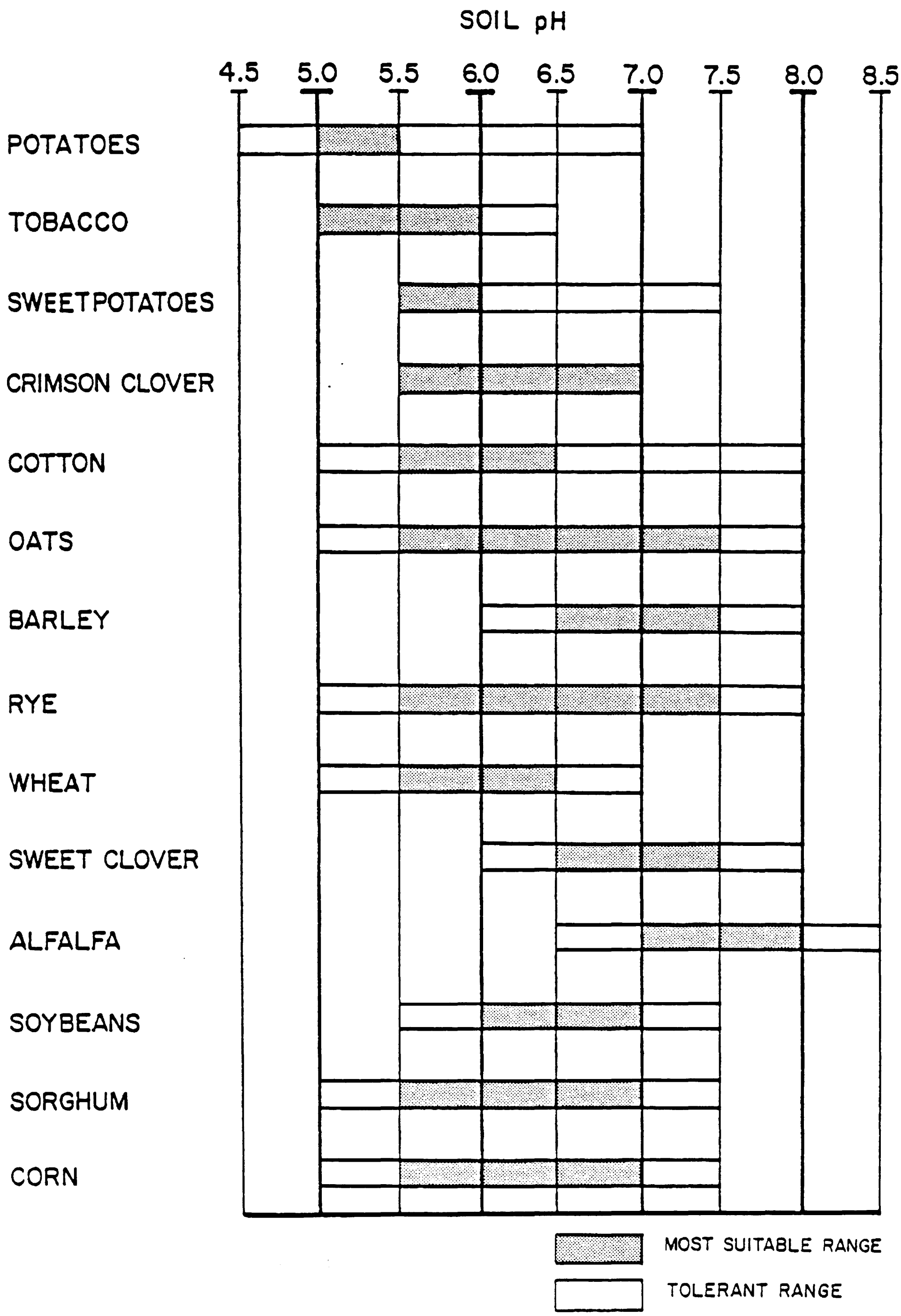


Figure 4: The pH suitability range of some major agricultural crops.

pans, erosion, and compaction on some sites. Management alternatives to alleviate these problems are limited to subsoiling and light tillage.

Soil pH. Many plants, particularly vegetable and field crops, are sensitive to extremes in soil pH. The optimum pH for crop plants (Figure 4) generally ranges between 5.5 and 7.0. Therefore, the soil pH of proposed forest intercropping sites should fall within this range. Problems associated with plant growth on acid sites include reduced nutrient availability and toxic soil conditions from high concentrations of aluminum and iron. Nitrification (microbial oxidation of ammonium to nitrate) slows appreciably in acid soils, producing higher concentrations of ammonium and restricting the growth of plants requiring the nitrate form of nitrogen. Phosphorus availability is also restricted in acid soils, probably as a result of precipitation of insoluble iron and aluminum phosphates (Bohn et al., 1979).

Lime applications to increase soil pH may be necessary on forest soils, particularly those previously supporting pine crops. Available tables help determine the amount of limestone required to reach a specific soil pH, based on soil texture and existing soil pH.

The effect of liming on pine growth was studied by Gilmore (1978) on old fields in southern Illinois. Results indicated that intensive liming to increase pH decreases height growth rates for both loblolly and shortleaf (*Pinus echinata*) pines. However, height growth differences for loblolly pine after continued liming was less than four percent.

Subjective soil-site evaluation. A subjective approach to the evaluation of soil-site conditions for intercropping purposes was constructed using material presented by Broadfoot (1969). The information in Table 1 illustrates the wide range of soil-site conditions that might be encountered on potential forest intercrop sites.

Limited availability of quality soils that can be used for forest intercropping restricts its adoption to highly productive forest and unused agricultural land. An economic incentive exists for maintaining these lands in a productive fashion, since leaving them fallow is literally money foregone. And, although these more productive sites are not as common as low yield forests, enough acreage is available to justify any management increasing their productivity.

TABLE 1

A subjective guide to forest intercropping site evaluation.[1]

Variable	Factors of Influence	* Description of Best Site	Poorest Site *
Soil Physical Condition	Parent Material, Past Use, Morphology of Soil	Medium texture Good structure Porous Deep soil Loams	Coarse texture Clays Sands Erosion Compaction Hardpan
Available Nutrients	Past Use History, Parent Material	High O.M. content (> 2%) Thick A Horizon (> 16 cm) Moderate pH (5.5 to 7.0) Alluvial soil Young soil (> 50 cm deep)	Low O.M. content (< 1%) Thin A Horizon (< 5 cm) Extreme pH (< 4 or > 8) Upland soil Heavily leached Old soil
Available Moisture	Physiography, Water Table Depth, Past Use History	Under Normal Conditions; Soil is moist throughout growing season	Under Normal Conditions; Soil is dry much of the season or saturated for periods longer than two days
Soil Aeration	Past Use History, Internal Drainage	Unmottled to 18 inches, Bright soil color (red, brown, etc.) Good drainage	Grey soils, Mottled surfaces or other high water table indicator

[1] Adapted from Broadfoot, 1969.

Crop Plant Considerations

Competition

Competition between intercropped plants depends on the type of planting pattern and spacing used during establishment. At least two patterns, strip and row, are used in agriculture and could be adapted for forest intercropping purposes (Trenbath, 1976).

As seen in Figure 5, intracrop contact occurs most frequently under a planting approach similar to that illustrated in (A), while intercrop contact is more common under pattern (C) where alternate rows contain a different crop. In contrast, pattern (B) encourages different levels of inter- and intracrop contact for the interplanted crops. Different plantation community structures are possible that match the planting arrangement to the type of crop competition expected. Planting arrangements can be modified to reduce or favorably affect intercrop competition at the discretion of management.

Competition for light and space. Light, moisture, and nutrients control the extent of plant growth and, as a result, are often in short supply for plant use. When immediate availability of these factors falls below the combined demands of the plants being cropped, competition begins (Donald, 1963).

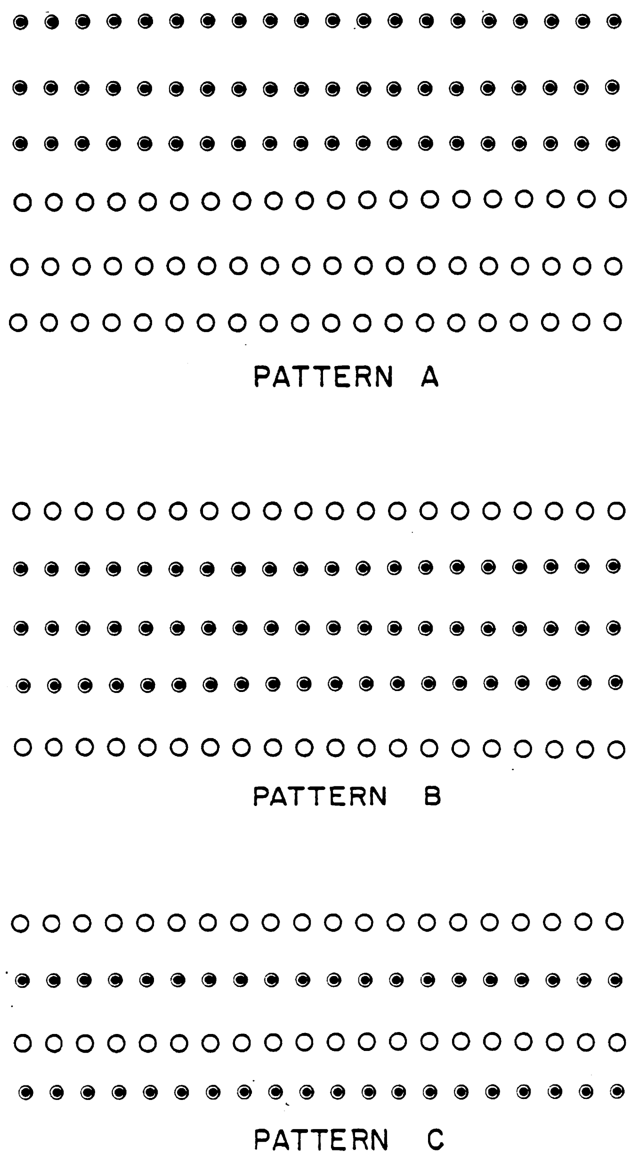


Figure 5: Potential intercrop planting patterns.

Although light competition is a problem on conventionally planted agricultural sites, it can prove to be even more difficult on intercropped plantations where the two crops may grow at significantly different heights. Serious shading could occur that eliminates one crop from the site. Extremely serious problems could evolve if the pines were over-topped and eliminated from the site.

Pine seedlings are most susceptible to damage from light competition just after establishment. After three years of growth, loblolly pine rarely exceeds 2.5 m in total height. In contrast, some agricultural crops, like corn, reach a height of 2.5 m in one growing season and can easily overtop and shade young seedlings.

After five to six years of growth, pines range in height from 3 to 6 m and become more capable of competing for light. Low growing interplanted crops become shaded and receive only low intensity light. In addition, the space allotted to other crops begins to diminish in proportion to the tree's lateral branch growth. At crown closure (between 10 and 15 years of growth), the trees begin to grow as a monoculture, making full use of the area previously allocated to other crops.

As intercropping yields diminish, the margin between gross revenue and the cost of production narrows. When the production costs equal gross revenue (i.e. a break-even point is reached), management should evaluate the situation and determine whether to plant another, less expensive crop or simply monocrop the pines.

In some cases, plants continue to produce in low light intensities. Biomass crops (i.e. sycamore, alder, and maple) can attain maximum height growth at 20 to 50 percent relative illumination (Treshow, 1970). Some forage grasses, particularly bermudagrass and bahiagrass, also persist under low light (Hart et al., 1970). Consequently, these plants could be intercropped where light intensities are too low to support other crops.

Loblolly pine, as a pioneer species, is very sensitive to shading. Shaded loblolly seedlings have a lower dry weight and smaller root-shoot ratio than unshaded seedlings (Wahlenberg, 1960). For this reason, crop plants that might overtop seedlings for even one growing period should be carefully managed or avoided. However, buffer strips can be used to ensure that both crops receive adequate sunlight.

Other methods that enhance light availability on intercropped sites include:

1. Correct orientation of crop rows to minimize shading by tall crops, ie. orient rows in an East-West direction (suggested by several studies; notably by Pendleton and Dungan, 1958).

2. Modify row spacing to provide more light over a longer period, thereby increasing the duration of the intercropping process.

3. Select appropriate plants to fit the situation; ie. where little light is available, select shade tolerant crops to plant with trees.

4. Limit competition for light by removing weeds that might overtop the crops and selecting low growing crops to interplant with the pine seedlings.

Competition for space, in the biological sense, is an exceptional occurrence (Donald, 1963). However, competition for 'operating space' is particularly critical on intercropped plantations. Operating space, in this sense, is the physical area allotted to the production equipment used for cropping. As crown closure becomes imminent, operating equipment is confined to smaller and smaller corridors. If these dimensions become too small, stand damage can result from cropping operations.

At least three alternatives are available for solving the problem of diminished operating space. Currently used machinery can be replaced with equipment of smaller dimensions; a different crop can be planted that uses equipment of smaller dimensions; or, finally, intercropping can cease on the site and the stand converted to a monoculture. In most cases, economic constraints will dictate the adoption of the least cost approach, where the site is simply converted to a monoculture of pines.

Competition for moisture and nutrients. The extent to which intercrop competition affects uptake of moisture and nutrients depends on the following factors:

1. The proximity of the roots of one intercrop to those of the other,
2. The rooting pattern associated with each intercrop,
3. The amount of moisture and nutrients available to plant roots during growth.

While proper spacing can minimize most intercrop root contact, plant rooting characteristics should be considered to further reduce intercrop root contact. Although root system modification is common, plants usually develop a genetically inherent rooting pattern. Taproots, heartroots, and plate roots are common tree rooting forms. Loblolly pine characteristicaly forms a taproot with smaller lateral roots extending out beyond the canopy dripline. Most of the fine roots used for mineral and nutrient uptake are located in the A horizon, with little penetration into the B and C horizons (Wahlenberg, 1960). Compacted soil can alter plant rooting structure by reducing depth of penetration and forcing the roots to develop more laterally. Poor drainage encourages shallow rooting and reduces the number of fine roots that develop. Conversely, plants on well drained soils develop deeper rooting structures to capture water from lower horizons.

At least one study has suggested that root competition is primarily restricted to two components, nitrogen and soil water. This hypothesis was proposed and tested by Kurtz et al. (1952), using corn intercropped with ten different forage plants. Study results generally supported the hypothesis that nitrogen and soil water are most critically competed for on planted fields. Analysis showed a marked increase in the growth of one crop at the expense of the other on nitrogen and water deficient fields placed in intercropping. Competition between the corn and grass crops decreased production of both, although corn production usually exceeded that of the gra s crop. However, even under non-competitive conditions, the production rates for intercropped corn and forage grasses were approximately 15 percent lower than when cropped separat ly.

Non-competitive Factors

Non-competitive factors include climate and growing season length. Both directly affect plant growth in a non-competitive manner, and neither is successfully modified by management efforts.

Plants not indigenous to a region are particularly susceptible to climate related problems. Extremes in temperature, the intensity of light, and the amount of rainfall in the region are important growth requirements that affect crop survival and production. Generally, plants used as intercrops should originate from the same (or a similar) climatic region. The simple rule of 'like with like' works best when dealing with climatic factors.

Because the Southeast is temperate, most plant growth occurs in the spring and summer months when moisture, light, and temperature availability peak. For example, average annual precipitation for the Piedmont and Coastal Plain of Virginia ranges from 109 cm in the Tidewater area to 115 cm in the lower Piedmont. Precipitation in North Carolina averages between 112 cm in the Piedmont to 128 cm along the lower Coastal Plain. Total rainfall between March and August in these states averages 66 cm in the Piedmont and 76 cm along the Coastal Plain. Virginia experiences drought conditions on an average of once every three years. These droughts are not state-wide, but occur regionally. Droughts are not as common in North Carolina, suggesting a slightly more stable climate (Anon., 1980).

Growing season length varies in the study region, from around 170 days in the Piedmont of Virginia to 296 days in the Coastal Plain of North Carolina. The Lower Coastal Plain of North Carolina can support two short-season crops, due to the relatively longer growing season. Temperatures are generally mild. Mean January temperatures range between 4.4° to 10° C, while mean July temperatures average between 24° and 27° C (Anon., 1980).

CLASSIFYING AND EVALUATING AVAILABLE CROPS

Classification Criteria

Plants in this study were grouped into several different classifications to simplify later analysis and provide a coherent structure to the different management alternatives available Four different groupings evolved based on management, end use, and crop value. These included:

1. Field crops: Crops grown for their seed or fruit which is used for both human and livestock consumption. This category includes the grains, the oil seed plants, and other crops, like sorghum, that are often managed as row crops.

2. Specialty crops: Crops with a high per unit value that require very intensive management. Crops in this category include tobacco, market vegetables, and peanuts.

3. Forage or pasture crops: This category includes all grasses grown for their leaf or plant parts through grazing or harvest. Typical forage crops include bermudagrass, alfalfa, and orchardgrass.

4. Biomass crops: Biomass crops can be used for fuel or fiber, depending on the need of the producer. Most biomass species are woody perennial shrubs or trees with rapid growth characteristics. Common biomass species include sycamore and cottonwood.

The study and,

consequently, the crops selected were restricted to those grown in the Piedmont and Coastal Plain regions of Virginia and North Carolina. Selection was initially based on the presence of market outlets for crops. Market existence was verified using information sheets provided by the Crop Reporting Services for these states. This criterion was relaxed if market potential existed in the study region. For example, many of the biomass crops are not marketable under current conditions. However, research interest in these crops throughout the South prompted their inclusion in the study. Crop production criteria, particularly soil pH and soil adaptability requirements, were used to further eliminate plants incapable of being cropped under forest conditions. Table 2 categorizes the crops considered in this analysis.

Field Crops

This category includes corn, sorghum, soybeans, and the small grain crops. Field crop production makes up a large portion of the agricultural yield in the United States. Most of these crops are classified as grains and used extensively for livestock and human consumption.

TABLE 2

Potential forest intercrop plants categorized by crop group.

Product Type	Crop Plant
Field or Row Crops	Field Corn
	Cotton
	Soybeans
	Sorghum
	Small Grains:
	Wheat
	Oats
	Barley
	Rye
Specialty or High Value Crops	Controlled Crops:
	Tobacco
	Peanuts
	Market Vegetables:
	Tomato
	Sweet Corn
	Cucumber
	Sweet Potato
	Watermelon
	Snap Bean
	Irish Potato
Forage Crops	Legumes:
	Alfalfa
	Clovers
	Sweetclover
	Lespedeza
	Trefoils
	Grasses:
	Orchardgrass
	Bermudagrass
	Tall Fescue
Biomass Crops	Black Alder
	Sweetgum
	Cottonwood
	Sycamore

Field Crop Characteristics

Dent corn (*Zea mays*). Field or dent corn grows as a tall, thick stemmed plant capable of producing between one and four 'ears' per plant. Individual plants can grow to a height of 3 m, but generally average between 1.5 and 2.5 m. Gross returns from one hectare of field corn averaged $578 in 1981 (based on a normal yield of 5.67 Mg per hectare), providing more gross revenue per acre than any other field crop grown in Virginia or North Carolina (Anonymous, 1982; Watson, 1982).

Nitrogen fertilizer is commonly applied to corn twice during the season, usually broadcast at planting and again later, as a side-band application. Phosphorus, the other critical soil nutrient in corn production, is usually applied at lower rates than those required for nitrogen. However, one study suggests that newly cleared sites require far more phosphorus than old fields. Alley and Bertsch (1979) found that newly-cleared sites were low in available phosphorus and required two to three times (500 to 675 kg per hectare in phosphate form) as much of this fertilizer as existing fields to attain normal corn yields. Acidic soil, while not the ideal environment, does not significantly affect corn yield until pH falls below 4.5, although a range between 5.5 and 6.0 is best for yields.

Spacings average 0.75 to 1 m between rows and 20 to 35.5 cm within the rows. A minimum between-row spacing of 75 cm is needed to accommodate mechanical cultivation.

Dent corn is suggested for use as an intercrop with some reservation. The crop commonly grows to 2.5 m in height and could shade pine seedlings during the latter part of the growing season. Large amounts of nutrients and moisture are required for adequate yields, again suggesting the possibility of competition during the growing season. If sufficient quantities of light, moisture, and nutrients are available, the crops should produce well together. If not, one or both crops could suffer production losses. The decision to intercrop corn with pines should be made judiciously with consideration given to site quality, nutrient availability, and moisture availability.

Soybeans (Glycine max). The soybean is shrub-like, ranging from 0.3 to 1 m in height. Soybeans grow best on nearly neutral soils with crop production dropping significantly under acid conditions. Soil pH should range between 6.0 and 7.0 for maximum yields. Fertilization requirements are low relative to most other field crops. As a legume, the soybean requires little nitrogen. However, phosphorus and potassium are necessary for proper growth and yield.

Plants are usually spaced in rows 0.5 to 1 m apart to facilitate cultivation and harvesting. Because weeds easily overtop soybean plants early in the season, the field is cultivated soon after planting. Cultivation continues until the plants are better able to compete for light and nutrients.

Soybeans are profitable, providing a gross revenue per hectare of $427 on soils yielding an average of 1.6 Mg per hectare (Anon., 1982; Watson, 1982). The soybean is suited for intercropping on many sites, except those with moderate to highly acid soils. On sites that can adequately support this crop, plantation intercropping with soybeans bear consideration as an economical investment.

<u>Cotton</u> (*Gossypium hirsutum*). The cotton plant is an herbaceous, long season crop that provides raw fiber used primarily for the manufacture of cloth. The climatic conditions favorable to cotton growth include a mean annual temperature of 10° to 15° C, a growing season of 180-200 days, and 50 to 190 cm of seasonally distributed rainfall. Soil fertility is not a critical factor, with good growth reported on even moderately fertile soils. In addition, cotton adapts to pH ranging from 5.0 to 8.0. Liming rarely increases growth, unless the soil pH falls below 5.3. Cotton plants have a characteristically long taproot, extending 90

cm into the soil by harvest. Plant height ranges from 60 to 150 cm. Continuous cropping is generally deleterious to soil fertility and can reduce yields by as much as 225 kg per hectare annually (Martin et al., 1976).

Spacings of .9 to 1 m are common between rows, while between plant spacings range from 7 to 20 cm. Conventional tillage is a common method of weed control, although herbicides are used extensively. Irrigation may be required, since cotton plants use up to 100 cm of soil water during production.

Cotton is harvested almost entirely by machine, either with pickers or strippers. Pickers remove cotton fibers from the opened bolls, while strippers snap off opened and unopened bolls from the plant. Prior to harvest, plants are treated with dessicants or defoliants to eliminate leaves and trash. Harvested cotton is taken to cotton gins to separate lint from the hulls and remove any remaining trash.

Intercropping cotton on pine plantations is possible. Fertility and soil pH requirements are not stringent, nor would the plant grow tall enough to suggest intercrop competition. However, on sites with moderate soil water availability cotton should not be considered, unless irrigation is possible. Crop rotation with winter legumes may be necessary to counter soil fertility problems, particularly when the plant is intercropped for several years. Harvest operations are generally compatible with the forest site when spacing adjustments are made. Custom harvests may be more economical, depending on the acreage intercropped and the number of cotton rotations being considered. Finally, cotton is restricted commercially to the lower Tidewater region of Virginia, although large acreages in North Carolina support the short season varieties.

Sorghum (*Sorghum vulgare*). Growth requirements and restrictions for sorghum are similar to those specified for corn, except that sorghum requires less nitrogen and soil moisture for good yields. Sorghum is also capable of slowing growth during dry periods, recovering when soil moisture becomes more available.

Sorghum is planted in rows 0.5 to 1.0 m apart using conventional planters adapted for dispersal of the sorghum grain. Weed control with conventional tillage equipment can require up to four cultivations prior to harvest. Chemical weed control is not suggested since sorghum plants are fairly susceptible to damage from these chemicals. The mature plants are harvested using a combine when a grain moisture content of 13% is reached. If the grain is harvested prior to this, provisions must be made for drying the grain (Martin et al., 1976).

The low per hectare value of sorghum as a field crop reduces its potential as an intercrop. The gross revenue for sorghum harvested for grain averaged $271 per hectare in 1981, placing this crop behind corn, wheat, and soybeans in profitability (Anon., 1982; Watson, 1982). Other difficulties include the uncertainty associated with establishing a stand and the necessity for prompt harvesting. Sorghum might make an ideal intercrop on dry sites where corn, wheat, and soybeans are not feasible, but should not be considered for highly productive sites capable of supporting more valuable crops.

Small grains. The small grains include wheat (*Triticum aestivum*), oats (*Avena sativa*), barley (*Hordeum vulgare*), and rye (*Secale cereale*). Generally, small grains grown in Virginia and North Carolina are planted in the fall and mature in early summer. Operations involved in production are similar among the small grains and include discing, harrowing, and fertilization. The need for plowing depends on soil water availability and the quantity of plant debris on the site. The amount of seedbed preparation and cultivation required for these crops is significantly lower than that required for crops planted in spring and harvested in the summer.

Barley is the most incompatible of the four grain types, due to its low productivity on acid soils that prevail over much of the South. The crop performs well on slightly acid to neutral soils, but yields decline significantly when the soil pH drops below 6.0. Studies also suggest that barley grows poorly on heavy, poorly drained soils or light, sandy soils that produce erratic growth rates (Martin et al., 1976).

In contrast, oats survive and produce on poor quality sites that will not support other small grains. Oats grown in Virginia and North Carolina are either fall or spring sown plants that range from 0.5 to 1.5 m in height. The plant thrives on well-drained loams or silt loams with a pH ranging from 5.5 to 7.0.

Oats require little preparation beyond discing and harrowing for establishment. Broadcast seeders or drills can be used for planting. Oats are sensitive to herbicides, particularly 2,4-D, and can be injured on soils where atrazine has been used the previous season. Approximately 95% of all oats harvested for grain are threshed using a grain combine. Oats are the least difficult of the small grains to harvest and thresh (Martin et al., 1976).

Demand and, consequently, production of oats in the United States declined with the replacement of work or draft animals by gasoline and diesel powered machinery. In addition, other crops used for feed are now capable of exceeding oats in per hectare yield. Gross returns from a hectare of oats range from $87 in Virginia to $103 in North Carolina, comparatively lower than other crops (See Table 4). There is some question as to whether the per hectare value of oats can justify intercropping on plantation sites.

Rye is a minor cereal crop used more often as a cover crop in the study region for no till corn and soybeans. There are a few biological problems associated with rye production. However, like oats, the revenues from this crop are probably too limited to justify intercropping with pine.

Wheat, on the other hand, generates per hectare revenues that could provide substantial returns under an intercropped setting. For example, one hectare of wheat grown in North Carolina in 1983 provided a net return of $128 (Neuman, 1983).

Wheat requires a fertile mildly acid (pH= 5.5 to 6.0) soil that has been prepared with a disc or springtooth harrow. Wheat is a winter annual crop that can be planted as late as October and harvested in late June or early July. Nitrogen fertilization is frequently necessary at rates up to 135 kg per hectare. Weed control is facilitated by herbicide application before and after planting. Post-emergents can be applied when the wheat grows to 10 or 15 cm tall. Mature wheat is generally unaffected by herbicide applications (Martin et al., 1976).

The advantages of producing wheat as an intercrop include the potential for greater financial returns, reduced tillage requirements, and the presence of an established market. In addition, wheat is harvested with equipment capable of harvesting other crops, like corn and soybeans, with little modification.

Site Preparation Requirements

Site preparation intensity for intercropped plantations producing field crops will certainly exceed that required for conventional plantations. The soil surface should be free of debris, slash, and stumps that impede crop production. As noted previously, the intensity of these seedbed preparation efforts will depend largely on the past site history and the type of crop being grown. Most field crops require a clean surface for equipment travel. Subsoil conditions may vary, however, depending on the type of tillage system used. Adoption of certain methods, particularly no-till, could reduce the extent and cost of preparation required below the soil surface. Conventional tillage will certainly require some cleaning of the A and B horizons on cut-over plantation sites, although this operation could probably be avoided on old fields.

Tillage Methods

Two alternatives, the conventional and reduced tillage systems, can be used for field crop tillage. Conventional systems typically place more emphasis on complete tillage, while reduced tillage methods emphasize less mechanical tillage and more herbicide cultivation.

Conventional tillage. Conventional row crop management usually consists of four separate operations that serve to prepare the site, plant the seed, and maintain the crop until harvest. These operations include:

1. Primary tillage: Soil is mechanically broken up and stirred to reduce soil strength and bury plant residue that might impede later crop growth. Primary tillage devices include the plow, the subsoiler, the lister, the rotary tiller, and the disc harrow.

2. Secondary tillage: Soil is worked to a shallower depth, leveling the soil and killing unwanted weeds. Shapers, rotary tillers, rotary hoes, discs, and rod weeders are commonly used implements for secondary tillage.

3. Seeding: Seed is placed into the soil at a density and depth that encourages germination and survival of the desired population. Typical equipment includes seeders and grain drills.

4. Cultivation:. Cultivation improves soil aeration, helps the soil to retain rainfall, and removes weeds through shallow post-planting tillage. Common field crop cultivation equipment includes row crop cultivators, rotary tillers, and rotary hoes.

Varying degrees of intensity are associated with conventional tillage. At one extreme, operations are performed several times to produce a smooth seedbed. At the other, the site is tilled with as few operational passes as possible. In any case, emphasis is placed on mechanically working the entire planting area to develop a good environment for seed germination and plant growth.

Soil compaction, seedling damage, erosion, and high operating costs are commonly associated with intensive tillage. Soil compaction throughout the tilled region can develop from continued tracking of equipment. Such problems on intensively tilled agricultural sites are discussed by Robertson (1974), who notes that the close proximity of the compacted areas to seedlings reduces growth and leads to poor survival. Multiple passes over the site also encourage compaction deep into the soil, causing the formation of dense pans.

Increased damage to tree seedlings can result from intercropping under conventional methods, particularly when making multiple passes over the site. Seedlings can be crushed, broken, or scraped by passing equipment, with the potential for damage increasing substantially as the stand ages. Damaged or dead seedlings can eventually result in lower tree crop yields and reduced revenues.

Conventional tillage encourages erosion by creating loose soil particles with high erosion potential. The effect of runoff is soil degradation that reduces site quality. Erosion is generally unavoidable under conventional tillage, a fact that has encouraged many farmers to shift to minimum tillage and no-till practices.

A tillage practice is economically justified only where it significantly increases production. For example, the per hectare cost for a two pass discing operation on a well cleared site is approximately $5.36 (Moore, 1983). Expanding operations to include extended cultivation can generate per hectare tillage costs exceeding revenues. Only where yields increase to a point beyond the marginal cost of tillage is it economical to use conventional tillage for intercropping.

Conservation tillage. Authors generally disagree on the precise definition of conservation tillage. For the purposes of this study, however, conservation tillage is defined as any method that leaves a crop residue on the soil surface to reduce soil erosion, increase infiltration, and hold soil moisture in the ground. One principal difference between conservation and conventional tillage systems is the common use of the moldboard plow in the latter system (Crosson, 1981). Moldboard plows turn the soil deeply, burying residues and plant cover in the process.

Conservation tillage ranges from minimum till to no-till systems. Minimum till methods restrict tillage operations to the minimum required for crop establishment, while no-till uses herbicide to replace tillage and cultivation.

Minimum tillage. Minimum tillage systems do not use the moldboard plow for primary tillage, leave some crop residue on the soil surface, and rely on herbicides for weed control. This approach can be used in some form or another for nearly every field crop grown. Yields from minimum tillage are similar to those from conventional tillage, although variations have been reported (Cschwald, 1974).

The implements used and the operations performed under minimum till vary widely. Chisel plows, coulters, disk harrows, and rotary tillers are frequently used for initial tillage, while later cultivation incorporates field disks, rotary hoes, and rotary tillers. Sprayers are used for herbicide and pesticide application, as well as fertilization.

Minimum tillage usually requires fewer operational passes and involves lower operating costs than many conventional systems. Tillage costs for five crops (cotton, corn, sorghum, wheat, and soybeans) under conventional and minimum till methods averaged as much as $29 per hectare in favor of the reduced tillage approach (Crosson, 1981). On the other hand, minimum till systems rely on standard equipment designed for the typical agricultural field. The terrain of some plantations, even after extensive site preparation, can be rougher than most agricultural sites. Tillage equipment used on these sites be more durable to operate on the potentially rougher terrain.

No-till techniques. No-till is defined as a production system where the crop is planted into herbicide treated soil with no prior mechanical tillage (Tessore, 1981). The benefits of no-till include soil and water conservation, lower production costs, and greater production efficiency in terms of time and money.

No-till cropping is used most commonly with corn and soybeans. The method is used to a lesser extent with crops such as alfalfa, small grains, cotton, and sunflowers. Small acreages of peanuts, tobacco, and certain vegetable crops have also been successfully grown under experimental no-till management (Rice, 1983).

Operations on a no-till site include the following:

1. Apply pre-plant herbicides to control weeds and kill any cover crop present,
2. Plant and apply necessary fertilizer for seed establishment,
3. Apply fertilizer to encourage growth and spot apply herbicide to remove any weeds, and
4. Harvest summer crop and plant cover crop on the site.

Cover crops such as rye (*Secale cereale*) are planted in the fall to reduce erosion and conserve soil moisture. Legumes, particularly clover and vetch, have also been used as cover crops.

Herbicides play an integral part of the no-till system by alleviating the need for mechanical cultivation. Three types are used in no-till; contact, pre-plant, and post-emergent. Herbicides in these categories must work without being incorporated into the soil. Table 3 lists some of the major herbicides for no-till corn and soybeans.

Most studies suggest that no-till management be restricted to locations not infested with johnsongrass, bermudagrass, broomsedge, nutsedge, and brambles. These perennials make herbicidal cultivation difficult (Rice, 1982; Tessore, 1981; Anon., 1976).

Herbicide use offers several advantages when intercropping under forest conditions. Seedling root damage from mechanical cultivation is avoided, because the soil remains untilled. Crops are able to make better use of available soil nutrients since weeds are checked by herbicides throughout the growing period. Many of the herbicides in no-till cropping are specific to broadleaf and grass vegetation (Table 3). Under proper conditions and with appropriate application, pine seedlings should be unaffected by no-till herbicide application.

TABLE 3

Herbicides used for no-till management of corn and soybeans and their potential effect on pine seedlings[4].

Common Name	Pine Sensitivity
Contact Herbicides[1]:	
Paraquat	Extreme
Roundup	Low
2,4-D[2]	Moderate
Pre-Emergence[3] Herbicides:	
Atrazine	Low
Cynazine	Unknown
Metolachlor	Unknown
Dyanap[2]	Unknown
Alachor	Low
Linuron	Low
Pendimethalin	Unknown
Propachlor	Unknown
Oryzalin	Low
Post-Emergent Herbicides:	
For Corn:	
Dicamba	Low
For Soybeans:	
Bentazon	Unknown
2,4-DB	Moderate
Dinoseb	Extreme
Metribuzin	Unknown

[1] The effect of contact herbicides will vary depending on the time of application.
[2] Used as a post-emergent for soybeans.
[3] Also used as post-emergents for corn.
[4] Table Adapted From Rice (1983) and Mullison et al. (1979).

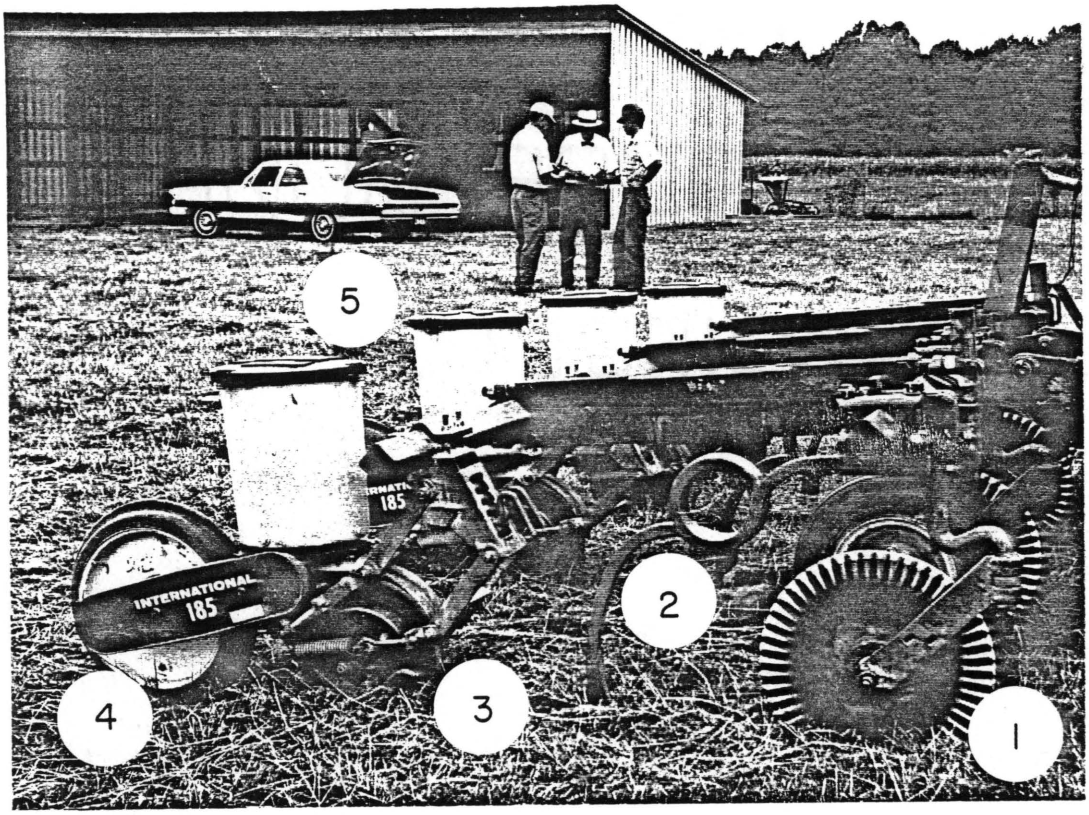
The primary implement for no-till (other than the herbicide applicator) is the specially designed no-till planter. These planters are equipped with a coulter, or cutting disk, set ahead of the planter to cut through plant debris and open a slot in the soil for planting. In this manner, only the small area covered by the planter is actually prepared as a seedbed. A typical no-till planter is illustrated in Figure 6.

The no-till system probably has the greatest potential for intercropped forest sites, due to the limited equipment requirements and minimum use of mechanical cultivation. In addition, reduced erosion and better soil water retention are possible with no-till management.

Harvesting

Economical, large-scale field crop harvesting has become possible since the development of the grain combine (Fig. 7). The combine functions as a single pass unit that cuts the crop, threshes out the seed or grain, and stores the separated grain for later removal. Residue is returned to the field to form a mulch behind the combine.

Combines typically cut the crop close to ground level, implying that the ground must be free of litter before harvesting. Sites set up to intercrop field crops must be



COMPONENTS

1 Rolling Coulter
2 Coil Spring with Alfalfa Chisel
3 Double-Disc Row Openers
4 Single-Rib Press Wheels
5 Seed Containers

Figure 6: No-till Planter.

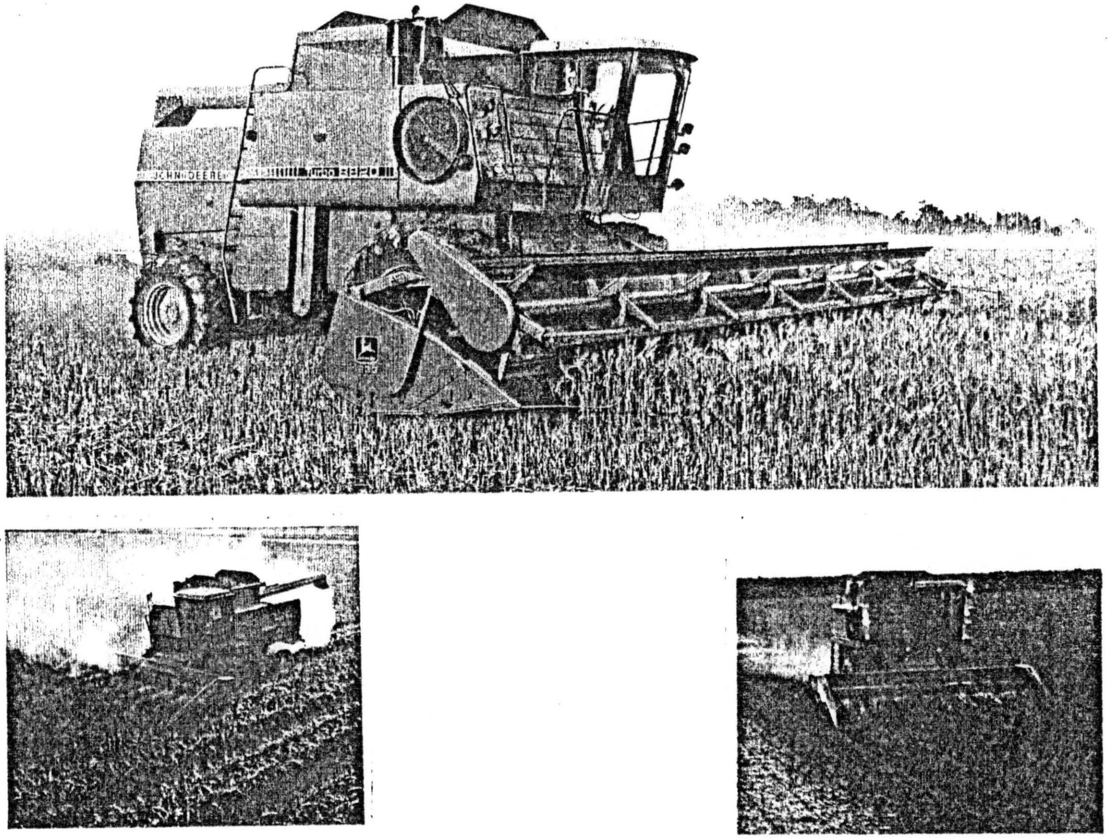


Figure 7: Grain combines used in agriculture.

clear of any surface litter that might hamper the cutting function of the combine header.

Another factor to consider on intercropped plantations is the operating width of the combine. Pull type combines are generally offset behind the tractor and have an overall width ranging from 4.8 to 6.7 meters. Self-propelled combines are manufactured with an overall header width as small as 3 m, although the standard sizes range between 4 and 5.5 m. The row spacing for pine seedlings interplanted with field crops must at least exceed combine operating width to avoid seedling damage.

Crop Production

Crop production, or yield, is affected by a variety of factors, including soil and site characteristics, the climate, and competition from other plants. The yield of field crops grown as monocultures vary from season to season, based on the interplay between these factors.

Intercrop production on a plantation forest is affected by the same factors, but in a slightly different manner. Soil characteristics are sometimes poor, the site may be crowded, and interplant competition is more likely on intercropped plantations. Field crop production under these conditions might be expected to diminish relative to normal agricultural yields.

On the other hand, some crop plants produce more total yield under intercropping than through monocultures of the component crops This phenomenon is documented in several agricultural studies, particularly Wiley and Rao (1979). Yield information is presently unavailable for field crops interplanted with pines and it is not known whether total yield would increase or decrease under this approach.

Crop production figures (See Table 4) for field crops grown as monocultures are useful as benchmarks for evaluating crop production on intercropped sites. They can also be used to project yield under theoretical scenarios, where the production rates are used as reference points to estimate proportional yields under a given intercropping system.

<u>Marketing and Transport</u>

Field crop marketing channels include county grain elevators, terminal and sub-terminal elevators, and port marketing agencies. A generalized marketing flow-chart detailing the marketing channels available for field corn production is illustrated in Figure 8

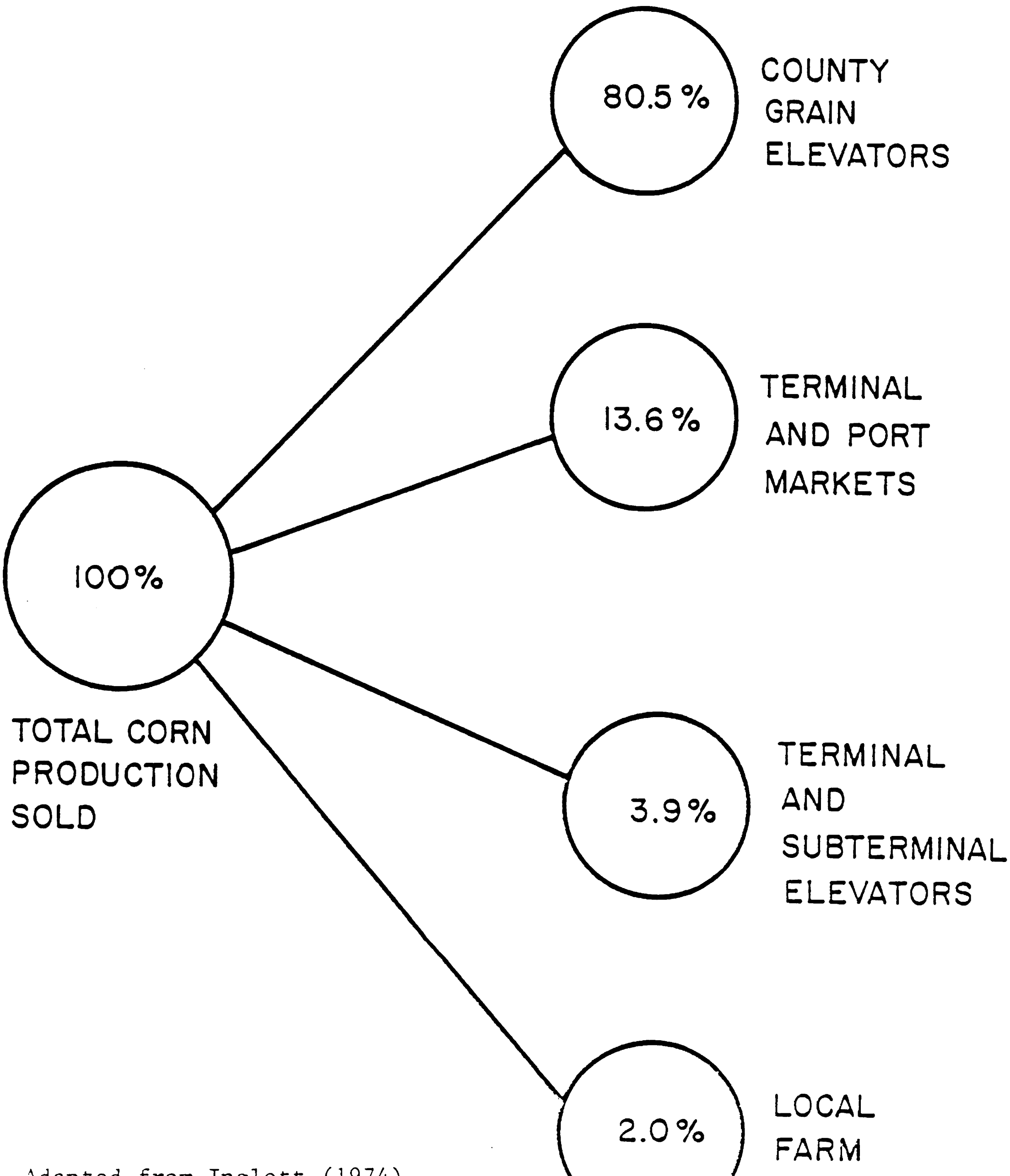
The most promising market available for intercrop production is the county grain elevator. These elevators are distributed throughout the South and serve as the major marketing outlet for most of the grain produced in this re-

TABLE 4

Field crop yields and revenues in Virginia and North Carolina for 1981.

Crop	Yield (Mg/Ha)	Value ($/Mg)	Total Value ($/Ha)
Virginia[1]:			
Dent Corn	2.29	$ 106.07	$243.00
Winter Wheat	1.32	111.36	147.40
Oats	1.07	81.40	86.95
Sorghum	1.25	88.00	109.76
Rye	0.77	109.38	84.00
Soybeans	0.60	269.42	161.65
Cotton	0.22	1276.00	278.40
North Carolina[1]:			
Dent Corn	2.32	$ 97.28	$ 225.68
Winter Wheat	0.78	161.45	125.93
Oats	1.23	84.04	103.14
Sorghum	1.46	102.08	148.71
Rye	0.73	107.49	78.76
Soybeans	0.69	267.52	184.83
Cotton	0.25	1203.40	297.02

[1] From Anon., 1982; Watson, 1982.
[2] Conversions from Bushel to Mg computed using data from Martin et al. (1976).



Adapted from Inglett (1974).

Figure 8: Market channels for corn production by destination and percent consumption.

gion. The advantages of using local grain distribution points include reduced transport costs, immediate disposal of the grain, and a rapid financial return from production.

Another marketing channel, although small, is through local farm sales. The other outlets, the terminal and sub-terminal grain elevators, are often located too far away for economic transport and, in terms of service, actually provide little advantage over the county elevators.

Grain transport is the responsibility of the producer, who is required to move the grain to the elevator at the lowest possible cost. Transport costs can be broken down on a per kilometer or per hauled load basis.

High Value Crops

Specialty Crops

Two crops in this category, tobacco and peanuts, might be termed 'restricted' crops, because their production is regulated by the federal government. Both crops are restricted by acreage and marketing quotas that can vary annually. Limiting the supply of tobacco and peanuts artificially maintains their market value. The high market value affords farmers the opportunity to monitor and modify soil and site conditions in their efforts to increase production. Soil conditions, such as nutrient levels and pH, are closely monitored and modified as needed to best accommodate plant growth. Fungicides, nematicides, and herbicides are applied as often as four times or more per growing season to ensure quality production. Substantial returns support these intensive cultivation efforts. For example, the gross return for a hectare of peanuts in 1981 averaged $2187, while tobacco grossed $9007 per hectare (Anon, 1982; Watson, 1982).

Peanuts (*Arachis hypogaea*). Adequate peanut yields require certain soil conditions that would be difficult to achieve on intercropped forest sites. The soil must be free of gravel, stones, or other litter that might be large enough to pass through the screens used to harvest the peanuts. A mildly acid sandy soil with a pH between 6.0 and 6.4 is necessary for profitable peanut production.

Preparing an intercropped site to the conditions required for peanut cropping is difficult to justify economically, particularly since peanuts could not be planted on the entire site Increasing soil pH to the range required could adversely affect pine growth over time (Gilmore, 1978). Difficulty with quota restrictions should be considered a major constraint to increased revenue. For these reasons, the peanut plant is not suggested for intercropping with pine.

Tobacco (*Nicotiana tabacum*). Tobacco is economically important in both Virginia and North Carolina. In 1981, one hectare of tobacco (regardless of type) grown in Virginia yielded approximately $9007 (Anonymous, 1982). In terms of physical production, a hectare of tobacco yielded 2.27 Mg of leaf in Virginia in 1981, while production in North Carolina averaged 2.44 Mg of leaf per hectare.

Tobacco, like the peanut, is regulated by the federal government which uses both a quota system to allocate acreage and poundage restrictions to limit annual production. Quota allocation is the responsibility of the federal government. Allotments may be leased, but only within the originating state. One estimate suggests that leased acreages account for nearly half of the tobacco production in the United States (Akehurst, 1981).

Soil-site conditions favoring tobacco are similar to those for many field crops. Soil pH requirements depend in large part on the type being grown. Flue-cured, the most commonly grown variety in Virginia and North Carolina, adapts well to extremes in pH. Akehurst (1981) states that good crops have been grown at pH conditions ranging from 4.5 to 8.0, but suggests that a pH of 5.5 be maintained to encourage growth. Fertilization follows a strict regime designed to enhance leaf quality and composition. Nitrogen and potassium are the most important nutrients for good production, with phosphorus and calcium ranking next in importance. The soil should be inherently fertile and well drained. Williamson and Kriz (1970) found that tobacco is susceptible to saturation and wilts within 12 to 24 hours under flooded conditions. Poorly drained sites, like those on the lower Coastal Plain, would require extensive modification to support an intercrop of tobacco and pines.

Tillage requirements parallel those for many field crops. Conventional methods are used for tillage and cultivation. No-till has been tried with some success (Morrison et al. 1973), but is not used to any extent in the U.S.

Tobacco is planted on hilled or ridged soil to reduce water damage, facilitate fertilization and drainage, and provide more loose topsoil for root development. Between row spacings range from 9 to 1.2 m, while between plant spacings range from 50 to 70 cm. Between row spacing distances are based on machinery access requirements, rather than physical crop constraints.

Intensive cultivation during growth halts weed competition that can reduce yield by 50 to 75 percent. Irreversible damage can occur if the weed population is not checked (Wilson, 1955). Herbicides are used in this context, with at least six registered chemicals approved for controlling weeds on U.S. tobacco fields. These herbicides include:

1. Diphenamid
2. Pebulate
3. Isopropalin
4. Oryzalin
5. Pendimethalin
6. Napropamide

Other herbicides used for tobacco include 2,4-D, Roundup (Glyphosate), Lasso (Alachor), Paraquat, and Princep (Simazine).

The leaf is harvested either manually or mechanically. Hand harvesting is popular on smaller tracts, but most larger farms have abandoned this form of harvesting in favor of mechanical systems. Over 38 percent of the tobacco grown in North Carolina in 1978 was harvested mechanically (Akehurst, 1981).

Other factors critical to the production of tobacco include curing, insect control, and disease control. These factors, particularly the control of insects and diseases, often dictate the quantity and quality of production. Facilities must be available for curing the crop in a controlled manner.

Intercropping tobacco would involve large expenditures for equipment, chemicals and fertilizers, and curing facilities. Expert control over nutrient supplements, diseases, and the time of harvest would be necessary to ensure good production. With expert management, tobacco has the potential to be a viable intercrop on forested sites. Current tobacco management practices manipulate the soil for optimum yield and quality leaf production. Extending this to the manipulation of forest soils is certainly possible with existing technology.

Perhaps the best alternative to direct intercropping of tobacco is a lease arrangement where established plantations are rented to tobacco growers for cropping. The advantages of this approach are numerous. No expenditures are required beyond initial site preparation costs. A return from the leasing arrangement is provided without risking crop failure. The management required to produce the crop is the responsibility of the leasee, as are all costs associated with tillage, planting, cultivation, harvesting, and curing. Potential benefits, such as additional fertilization and weed control, occur as part of the production process, costing the leasor nothing.

Potential participants in such an approach should be educated regarding the possibility of seedling damage and the need to avoid detrimental practices during production. Particular systems could be developed to the advantage of both parties in the leasing arrangement. The potential for site amelioration is far better with tobacco than other crops, because the returns justify beneficial practices not normally carried out with other, less valuable crops.

Vegetable Crops

The vegetable crops grown in an intercropped forest setting in the South are most restricted by marketing constraints. While produce can be sold to supermarkets and fresh produce stands, the producer is not commonly guaranteed sale of total production. Bulk sales are uncommon and price often depends on product appearance, in addition to quality. Problems associated with marketing and transport of vegetable crops for the fresh produce market include the one-to-one sales relationship involved in marketing, the seasonality of the market, and the massive losses incurred when marketing deadlines are not met. Delicate handling during transport and stringent storage conditions must be maintained to avoid damaging most vegetables prior to sale.

Process markets that procure large quantities of vegetables for canning and freezing comprise the other marketing channel for vegetable production. The producer selling to a process market can rapidly turnover bulk lots of produce without consumer involvement. In addition, these markets require little sales effort and are less seasonal than most fresh produce markets. Most process markets situated in the Coastal Plain are restricted to cucumber, tomato, and snap bean processing.

Cucumbers (Cucumus sativus). The process market for pickling cucumbers is well developed in Virginia and North Carolina, where 10,320 hectares were devoted to cucumber production in 1981. The plant requires light, well drained soils with a mildly acid pH (ranging between 5.0 and 6.8). Plowing, discing, and harrowing operations are commonly used to remove weeds and prepare the seedbed. The crop is planted in rows or hills late in the spring to avoid frost damage. Row spacing ranges from 1.5 to 2.0 m, while hills are offset in spacings of 1 to 2 m apart. Cultivation starts early and continues until harvest. With the onset of vining, cultivation is done either by hand or with herbicides. The crop is harvested within 2 to 3 months of planting using mechanical harvesters that destroy the plants during harvest. The harvesters are small scale units, easily capable of working in an intercropped plantation environment.

The advantages of intercropping process cucumbers include the presence of an established crop market, the possible use of herbicides to alleviate mechanical cultivation, low growth characteristics that minimize competitive interaction between the pines and the cucumbers, and the high rate of return associated with cucumber production. In addition, the site requirements of cucumber can be created on pine plantations without extensive and costly preparation.

Tomatoes (Lycopersicon esculentum). Although both Virginia and North Carolina commercially produce tomatoes, process markets for tomatoes exist only in Virginia. At least 50% of the annual tomato production in Virginia goes to canning factories on the Eastern Shore with an annual reported gross value of $1.5 million (Dunkerley and Bowley, 1982).

Tomatoes can grow on a variety of soil types. A soil pH ranging from 5.0 to 6.0 will encourage good yields. Tomatoes require extensive phosphate and sulfur fertilization for proper growth. Nitrogen application is also necessary, either as a side-band application or broadcast over the entire site. However, potassium is required in large quantities, since this element is heavily absorbed during growth. For example, between 2 and 3 kg of extractable potassium can be found in one ton of tomatoes (Gould, 1974).

Direct seeding into rows, rather than transplanting, is preferred for commercial tomato crops. Row spacings of 1 to 2 m are common, with spacing for mechanical harvesters averaging 1.5 m between rows to facilitate the harvest.

Tomatoes succumb easily to weeds, especially when grown close to the ground. As a result, the crop is cultivated several times prior to harvest. Pruning and staking also reduce competition, but require extensive manual labor and are incompatible with mechanical harvesting. No-till cultivation is a valid alternative tc the more intensive conventional approach currently used for tomato production. This method alleviates the need for mechanical cultivation and staking, although herbicide may be required throughout the production period to fight patches of weeds that resist initial treatments.

Either manual or mechanical methods can be used for the harvest. Manual harvesting costs more, but compensate by allowing for more than one harvest in the season. Mechanical methods are faster and cost less, but allow only one harvest.

Tomatoes are adaptable to intercropping, particularly on plantation sites. Moderately acid soil, commonly found on pine sites, adequately supports tomato growth. Mechanization can be used to plant, cultivate, and harvest tomatoes on large tracts reducing the overall cost of production. No-till tomato cropping, although still experimental, was used successfully on experimental sites for several years with no adverse effect on yields (Tessore, 1981) and could be adapted to intercropped forests. Conversely, process markets for tomatoes are confined to the Eastern Shore of Virginia. For this reason, market location and transportation costs must be considered prior to intercropping with tomatoes.

Snap beans (_Phaseolus vulgaris_). Snap beans are grown in both Virginia and North Carolina for processing. Over 729 hectares of snap beans were grown for the process market in Virginia in 1981 with an annual gross revenue exceeding $770,000 (Dunkerley and Rowley, 1982).

Snap beans grow well on sandy soils and clay loams, under a pH ranging between 5.5 and 6.5. Unlike other legumes, beans are inefficient nitrogen fixers and respond well to complete fertilization. Weed control is essential, as the plants are quite susceptible to weed competition. Shallow cultivation or scraping can be used to avoid damaging the shallow root system. Herbicides are occasionally used in conjunction with mechanical cultivation.

Beans are harvested both manually and mechanically. Mechanical harvesters yield only one picking, because the plant is destroyed by the machine during harvest. The use of hand labor allows for two or more pickings, but labor availability problems can lead to significant losses in yield when the harvest is delayed.

Profitable bean crops should be possible on fertile pine plantations within a reasonable distance of a processing center. Site preparation costs should be kept to a minimum, but at the same time the soil must be prepared and tilled well enough to support a productive crop.

Tuber and root crops. Although the sweet potato (*Ipomoea batatas*) and Irish potato (*Solanum tuberosum*) are unrelated biologically, production of these crops follow similar patterns. Sweet potatoes are a major crop in North Carolina, while Irish potatoes are grown commercially in both states along the Lower Coastal Plain. Potatoes grown in Virginia in 1981 provided over 16.2 Mg per hectare and were sold for an average price of $212 per Mg. The gross revenue provided by one hectare of potatoes in 1981 averaged $3439 (Anon., 1982).

The use of these crops, or any below ground crop, as plantation intercrops is not feasible on cut-over sites. Mechanical removal of a tuber or root crop requires that a subsoil that is relatively free of debris and obstacles during harvest. Site preparation ensuring clean subsoil conditions are too costly for sites being interplanted with timber crops. As a result, tuber and root crop harvests would be difficult on heavily littered sites.

Many of the growth characteristics of the sweet and Irish potatoes are compatible with conditions existing on plantation sites. Soil pH requirements for the Irish potato range between 5.0 and 6.0, with the sweet potato having similar requirements (5.2 to 6.7).

Irish potatoes are low growing plants that reach a height of less than 1 meter. A balanced fertilizer is frequently applied as a side-dressing early in the production cycle. A single early fertilizer application can increase growth as much as several applications made later in the season. Soil pH levels above 5.2 do not require liming and, in cases where lime is needed, applications should be made sparingly to minimize scabbing.

Special planters are frequently used to plant the tuber cuttings, although on smaller tracts hand planting is possible. Cuttings are planted 8 to 10 cm deep in rows 1 meter apart soon after the soil has thawed. Weed control can be avoided by mulching shortly after plant emergence, although pre- and post-emergent herbicides can be used to control weeds where mulching is not possible. Three to four months after planting, the tubers are harvested with mechanical diggers. These diggers pose a problem on intercropped plantations with cluttered subsoil conditions.

Sweet potato production requires up to seven times the labor required to produce white (Irish) potatoes and can result in losses of between 20 to 40% of the total harvest (Martin et al., 1976). In addition, harvest involves mechanical diggers similar to those used for Irish potatoes with all the same problems on intercropped plantations.

Sites that can support interplanted tuber or root crops without extensive preparation should probably be placed into Irish potato production. Irish potatoes are less subject to damage during harvest and storage. They can be marketed through cooperatives or central packing sheds which eliminate requirements for individual marketing contacts.

Watermelons (Citrullus lunatus). The watermelon market is essentially a fresh produce market. However, the plant grows best on newly cleared soils, making the watermelon ideal for intercropping on plantation sites. In addition, the plant is relatively insensitive to acid soil conditions and thrives on fertile sandy loams with a moderately acid soil pH (ranging from 5.0 to 7.0).

Most of the production operations for watermelon are labor intensive. Conventional seedbed preparation that includes plowing, discing, and harrowing is followed by a hand planting operation. The seeds are planted in hills spaced 3 to 4 m apart. Shallow cultivation with mechanical cultivators is performed prior to vining, but at the onset of vining hand cultivation is required to avoid plant damage. In addition, harvesting and packing operations are done totally by hand.

The complexities associated with production and marketing limit the potential of watermelon as an intercrop.

These problems can be avoided by adopting a lease arrangement with growers that would effectively remove the timber grower from any any involvement with crop production. The annual lease payment to the grower would help to offset site preparation and regeneration costs.

Site Preparation Requirements

Sites supporting vegetables must be well cleared, to accommodate tillage and mechanized or hand planting operations. Site preparation techniques for establishing vegetable crops are similar to those used for field crops. The site must be clean of debris, slash, and stumps. Operations to enhance subsoil conditions may be required for certain crops.

However, recent use of no-till methods for vegetable crop production may alter the conventional approach to site preparation. A number of researchers reported successful no-till management of vegetable crops (Beste, 1973; Knavel et al., 1977; Thorton, 1977). Using no-till on intercropped plantations could significantly reduce the degree and cost of site preparation.

Planting

Vegetables are usually seeded with mechanical planters. Tomato seeding efforts have included seed strips laid out using specially designed seeders and fluid-gel seeding. Beans and peanuts may be planted with conventional field crop seeders. Cucurbits can be seeded, but are commonly transplanted to expedite production on the site.

Transplanting often involves manual labor, since the cost of the seedling or transplant warrants this type of attention. Plants that have been manually transplanted receive more attention and probably have a greater field survival rate than those mechanically transplanted. However, the advantages of mechanical planting can include lower costs and faster planting rates.

Tillage

A continuing trend exists in agriculture which replaces conventional tillage with conservation methods that include some herbicidal weed control, like minimum till and no-till methods. Minimum tillage is commonly used with vegetables and other high value crops, while no-till has been tried experimentally with selected vegetables.

Using minimum till cultivation on intercropped sites would probably cost as much as conventional methods, particularly in terms of capital investment. There is also potential for incompatibility between the cultivating equipment and the site.

Although no-till is a relatively new method of cultivation for high value crops, there is little to suggest that this technique cannot be applied, particularly in an intercropped setting. No-till snap bean yields, in two studies, were comparable to yields from conventionally tilled crops (Mullens et al., 1980; Beste, 1973). Similar findings were reported by Beste (1973) for no-till tomatoes. No-till production does involve some risk, due to the limited information regarding no-till cultivation of vegetables and specialty crops. Several years of study may be required before no-till vegetable cropping becomes an accepted alternative to conventional methods.

<u>Harvesting</u>

Vegetable crops are harvested with large mechanical harvesters or manually. Mechanical harvesters are preferred for large acreages, while manual methods predominate on small tracts. On intercropped plantations mechanical harvesters would probably require minimum between row spacings of 3 to 4 meters. Examples include the FMC 5600TE tomato harvester and the FMC GB 110 bean harvester which require operating widths of 4.4 and 3.2 m, respectively. the FMC GB 110 bean harvester requires at least 3.2 m. The Pixall Beanstalker and the Chisholm-Ryder MDH bean harvesters are somewhat smaller with widths of 2.95 and 3.15 m, respectively. These units are single pass harvesters that destroy the plant during harvest. In addition, specific tomato crop row spacings are required to match header characteristics.

Manual methods, on the other hand, can provide greater yields since the plant remains intact after harvest. Intensive cultural practices, such as staking, do not impede the harvest. The primary limitation of manual harvesting is the labor requirement that must be made available at the appropriate time.

Forage Crops

The major forage plants grown in Virginia and North Carolina include alfalfa, the clovers, timothy, and tall fescue. Minor forage crops grown in the region include orchard grass, Kentucky bluegrass, lespedeza bermudagrass, sudangrass, and millet. In addition, small grains are sometimes grown for forage, particularly wheat, rye, and oats.

Legumes

Although alfalfa (*Medicago sativa*) is one of the more popular forage legumes in the South, it is poorly suited to forest intercropping. Production declines on even mildly acid soils, with best growth on neutral or slightly alkaline soils. Conversely, the soil pH of old fields and cut-over plantations frequently ranges between 4.5 and 6.0. Alfalfa competes poorly with annual grasses and thrives in mixed plantings only on dry sites. As a result, alfalfa production may be difficult to maintain on intercropped sites.

Sweetclover (*Melilotus spp.*), like alfalfa, thrives on "sweet" soils with a pH of 6.5 or greater and typically requires liming prior to establishment. Biennial and annual varieties occur. White sweetclover is a tall growing, high branching plant with few leaves. Yellow varieties are bushy with finer stems and a tendency to lower production. The hay from sweetclover is poor quality and less marketable than other legume hays. The primary use for sweetclover is as a green manure to increase soil fertility.

Many of the clovers (*Trifolium spp.*) grown as forage have been considered poorly suited for forest interplanting as nurse crops. These include ladino or white clover (*T. repens*), crimson clover (*T. incarnatum*), and red clover (*T. pratense*). These and several other clovers were studied by

Jorgensen and Craig (1983) to determine their adaptability under forest conditions in North Carolina. Of those tested, only subterranean (*T. subterraneum*) and rose clover (*T. hirsutum*) provided promising results. Crimson clover was successful only on fertile, less acid sites, while the red and ladino clovers were unable to become established after one year of testing. These results suggest that clovers have only limited potential as intercrops on southern pine plantations without extensive modification of the site.

The most promising legume studied by Jorgensen and Craig (1983) was sericea lespedeza, a perennial that is well known for its ability to grow on infertile acid soils. Sericea is a fast growing plant capable of eliminating many annual and perennial weeds. Lespedeza is a warm season legume capable of growing on acid soils without liming. Phosphorus applications are frequently required on the Coastal Plain. The crop is usually sown alone in early spring and becomes established most readily on prepared soils. First year growth averages 30 to 40 cm with subsequent seasonal growth averaging 0.6 to 1.5 m. Root penetration into the soil can exceed 1 m.

Studies by Cushwa et al. (1970) and Landers (1978) suggest that sericea lespedeza is suited for growth on forested sites.

Sericea can be cut for hay at a height of 25 to 40 cm, but larger plants with woody stems will consistently contain high concentrations of tannin (tannic acid) that makes the hay unpalatable for livestock consumption. Because the hay cures rapidly, mowed sericea must be windrowed within an hour of cutting and baled within 24 hours to avoid severe leaf shatter (Guernsey, 1970). Two to three cuttings are possible on fertile soils, although four cuttings can significantly reduce hay yield. The inferior quality hay that is occasionally produced from lespedeza must be mixed with other forages for consumption. The hay from lespedeza can have lower economic value than hay from other legumes and may be economically unattractive for plantation intercropping.

Two species of annual lespedeza are important as forage crops in the South. Korean lespedeza (L. stipulacea) is less tolerant of acid soils than the striated or common lespedeza (L. striata) and, consequently, is less preferred for acid soils. Both species respond well to lime and fertilizer, requiring a pH of 6.0 or greater for favorable growth. The quality of hay from annual lespedeza compares favorably to alfalfa. Although the annual lespedezas thrive under minimal management, the extensive requirement for lime and fertilizer pose a problem in terms of intercropping potential. However, on fertile sites, an annual lespedeza intercrop might provide adequate returns.

Birdsfoot trefoil (*Lotus corniculatus*) and big trefoil (*L. pedunculatus*), like lespedeza, adapt to acid soil conditions. However, plant growth is best in the northeastern region of the country and may not be adapted to the warmer climate of the South. Few studies have examined trefoil in the forest setting, with many of the available studies dealing with the use of big trefoil for erosion control on forest roads in the West (Dyrness, 1967; Dyrness, 1975). Jorgensen and Craig (1983) suggested that both species of trefoil can be grown under forest conditions in the South, although their results were preliminary.

In summary, many legumes make valuable forage crops, but are poorly adapted to growth on the acid, infertile soils characteristic of pine plantations. Lespedeza, best suited for intercropping in terms of adaptability, provides little economic return. The trefoil species show promise, but little information is available regarding their adaptability to southern forest conditions.

Grasses

Four grasses are grown in the upper South for forage. Most of these grasses range throughout the South with the exception of orchardgrass (*Dactylis glomerata*) which is restricted to Virginia and the Piedmont of North Carolina.

Orchardgrass grows under even the most adverse conditions, including shallow, infertile soils considered unfavorable for other forages. However, the limited range of this grass reduces its application as a forest intercrop on southern sites.

Tall fescue (*Festuca arundinacea*), a more commonly used southern forage grass, could prove to be a valuable forest intercrop. Fescue grows under a variety of soil and moisture conditions, tolerates acid soils, and can produce a quality hay. Variability in hay quality and palatability can dramatically reduce the earnings from a fescue hay crop. Fescue does grow on wet sites and could prove to be adaptable to wet site plantations incompatible with other intercrop plants.

Bermudagrass (*Cynodon dactylon*), is a wide ranging forage particularly suited to intercropping on Coastal Plain sites. Coastal bermudagrass provides up to five cuttings per season, tolerates mild frosts, is relatively drought resistant, and can survive flooded conditions. The Coastal cultivar is generally easier to cure than any other hay crop used in the South (Burton, 1973). The grass is propagated vegetatively by planting sprigs, rather than seeding. Tree planters have been successfully used as sprig planters. Weeds can be controlled during establishment with 2,4-D which has little effect on the bermudagrass. Winter burning in established stands is another common weed control practice.

Bermudagrass is perennial, provides several harvests in a single season, and has adapted to much of the South. Whether this crop would actively compete with the pine over time is unknown. However, many other qualities suggest its use for intercropping. Hart et al. (1970) studied the growth characteristics of bermudagrass intercropped with slash pine and found the two plants compatible. No significant changes in pine growth were detected over a four year intercrop period. The bermudagrass remained productive for three years, even with the incident light entering the stand at levels less than 16% of that on unshaded locations. Forage yields decreased significantly when light in the stand fell to 7% of full sunlight.

Other grasses grown in the lower South might also be compatible intercrops. One notable forage is bahiagrass (_Paspalum_ _notatum_). The plant responds to nitrogen at relatively low levels, provides good yields under shade conditions, and does not impede pine growth on the site (Hart et al., 1970) .

In summary, grasses may be better adapted to intercropping than legumes on some forest sites. Although no soil improvement occurs, some grasses thrive under forest conditions that will not support legume forages. Bermudagrass and orchardgrass have shown the greatest potential in the upper South. Further study is suggested for these forages in an intercrop setting to determine their economic potential on the site.

Site Preparation Requirements

Forage crops rarely require extensive site preparation. Site preparation for continuous forage cropping includes clearing of the soil surface and removal of stumps or other material protruding from the soil. The site contours should be level or, at least, follow a continuum rather than drop or rise abruptly. Efforts must take into account the fact that forage crops are harvested with machinery that cuts, rakes, and picks up material close to the groundline.

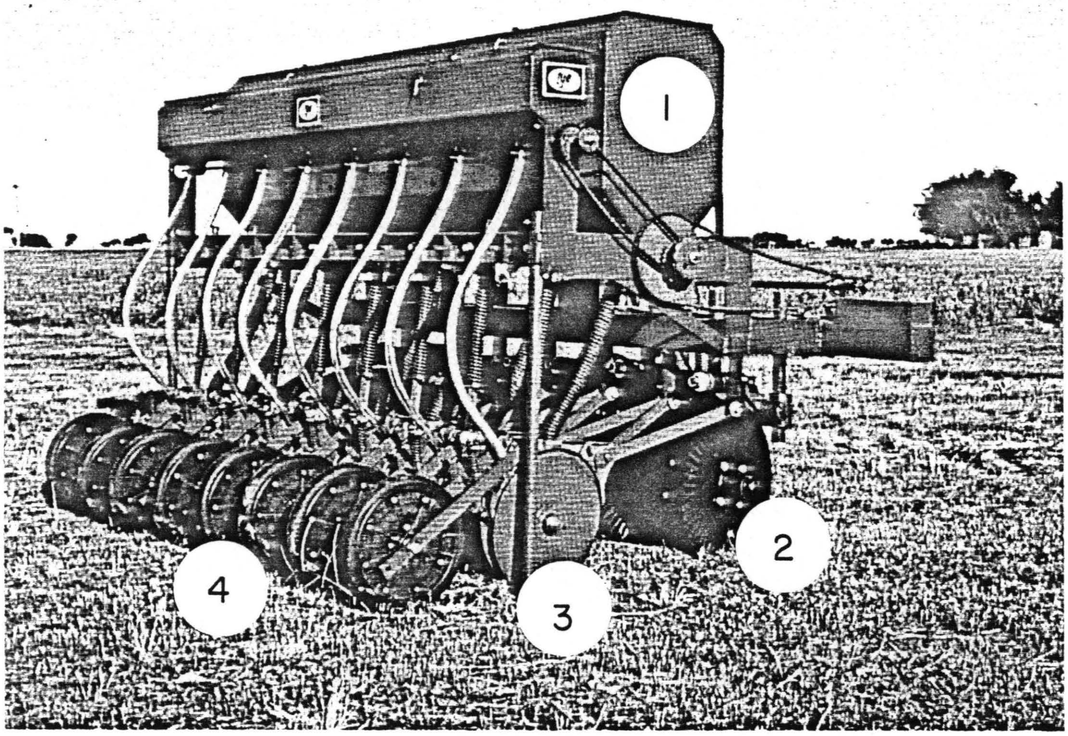
Planting or Seeding

Forage crops are planted using grain drills, sod seeders, or broadcast seeders. The cheapest method of pasture seeding is with the broadcast seeder, while sod seeders can plant both small grains and grass seed. The grain drill, unlike the others, lacks the heavy construction for operating on rough soils.

The sod seeder (See Fig. 9) is a heavy duty no-till planter used for interplanting grain and grasses on unprepared pasture soils. Fertilizer, grain, and grass seed can be applied simultaneously in rows at desired spacings, requiring fewer passes to seed and fertilize the site.

Broadcast seeders are low cost units used for fertilization, planting, or dry chemical application. Generally, one compound is applied in each pass, requiring more passes over the site than the sod seeder or grain drill to plant and fertilize.

The planting process differs, based on the type of seeder used. Grain drills and sod seeders place seed in parallel rows, while broadcast seeders simply disperse seed on the ground where a certain percentage germinates. The sod seeder requires no primary tillage and only a small portion of soil is prepared as part of the planting operation. Problems foreseen when planting intercropped sites include the possibility of restricted movement across the site and obtaining adequate germination rates for planted forage seeds. Much depends on the equipment used and the extent of site preparation efforts to remove debris.



COMPONENTS

1 Seed Container
2 Rolling Coulter
3 Double-Disc Row Openers
4 Rubber Tired Press Wheels

Figure 9: The Pasture Drill or Sod Seeder.

Tillage Requirements

Few tillage operations are needed for land in forage production. The control of noxious weeds requires ocassional mowing and herbicide treatment, while the application of manure and/or manufactured fertilizers is performed on an annual basis.

Tillage operations, such as discing or plowing, are rarely necessary. The lack of a tillage component in the continuous forage cropping process is an advantage in terms of both operating and capital investment costs. These advantages are, of course, offset by the lower monetary return provided by forages.

Forage Harvesting

Hay harvesting involves at least three processes; mowing, windrowing, and baling. Conditioning which crushes the leaves and stems for faster drying is frequently included as a part of the mowing and windrowing functions.

Side-mounted mowers attached to a conventional tractor are frequently used to mow hay crops. These units work on open fields where the mowing process moves from one end of the field to the other allowing the tractor to travel in the cut-over portions of the field. On intercropped plantations, seedling rows make this approach impossible. Another factor to consider is the double pass requirement for mowing and windrowing with separate mower and rake operations. Single pass operations are available with mower-conditioners and mower-windrowers.

Mower-conditioners mow, condition, and windrow the hay in one pass. Conditioning helps to shorten field drying time and reduces the time interval between mowing and baling when the hay is most vulnerable to damage from rain. Most mower-conditioners marketed in the U.S. are pull-type units that must be offset behind the tractor (See Fig. 10). Dimensions vary, but the minimum overall width of these units averages 3 m. In addition, the tractor used to power the mower-conditioner adds more operating width. Another unit, the windrower, mows and windrows hay without conditioning. These units are usually self-propelled with a minimum operating width ranging between 3 and 4 m, depending on header width. Generally, the operating dimensions of these units do not match the spacing available on conventional plantations in the South. At most, one pass could be made on widely spaced sites and in two or three years seedling growth would prohibit equipment movement. The only alternative to this dilemma is increased plantation spacing that would allow several years of hay production before pine competition inhibit equipment operation and forage growth.

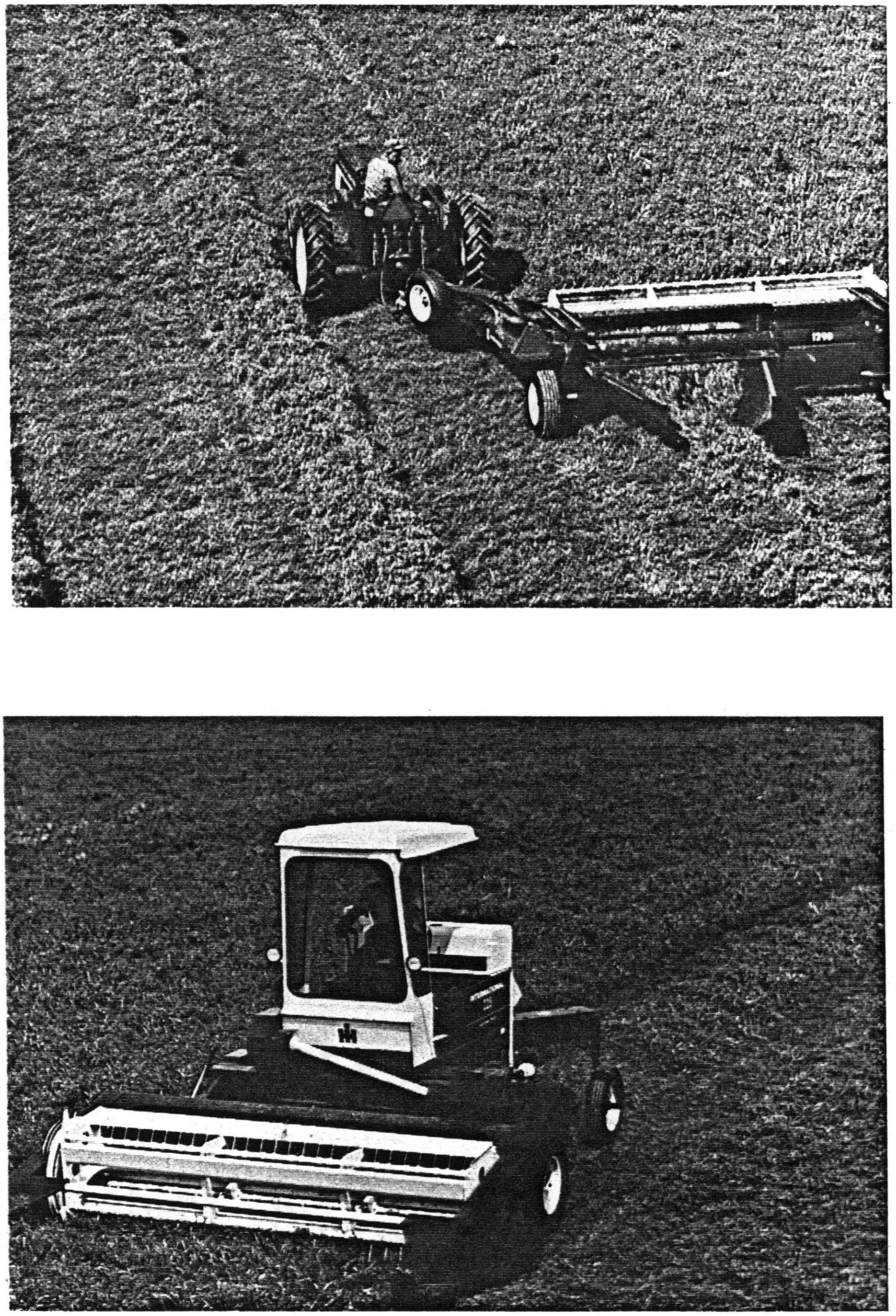


Figure 10: Pull-type mower-conditioner and self-propelled windrower used for hay harvesting.

After mowing, drying, and windrowing the forage crop is baled and stored for later sale or use. Baling removes loose hay or other forage material from the ground, compacts this material in the baling unit, and expels baled material in a condition that allows immediate storage in a dry environment. Bale sizes can range from the small rectangular 18 to 27 kg bales to round bales weighing up to 550 kg.

Conventional balers are normally offset behind the tractor to allow access to the windrows. These units have relatively small operating dimensions and rarely exceed 3 m in overall width. Big package, or round bale, balers are generally wider than the conventional balers, but still average between 2.0 and 2.4 m in overall operating width. Big package balers can be either self-propelled or pulled by a tractor. However, tractor requirements for these units are somewhat greater in terms of HP rating than for the conventional balers. Either pull-type or self-propelled balers could be used on intercropped sites, particularly where row spacings are increased.

Marketing Considerations

When growing forage crops as forest intercrops, one must eventually face the problem of how to market the crop. No established market exists for forage, as there is for vegetable and field crops. The grower must deal with the public on a one-to-one basis for sales. Market demand fluctuates extensively, based on the available supply of forage material offered in the market. In many cases, those who need forage material grow it themselves and enter the market only when production declines. Only 14% of all hay produced annually is sold on the open market (Martin et al., 1976). Most of this material is produced and sold in the West.

However, hay forage could be grown on plantations through lease arrangements with local farmers needing hay to winter their livestock. Some profit is possible from the arrangement in the form of rental fees, while the seedlings on the site could be protected from weed and herbaceous competition. The opportunity to raise and sell cattle or other livestock is also possible on plantations intercropped with forages. Using loblolly stands for grazing purposes is not uncommon and was demonstrated to be a profitable management alternative by Faircloth (1976). This approach could prove more profitable than the forage-timber scenario presented here.

Biomass Crops

Plants grown as biomass are typically woody, fast growing, and able to regenerate as coppice. Hardwood timber species with these characteristics have been tested for biomass production in several studies (Briscoe, 1969; Dickman, 1975; Belanger and Saucier, 1975).

Sycamore (*Platanus occidentalis*), already established on more than 600 hectares in the Coastal Plain and Piedmont, appears to be the most acceptable hardwood for biomass cropping (Belanger and Saucier, 1975). Other crops tested include sweetgum (*Liquidambar styraciflua*), cottonwood (*Populus deltoides*), and European black alder (*Alnus glutinosa*).

Biomass Characteristics

Biomass interplanted with pine should have characteristics compatible with pine growth. Biomass characteristics preferred for forest intercropping include the following:

1. Possess a narrow crown and have little tendency for lateral branching,
2. Have deep rooting habits with lateral root growth confined to the drip line,
3. Take up nutrients and soil moisture at low rates or be a net provider of nutrients, like European black alder,
4. Tolerate acid soil conditions, poor drainage, and shade.

Sycamore (*Platanus occidentalis*). Sycamore grows as a plantation crop throughout the Piedmont and Coastal Plain. Products include pulp and lumber, in addition to fuel. The tree is relatively well adapted to extremes in soil pH and is capable of growing on mine spoils (Merz and Plass, 1952) or under mildly alkaline conditions (Broadfoot, 1964). The tree can survive in droughty conditions (Briscoe, 1969), but poor drainage and standing water significantly limit growth (Bonner, 1966).

Sycamore is established with transplanted seedlings on intensively prepared sites. Yields are exceptional on good sites, with annual per hectare growth of 18.0 Mg reported on bottomland sites. Stump sprouting rates as high as 85 and 95% were reported in at least one study and evidence suggests that up to three harvests are possible without reducing vigor (Belanger and Saucier, 1969).

The products from sycamore are diverse, but when grown on short rotations of 3 to 5 years production is restricted to biomass. Pulping for fiber is not possible since the fiber length of young wood is too short for quality pulp. The rotation must be extended to 12 years or longer before pulping becomes possible.

Eastern cottonwood (*Populus deltoides*). Eastern cottonwood ranges from Arkansas and Oklahoma to Virginia. Approximately 14 million m^3 of cottonwood was inventoried in the South in 1976 (Sternitzke, 1976), much of it commercially owned and managed. A breakdown by state indicates that Virginia and North Carolina produce only a small proportion of the cottonwood grown in the South.

State	Volume (MM m^3)
Alabama	0.87
Arkansas	2.38
Florida	----
Georgia	0.13
Louisiana	3.01
Oklahoma	0.48
Mississippi	3.04
North Carolina	0.56
South Carolina	0.77
Tennessee	1.55
Texas	1.28
Virginia	0.11
Total	14.18

From Sternitzke (1976).

Products are diverse and can include biomass fuel, pulp, saw logs, and veneer logs. Pulpwood and biomass products prevail in the South, where over 20,000 hectares of cottonwood have been planted (Anderson, 1976). Again, short rotations limit production to biomass for reasons similar to those noted for sycamore. Presumably, intercropped sites would be limited to biomass, unless rotations were specifically developed with other products in mind.

Johnson and Burkhardt (1976) measured 3-year-old cottonwood on sites in Mississippi having an average height of 8 to 10 m and DBH ranging from 5 to 7 cm. Crown widths for these trees ranged from 2 to 3 m.

Plantation intercropping with cottonwood for timber-biomass yield is not suggested within the study region. Virginia and North Carolina define the border of cottonwood growth in the Southeast and, as noted previously, account for little production. Potential problems include poor growth and a marked susceptibility to freeze damage.

European black alder (*Alnus glutinosa*). European black alder naturally ranges throughout Europe to Asia Minor and North Africa (Goncalves and Kellison, 1980). Plantings in the southern U.S. have provided good survival and rapid height growth, averaging rates of 1 m per annum.

Black alder tolerates soil pH levels as low as 3.4, although optimum growth occurs at a pH of 5.4 (Funk and Dale, 1961). Alkaline soils retard growth and produce poorly formed stems. The ability of alder to fix atmospheric nitrogen is well documented. Dale (1963) reported that the height of trees interplanted with alder on mine spoil sites increased by 4 to 50%, attributable to the soil ameliorative qualities of the black alder. However, alder produces poorly on such sites and requires a well prepared fertile soil for quality production. A preparation regime of burning, discing, and plowing encourages seedling establishment and growth on most sites (Goncalves and Kellison, 1980).

Black alder grown under biomass spacings can produce over 13,000 kg dry weight) in total tree material per hectare after 3 years of growth. However, some studies indicate that plant vigor and growth can decline within 4 to 6 years of establishment, severely restricting the overall biomass yield from alder (Frederick, 1984; Steinbeck, 1984).

Alder growth in the first years of establishment can outpace loblolly pine with average growth ranging to 6.4 m in height and 7 3 cm in diameter on some fertile bottomland sites. In other respects, this species is well suited to intercropping. It tolerates shade better than many other biomass species and increases site quality by fixing atmospheric nitrogen. It is acid tolerant and can significantly increase the growth of tree species interplanted with it (Dale, 1963). Even when planted as an intercrop, black alder has the potential to produce as much as 3.5 tons of dry matter per hectare per year (Goncalves and Kellison, 1980).

A black alder-pine intercrop would require extended buffer strips to reduce shading and root competition, although nitrogen applications would be unnecessary, except on deprived sites. The alder should be selected for provenance compatability, particularly since this introduced species is not adapted to all areas of the South. A significant drop in vigor and growth may be encountered after 4 to 6 years.

Sweetgum (*Liquidambar styraciflua*). The sweetgum, common throughout the South, is an important hardwood timber species considered for biomass production in certain parts of the South. The species ranges from Florida to the southern end of New York State.

The species is relatively intolerant and requires fertile bottomland sites for good growth. Studies indicate that sweetgum performs inadequately as a biomass crop, with total tree yields of 4726 kg per hectare after 3 years of growth (Frederick, 1984). In contrast, sycamore on a similar site can produce approximately 15,240 kg per hectare in 3 years, increasing total tree yield for the 3 year period by 170%. However, sweetgum is well adapted for growth in the South and can survive on dry sites that might not support sycamore growth.

Planting

Most hardwood species are transplanted as nursery stock. Cottonwood is commonly established with cuttings, rather than seedling stock. Mechanical planting with a standard seedling planter is most economical, but manual methods are necessary on sites too rugged for mechanical planters.

A variety of spacing options are available. Hardwood plantations grown for pulp are usually spaced at 3 by 3 m intervals. Plantations of intercropping biomass would necessarily have higher planting densities, with spacings of 1 by 1 m possible. Seedling stock is usually planted in the fall or spring. Winter plantings should be avoided to minimize the possibility of frost heaving. Nugent (1971) suggests that planted seedlings have a minimum root collar diameter of 1 cm to ensure adequate survival and growth.

Tillage

Biomass plants require some tillage during the first and possibly the second year of growth. Nugent (1971) listed the equipment required to cultivate a 100 hectare tract. Equipment consisted of one 70 hp tractor and a heavy duty disc capable of working on forest sites. Disc cultivation depths of 18 to 20 cm are suggested. Fertilizer should be applied as needed during cultivation. Two to six separate cultivations are required during the first growing season, while one or two passes suffice during the second season.

Biomass crops are rarely cultivated with herbicides, because many of the herbicides used for crop cultivation are also capable of destroying these tree species. If herbicides are used, great care must be taken to minimize contact between the biomass crop and the applied herbicide.

Harvesting Methods

Harvesting biomass requires a technology similar to that used in agriculture. Biomass is grown in rows, like vegetable and field crops, and at a density that facilitates mechanized processing. Mechanical biomass harvesting has been studied by several researchers (Koch and Nicholson, 1978; Mattson, 1981; and Marley, 1982). One of the major drawbacks of biomass intercropping is the limited commercial availability of harvesting equipment. The few privately developed harvesting units have yet to be marketed by equipment manufacturers. Companies interested in biomass crop production must either contract construction of a working harvester or manufacture one with company funds. An example is the 'Jaws' biomass harvester, designed, constructed, and tested by the Georgia-Pacific Corporation in the late 70's for harvesting biomass and scrub growth on plantations and in natural stands. A summary of equipment designed and developed for biomass harvesting follows in Table 5.

Intercropping biomass with loblolly pine is viable until the harvesting phase. Problems associated with biomass

TABLE 5

Designed or developed biomass harvesting prototypes.

Manufacturer and Unit	Dimensions Width	Length	Production Rate
Koch and Nicholson Mobile Chipper	2.8 m	8.6 m	Not Available
Georgia Pacific Biomass Harvester	2.4 m 2.4 m	N/A N/A	5.2 Mg per Hr
Shar Corp. Shar 30	N/A	N/A	1.4 Ha per Hr
Bord na Mona (Ireland) Biomass Harvester	3 m	N/A	2.5 Ha per Hr
Virginia Tech Biomass Harvester	3.5 m	8.0 m	2.3 Ha per Hr

harvesting are difficult to overcome. Few harvesters, if any, are available for commercial production. The cost per harvested dry ton of biomass can range from $11 to $65, depending on harvester characteristics (Marley, 1982). Until the problems associated with harvesting are overcome, biomass intercropping will be extremely limited.

Marketing and Transport of Biomass

Although wood has many uses, tree species grown on short rotations can be used only for fuel. Fiber from juvenile trees is generally too short for use in commercial pulping, while solid wood products require much longer rotations. However, biomass wood chips can be used to fire industrial boilers, particularly those found in the wood products industry. The incentive for using biomass for fuel includes market stability, low cost per kcal, and better control over product availability. And, since many wood product companies use waste wood chips for fuel, the conversion to biomass wood chips could be accomplished with few problems. However, the prospect of marketing biomass to other sources is slight. Few companies are interested in purchasing large, wood-fired boilers to accomodate biomass fuel. Those that do must be assured of a constant supply of biomass fuel chips over time.

Many forest product companies in the South could establish biomass intercrop plantations for 'in-house' use without diversifying beyond the expertise of management, particularly since the production operations are relatively similar. And, although harvesting requires a different technology, biomass establishment and transport could incorporate equipment and methods currently used for plantation pine.

METHODS AND PROCEDURES

Several hypothetical intercropping scenarios were constructed and analyzed to estimate the financial impact of intercrop management on loblolly plantation yields. Efforts were made to analyze plants in each of the major crop groups defined in the previous chapter.

Scenario Assumptions

The assumptions made during this analysis deal with site preparation, plantation configuration and management, and site yields. Generally, assumptions were held constant for all scenarios to facilitate later investment comparisons.

Site Preparation

Analysis precluded cut-over natural stands because of the high cost associated with removing stumps randomly distributed across the site. Old field sites which require little in the way of preparation were not initially considered due to the unrealistically low cost of preparing these sites. Instead, analysis focused on a cut-over plantation subjected to a whole-tree or tree-length mechanical harvest. Advantages of this type of site in terms of preparation include less slash, few hardwood stumps, and a relatively consistent placement of pine stumps.

Cropping patterns suggested at least three intensities of site preparation. Field, vegetable, and forage intercropping required a relatively intense approach designed to remove all slash and stumps from the cropping area. Conversely, biomass intercropping precluded the need for pine stump removal, while the pine monocrop alternative required only minimal preparation prior to establishment.

Site preparation for the agricultural crops involved a seven step operation designed to remove slash, stumps, and level the cleared site. Operations included a chop and burn sequence, followed by stump removal, raking, burning in the windrows, two pass discing, and a last raking to remove fine debris (See Appendix A, Table 1 for details). This was considered adequate for the field, forage, and vegetable intercrops at a total cost of $708 per hectare.

Preparation for biomass intercropping involved a four pass operation where the site was chopped twice, raked, and disced, while pine stumps were left on the site. Preparation costs at this intensity totalled $452 per hectare.

Preparation for the conventional plantation incorporated a low cost approach using a two pass chopping operation and burning. These operations were assumed adequate for pine establishment, based on information presented by Beisinger (1983). The cost of preparation for the conventional plantation totalled $282 per hectare.

A detailed listing of these site preparation alternatives and the associated operating costs are provided in Appendix A, Table 1. Individual operating costs were derived from Kluender (1983) and industrial sources.

<u>Intercropped Plantation Configuration</u>

Planting configuration for the intercropped stand was designed to accommodate production of at least two crops simultaneously. he timber crop was established first, using between row spacings of 8 m and between tree spacing of 2 m. The wide rows allowed establishment and production of other crops during the first years of the rotation. In this case, intercropping was assumed possible on the site for an average 10 year period, after which the stand was converted to a pine monocrop until harvest at age 25.

Operations directly associated with loblolly production on the intercropped plantation included the planting and harvesting operations. Assumed mortality was approximately

10% by age 25, with only 63 trees per hectare lost to disease, damage, or competition. Even lower rates could be expected on well managed intercrop plantations as a result of lower stocking, better care, and less intracrop competition in the later years of the rotation.

The 2 x 8 m spacing pattern accommodated 625 pine seedlings per hectare. A minimum 5 m strip between each row of pine was available for non-timber crops, while a 1.5 m buffer to either side of the crops was used to minimize intercrop competition. The intercropped plantation configuration is illustrated in Figure 11. Cash flows associated with intercropped pine production are detailed in Appendix A, Table 2.

Conventional Plantation Configuration

A monocropped plantation that used more conventional spacing and management practices was considered in the analysis for comparison purposes. Under this configuration, the site was spaced in a 2 x 3 meter pattern common to many southern plantations (See Reisinger, 1983). Production operations associated with pine production in the monocropped stand included planting, chemical release at age 7, and the final harvest at age 25. Cumulative mortality was relatively high, with 50% of the stand succumbing to death prior to

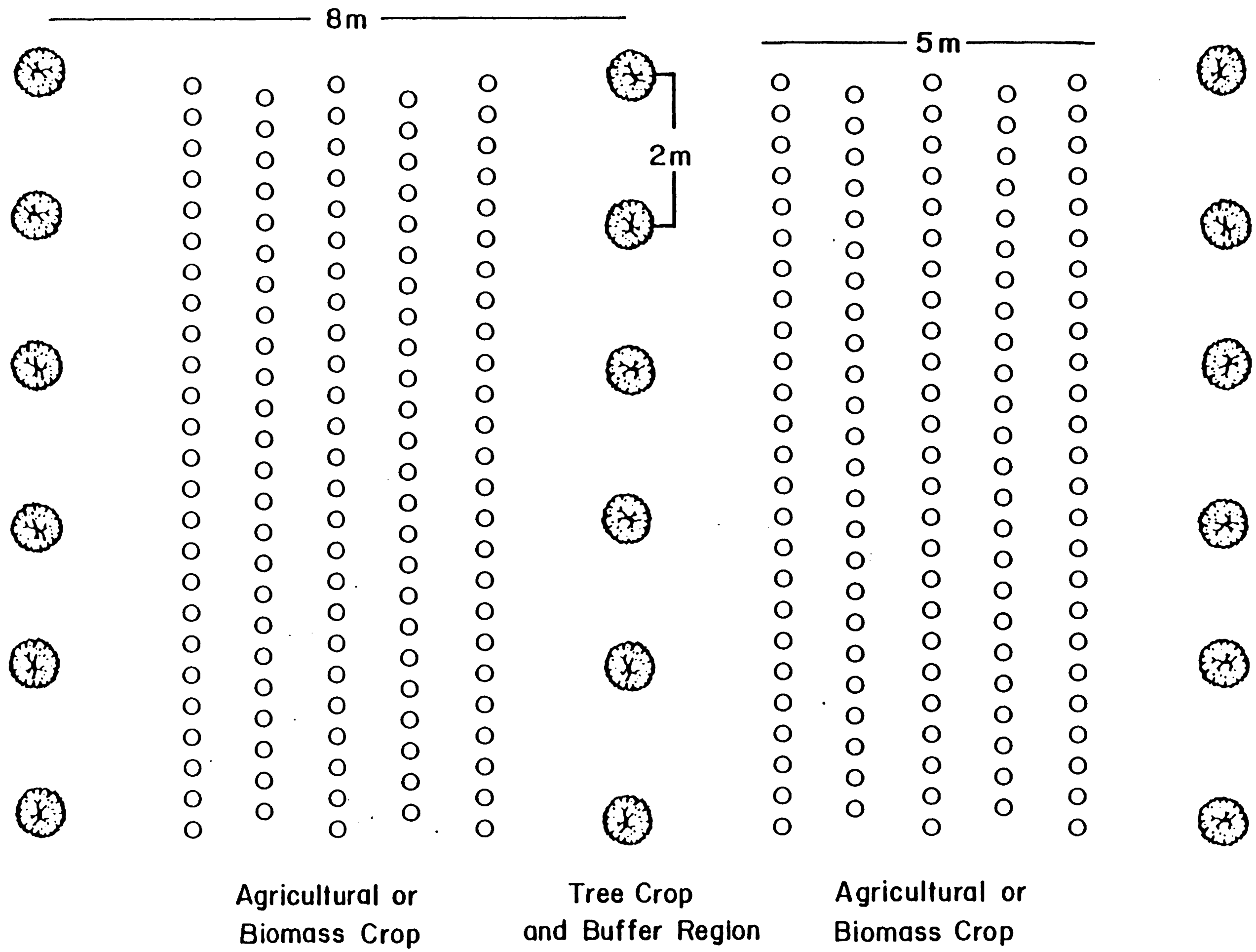


Figure 11: Intercropped plantation configuration.

harvest at age 25. Cash flows associated with the conventional plantation are detailed in the pine crop budget in Appendix A, Table 3.

Pine Production Estimates

Timber yields for a widely spaced, intercropped pine stand were estimated using computer simulation. The original intent of this study was to derive these yields through PTAEDA, an individual tree simulator developed by Daniels and Burkhart (1975) for simulating loblolly pine growth on old field sites. However, the PTAEDA simulator over-predicted tree diameter growth, under-predicted stand mortality, and subsequently produced inflated yield estimates. These problems were corrected by incorporating a diameter growth equation developed by Thurmes (1980) into the original PTAEDA model to accurately reflect diameter growth of stands established on cut-over sites. In addition, the Smalley and Bailey (1974) mortality predictor used in PTAEDA was replaced by a more accurate equation developed by Feduccia et al. (1979). Thorough discussion of the revised individual tree simulator, known as PTAEDAB, and the modifications involved may be reviewed in Reisinger (1983).

Stand growth irregularities using the PTAEDAB model were alleviated by using the original PTAEDA model for the first 17 years, then switching to the PTAEDAB model for the remainder of the rotation. The combined PTAEDA/PTAEDAB model simulated growth and yield of individual trees under user specified spacing and site conditions. The model was used to predict growth in diameter and height as a function of site, spacing, level of competition, and age. The growth and yield values generated, as well as individual tree location coordinates, were used in later simulations of the harvesting process. Parameters used to drive the PTAEDA/PTAEDAB generators follow in Table 6.

The yield and location parameters generated by the PTAEDA/PTAEDAB simulators for the conventional and intercropped plantations were incorporated in GENMAC, a generalized machine simulator, to estimate the production functions of equipment used during harvest operations. A tree length harvesting system was used throughout the simulation. Material was felled and bunched, skidded to a gate delimber and processed, skidded to the deck, and finally loaded by product type onto set-out trailers. The equipment spread, labor organization, and method of operation are provided in Table 7. Discussion of the GENMAC simulator and its capabilities is available in Stuart (1980).

The generated production functions were passed to HSS, the harvesting system simulator, to estimate the total costs

TABLE 6

Stand parameters used in the PTAEDA/PTAEDAR simulator.

Parameter	Assigned Value
Site Index:	
Monocropped	60 at Base Age 25
Intercropped	60 at Base Age 25
Spacing:	
Monocropped	2 x 3 m
Intercropped	2 x 8 m
Trees per Hectare:	
Monocropped	1666 Trees/Ha
Intercropped	625 Trees/Ha
Competition Level:	
Monocropped	166 stems/Ha
Intercropped	156 stems/Ha
Release Age:	
Monocropped	7 years
Intercropped	no release
Harvest Age:	
Monocropped	25 Years
Intercropped	25 Years

TABLE 7

Equipment and method of operation for timber harvest simulations.

Tree Length Harvesting System[1]

<u>Labor Organization</u>:

1	Feller buncher operator
2	Skidder operators
1	Sawyer-deck operation
1	Loader operator/Foreman

5	Total crew required

<u>Equipment Spread</u>:

1	Accumulating Feller Buncher
2	Grapple Skidders
1	Delimbing Gate
1	Knuckleboom Loader
1	Chainsaw

<u>Method of Operation</u>:

Feller buncher fells, accumulates, and bunches trees in the woods. Two grapple skidders skid stems to the gate delimber for delimbing. Limbed stems are then skidded to the landing and deposited beside the loader. At the landing, the sawyer tops and finishes delimbing. The tree length stems are then loaded onto 8.75 cord capacity set-out trailers by the loader operator.

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[1] Operating budgets detailing the costs associated with this harvesting system are provided in Appendix A, Tables 2 and 3.

associated with harvesting the stand generated by PTAEDA. Budgets used to generate the cost and revenue data are provided in Appendix A, Tables 2 and 3. Contract hauling assumptions used throughout the HSS simulation are provided in Appendix A, Table 4. Detailed discussion of the HSS simulator is available in O'Hearn (1977) and Stuart (1980).

Agricultural and Biomass Production Estimates

Many of the crop production estimates used in the analysis were derived from crop budgets for the Coastal Plain of North Carolina provided by Neuman (1984). Cost and production information in these budgets was modified to reflect the constraints associated with intercropping. Continuous cropping patterns were assumed for the field and vegetable crop components.

Agricultural and biomass crops were confined to the strips of land separating the pine seedlings. Production from one intercropped hectare was assumed to provide approximately 60% of the expected agricultural or biomass yields produced when cropping a full hectare. Crop losses from intercrop competition were assumed to be negligible, due to the use of buffer areas between crops and the judicious application of fertilizer, lime, and herbicides on the site. However, field and vegetable crop production and subsequent revenues were modified to reflect the poor production associated with growing agricultural crops on newly cleared forest sites. Yields for these crops were arbitrarily reduced to 50% of expected production in the first year of cropping, 70% in the second year, and 85% in the third. Expected levels were assumed in year 4 and maintained for the remainder of the intercropping period. Forage production was reduced in the establishment year, but reached expected levels by the second year of production. Biomass production rates were not modified, due to expected compatability between crop and site.

Cost estimates were separated into four headings. Operating costs included expenses associated with annual operations, such as fertilizer, seed, and fuel costs. Interest costs included the cost of capital required for annual operations and equipment financing. Equipment depreciation, taxes, and insurance costs were covered as capital costs. Labor costs were included for operations throughout the cropping period. Forage establishment costs were considered capital expenses and categorized as such in the budgets. Crop budgets used in the analysis are provided in Appendix B, Tables 1 - 10.

Scenario Descriptions

Eight crop plants within the four major crop groups defined in this study were selected for analysis under an intercrop setting. Crops were selected for analysis based on several factors. Three field crops were included in the study and included soybeans, dent corn, and winter wheat. These crops are typically grown in Virginia and North Carolina, with well established markets present in both states. In addition, these crops could either be grown using no-till methods or required low intensity management, as in the case of winter wheat. The vegetables included tomatoes and cucumbers. Both of these crops are grown in the study region as process vegetables and could be marketed to process canneries in the Coastal Plain and Eastern Shore areas. The forage crops selected for study included bermudagrass and sericea lespedeza. These hay crops have been studied for their compatibility with pines (Jorgenson and Craig, 1983; Hart et al., 1970) and would probably be the most adaptable on many plantations in the study region. The biomass crop considered for analysis was sycamore which produces nearly twice as much fiber per hectare than any other biomass species studied. Other biomass crops were not considered in the analysis, because of the limited market for biomass wood chips and the problems involved with harvesting the biomass material.

Field Crop-Timber Production

Dent corn, soybeans, and wheat were separately integrated with timber production to determine the financial impact of interplanting field crops with pine. Production operations for the corn and soybean intercrops included discing in the spring, pre-emergent herbicide spray, planting with a sod planter, post-emergemnt herbicide spray, and harvesting with a standard combine. Production operations for the wheat crop included discing, planting, late fertilization, and harvest in June or July. Double cropping (where wheat and soybeans are sequentially cropped on the site) was not considered in this scenario.

Budgets for these crops, presented in Appendix E, Tables 1, 2, and 3 reflect intercrop management and detail the cash flows associated with interplanted field crop production on a per hectare basis. The annual net return from the wheat crop at expected levels of production averaged $49 per hectare, while intercropped field corn returned approximately $60 per hectare. The soybean intercrop provided the greatest net return at $80 per hectare. Revenues for each crop were modified in the first three years of production to account for the lower yields expected from crops on newly cleared forest soils.

Process Vegetable-Timber Production

Two vegetable crops, process tomatoes and pickling cucumbers, were considered in this scenario. Production was restricted geographically to the eastern region of the North Carolina Coastal Plain. Crop production was modified for the first three years of intercropping to account for losses from cropping on newly prepared forest soils. Yields increased annually from 50 to 70 to 85% of expected production over the three year period. Yields attained expected levels in year 4 and were maintained until year 10.

Process tomato production involved fourteen separate operations. Cultivation included two passes with a rolling cultivator, herbicide application, and low bedding. Fertilizer applications were made prior to transplanting and twice during production. Fungicides and insecticides were applied at monthly intervals until harvest in July. Custom harvest and haul were included as part of the operation. Expected net revenues from intercropped tomato production averaged $328 per hectare annually. The crop budget in Appendix B, Table 4 details annual cash flows associated with production.

Cucumber production followed a similar pattern with twelve operations. The site was plowed and disced, fertilized with bulk 10-10-10, and sprayed with nematicide, fungicide, insecticide, and herbicide. These operations were followed by planting, liquid nitrogen application, secondary cultivation, and further herbicide and fungicide applications. The produce was custom harvested in June, providing a net annual revenue of $143 per hectare. A crop budget for this intercrop is provided in Table 5.

<u>Forage-Timber Production</u>

This scenario included analysis of bermudagrass/pine and lespedeza/pine intercropping on Coastal Plain sites in North Carolina. Analysis assumed that all hay yield was sold on the open market in large lots at competitive prices.

The lespedeza intercrop was established at a per hectare cost of $215 with no expected yield in the establishment year and a productive life of 10 years after establishment. Fertilizer and lime were applied during establishment and annually thereafter. Operations included fertilization, liming, and two harvests in June and August. A net revenue of $200 per hectare was provided annually until year 10, when the forage component was phased out of production. Budgets detailing the establishment and production cash flows for this intercrop are presented in Appendix B, Tables 6 and 7.

Bermudagrass was established over 60% of the site in year 1 at a per hectare cost of $326. Lime and fertilizer were applied to the forage in the establishment year and each year thereafter to maintain yields. Production in the establishment year averaged 25% of that provided in years 2 through 10. Operations associated with production were those dealing with fertilization, liming, and harvest operations in May, June, July, and August. Annual net revenues from the bermudagrass intercrop averaged $31 per hectare. Crop budgets outlining establishment and production costs for the bermudagrass intercrop are presented in Appendix B, Tables 8 and 9.

Biomass-Timber Production

One biomass species, sycamore, was analyzed under an intercropped setting with loblolly pine. A 10 year intercrop period encompassing three harvests was assumed for production purposes, although this could conceivably be extended to 15 years and four harvests for widely spaced biomass crops. The stand was established in year 0 and harvested in years 3, 6, and 10. Establishment operations consisted of planting and fertilization on a prepared site. Harvesting operations included felling, chipping, and post-harvest fertilization. Harvest production data for the Georgia-Pacific biomass harvester (Marley, 1982) were used to estimate biomass harvesting costs. Biomass yield in each of the three harvests was assumed constant, although the last rotation was extended to a 4 year interval to account for reduced sprout vigor. Net revenues at harvest averaged $104 per hectare or, taken annually, $34 per year. The budget in Appendix B, Table 10 details cash flows associated with sycamore intercrop production.

Investment Analysis

The presented scenarios were subjected to an investment analysis to determine their value in purely financial terms. In this manner, the intercropped scenarios could be compared against each other and the monocropped pine scenario to evaluate their relative appeal. Two measures of worth were generated in the analysis, present net worth (PNW) and internal rate of return (IRR).

The question of which investment measure is better for evaluating investment proposals depends upon two factors, the appropriate rate of reinvestment for intermediate cash flows and the scale of investment. The internal rate of return ignores the scale of investment and assumes that intermediate cash flows are reinvested at rates that depend on the cash flow stream of the investment being considered. In this sense, cash flows from different investments would be reinvested at different rates when calculating the internal rate of return.

Conversely, the present net worth method assumes a single rate of return for all the cash flows from an investment. The PNW value is also an absolute measure that can be used to directly compare investment alternatives. For these reasons, scenarios were evaluated on the basis of their present net worth under a specified rate of return, assumed to be that rate provided by other available market investments with comparable risks.

Investment Analysis Program

Annual cash flow data for the individual scenarios were entered into an investment analysis program developed by Vasievich and Frebis (1981) at the Southeastern Center for Forest Economics Research. The program was designed and developed for use with the Apple II+ and //e microcomputers.

Input to the analysis package included a chronological listing of management activities, cost and revenue data, and investment parameters. Cost data included estimates for site preparation, planting, herbicide release, intermediate cropping operations, crop harvests, and annual management expenses. Investment parameters required from the user included the appropriate discount rate, expected inflation rate, marginal tax rate, and a series of alternative investment rates used to calculate the present net worth of each investment.

Output from each investment analysis included a summary of the investment parameters, a listing of the transactions considered in the analysis, the cash flows associated with the investment, and the financial analysis results. The financial analysis results include before tax present worth of expenditures and revenues, the present net worth of the investment, a benefit/cost ratio, annual equivalent ratio, composite rate of return, and the internal rate of return. These values are computed for five discount (or alternative) rates of return.

Financial Parameters

The financial parameters required for the investment analysis included product costs and revenues, tax options, the inflation rate, and the discount rate. Once defined, these cash flow factors were held constant throughout the analysis to facilitate later investment comparisons.

Costs and Revenues. Cost categories included site preparation, pine planting, intercrop establishment, chemical release (pine crop), intercrop production, annual management, and timber harvest costs. Specific production costs have been detailed in Appendices A and E. Expenditures were further classified for tax purposes as capital costs, ordinary expenses, reforestation costs, or timber harvesting costs. Generally, the costs associated with intercrop production were considered ordinary expenses. In the case of forage and biomass crops, however, the first year expenses were classified as capital costs for the life of the investment (10 yrs. for the lespedeza, bermudagrass and sycamore intercrops). Site preparation and pine planting costs were classified as reforestation costs in every scenario, while annual management and the chemical release costs were classified as ordinary expenses.

Revenues were classified for tax purposes as either timber related or derived from other sources; ie, intercrop production. Timber revenues were derived using the pulpwood, sawlog, or peeler yields generated through the PTAEDA/PTAEDAR simulation discussed previously in this chapter. Per unit values for each product category were developed from price quotes for delivered wood products published by Timber Mart-South for North Carolina for the 1983 period. The per unit prices are presented in Table 8.

Discount rate. The discount rate, or alternative rate of return for an investment, can vary. While real rates are generally stable over time, nominal or current rates reflect factors like the inflation rate, that cause the nominal rate of return to fluctuate over time. Assuming a real rate of return equivalent to 5 or 6%, as suggested by Beisinger (1983), the contributory effect of inflation on the nominal rate can lead to alternative interest rates ranging from 10 to 25%. For this reason, the investment analysis package was structured to evaluate an investment using several discount rates. The alternative rates considered included 10, 13, 15, 17 and 20% investment rates.

Inflation rate. The analysis was structured to consider the nominal rate of return as an economic parameters and, as a consequence, it was necessary to factor in the effect of inflation on an investment. Fisher (1896) illustrated the effect of inflation on nominal rates using the following simple equation:

$$R = R^o + ro$$

where;
- R = nominal rate of return
- R^o = real rate of return
- ro = weighted average anticipated inflation over project life.

Using the nominal rate of return without considering the effect of inflation on cash flows produces a bias in the selection process, since the rate of return is based on current capital costs that place a premium on anticipated inflation. To avoid bias in the analysis results, an inflation rate of 7% per year was assumed. This rate was suggested by recent long-term forecasts of inflation in the timber industry (Clephane and Carroll, 1982).

<u>Taxes</u>. The analysis assumed corporate tax rates to be appropriate in the analysis. Ordinary income was taxed at 46%, while long-term capital gains were taxed at 28%. Cost categories expensed as capital investments included site preparation, pine planting, and forage crop establishment. The Packwood Amendment (PL 96-451) which allows a 10% investment tax credit and a 7 year amortization of reforestation costs was not applied, due to the relatively small tax savings provided to corporate landowners.

The investment analysis program was not structured to consider agricultural or biomass costs and revenues and, consequently, the effect of potential tax benefits were unaccounted for during the analysis. After tax discounted net worth of the intercrop investments might improve substantially if other taxation factors were considered.

TABLE 8

Summary of financial analysis parameters.

Assumption	Parameter Value
Discount Rate of Return	Five rates considered: 10, 13, 15, 17, and 20%.
Inflation Rate	7% based on Clephane Carroll (1982) forecasts.
Tax Rates	Ordinary Income: 46% Capital Gains: 28% Packwood Amendment (PL 96-451) not considered.
Market Value of Wood Products	Based on monthly averages from Timber Mart-South for North Carolina (1983):

Product	Unit Value
Pulpwood	$ 45.12/cord
Sawlogs	197.93/MBF
Peelers	222.94/MBF

Sensitivity Analysis

A sensitivity analysis was conducted to determine the financial effects associated with relaxation of certain assumptions common to the intercrop scenarios. Analysis focused on site preparation, rotation age, and level of investment.

Site Preparation Intensity

The intensity and cost of site preparation operations were modified to determine what effect these changes would have on the intercropping investment. A site preparation regime was assumed that was equivalent to that used for to prepare the pine monocrop site. Three field crop-pine alternatives were analyzed under this assumed site preparation regime. Details associated with the site preparation process are provided below:

Operation	Passes	Cost
Chop	2	$252.48
Burn	1	$ 29.31
Total Cost per Hectare		$281.79

Site preparation costs under this regime fell by $428 per hectare (60% reduction) when compared with the intensive approach used in the previous analyses. All other factors of production were held constant, including crop and timber yields. Analysis was restricted to the soybean, wheat, and corn intercrops. The crop budget for the timber component is available in Appendix A, Table 2, while budgets for the field crop components are provided in Appendix B, Tables 1, 2, and 3.

Early Rotation Age

Stand simulations using PTAEDA/PTAEDAB suggested that diameter growth rates for widely spaced intercropped stands can exceed rates for conventionally spaced plantations. Reducing the rotation age of an intercropped plantation from 25 to 20 years was examined to determine the effect on product type and the present net worth of the investment. The PTAEDA/PTAEDAB simulator was used to estimate the effects of shorter rotations on stand production, while the GENMAC and HSS simulators were incorporated to estimate harvesting costs on the intercropped plantation. A detailed crop budget based in part on these results is given in Appendix C, Table 1. Analysis was restricted to the three field crop-pine investments. Field crop production levels were assumed to be unaffected by the change in rotation age (See Appendix B, Tables 1, 2, and 3 for detailed field crop budgets).

Leased Plantation Option

The final alternative considered in the analysis was a lease arrangement where the site is prepared for intercropping, but leased on an annual basis for intercropping agricultural or biomass crops. It was hypothesized that a lease arrangement can reduce the total cost of investment, while providing an income stream early in the rotation.

Three lease holding scenarios were considered, based on different lease rates, ranging from $15 to $40 per leased hectare. The timber crop was managed under a 25 year rotation and configured in a 2 x 8 m spacing equivalent. A representative crop budget detailing the cash flows associated with the leased scenarios is provided in Appendix C, Table 2.

RESULTS AND DISCUSSION

Discounted cash flow analysis was performed to determine the present net worth of the nine investment alternatives outlined in Chapter IV. Investment present net worth was computed for five discount rates ranging from 10 to 20%. A summary of results for each investment at a 13% discount rate is provided in Table 9.

The three investment measures used for investment comparisons included investment present net worth, internal rate of return, and the benefit/cost ratio. Present net worth (PNW) provides a measure of the present value of investment cash flows over time, while the internal rate of return (IRR) pairs gross revenues with costs to measure the rate of return provided by an investment. The IRR of an investment can be compared with a target investment rate for capital budgeting and decision making purposes. The benefit/cost ratio is simply a ratio of the gross revenues divided by the total cost of investment at a particular discount rate. B/C ratios that exceed 1.0 suggest a profitable investment, while those that fall below 1.0 are considered unprofitable at the investment rate of return used. The B/C ratio measures the magnitude of costs and revenues in relation to each other and provides a ratio that can be used for direct investment comparisons.

Tax Effects

The effect of taxation on the intercropped investments using the Forestry Investment Analysis Package was substantially greater than that for the conventional, or monocropped pine, investment. The capital gains treatment afforded the timber revenues significantly reduced the level of tax incurred by the conventional investment. Conversely, revenues from agricultural and biomass production were taxed as ordinary income (46% of the revenue basis) and, as a result, all of the intercrop investments realized substantial declines in revenue due to taxation. The effect of taxation increased with increasing crop revenues, as indicated in Table 9. These differences occurred because the forestry investment analysis package failed to account for alternative tax strategies for the agricultural and biomass crop revenues. For this reason, the analysis results are presented using before-tax cost and revenue information. The after-tax results illustrate a worst case tax position for the intercrop investments, since the tax benefits that might be available to reduce crop revenue taxes were not considered in this analysis.

TABLE 9

Before and after tax per hectare present net worth for intercropped and conventional plantation investments.

Investment Alternative	Tax Basis	*Present Net Worth per Hectare* *-----Investment Rate-----* 10%	13%	15%	17%	20%
Intercropped Investments:						
Field Crops:						
Soybean-Pine	BT	$2576	$1156	$ 611	$ 249	-$ 87
	AT	1800	659	226	- 58	- 316
Dent Corn-Pine	BT	$2321	$ 932	$ 403	$ 57	-$ 260
	AT	1660	536	113	- 162	- 410
Winter Wheat-Pine	BT	$2249	$ 880	$ 361	$ 24	-$ 282
	AT	1623	509	91	- 179	- 421
Vegetable Crops:						
Tomato-Pine	BT	$3467	$1747	$1039	$ 538	$ 31
	AT	2281	981	460	100	- 251
Cucumber-Pine	BT	$2269	$ 800	$ 228	-$ 153	-$ 513
	AT	1650	472	23	- 273	- 544
Forage Crops:						
Bermudagrass-Pine	BT	$2238	$ 847	$ 317	-$ 30	-$ 348
	AT	1630	498	72	- 206	- 455
Lespedeza-Pine	BT	$1884	$ 573	$ 86	-$ 225	-$ 498
	AT	1440	351	- 53	- 311	- 536
Biomass Crop:						
Sycamore-Pine	BT	$1799	$ 460	-$ 41	-$ 363	-$ 651
	AT	1145	349	58	- 125	- 282
Monocropped Investment:						
Loblolly Pine	BT	$1312	$ 410	$ 82	-$ 123	-$ 296
	AT	1507	405	- 5	- 269	- 282

Investment Analysis Results

Field Crop-Pine Scenario

The three field crops examined for intercropping with loblolly pine included soybeans, dent corn, and winter wheat. The best investment in terms of present net worth was the soybean-pine alternative with discounted net revenues of $1156 per hectare before taxes. In comparison, the winter wheat and dent corn intercrops provided before tax discounted returns of $880 and $931 per hectare, respectively. The internal rate of return (IRR) generated by these crop combinations ranged from 17.18% for winter wheat-pine to 19.05% for the soybean-pine combination. The soybean-pine investment provided between 24% and 31% more before tax discounted net revenue than the corn-pine and wheat-pine combinations, respectively.

The field crop-pine alternatives typically required only moderate capital investment for crop production. Before-tax discounted total investment costs ranged from $2972 per hectare for the wheat-pine alternative to $3767 per hectare for the dent corn-pine investment. Other pertinent analysis results are summarized in Tables 9 and 10.

Vegetable Crop-Pine Scenario

The alternatives analyzed under this scenario included tomato-pine and cucumber-pine intercrops. Based only on investment present net worth, the tomato-pine intercrop proved the better investment with a before tax discounted net worth of $1748 per hectare. Conversely, the cucumber-pine investment yielded relatively lower discounted returns of $799 per hectare. The IRR generated by these crop combinations ranged from 16.10% for cucumber-pine to 20.24% for tomato-pine. The substantial difference in discounted net worth for similar management efforts can be attributed to the lower annual revenues from process cucumber production combined with the high annual establishment costs. These factors, coupled with assumed crop production losses in the first 3 years of intercropping, contributed to net negative cash flows over portions of the intercropping period for the cucumber-pine alternative. In contrast, the tomato-pine alternative yielded greater discounted revenues, primarily because of the higher net returns from tomato crop sales relative to annual production costs. For this reason, the losses from reduced tomato yields did not have a significant impact on investment net revenues.

The cucumber-pine investment illustrates what can happen when a crop requiring a large annual production investment incurs financial losses. Because these losses can and do occur, vegetable-pine intercrops must be considered high risk investments, particularly in the event of a crop failure. Annual establishment costs for the vegetable crop is typically large and, although gross returns usually cover these costs, irreversible financial losses could occur in just one season.

Forage-Pine Scenario

Before tax discounted net revenues from the two forage-pine alternatives were relatively high, although the serecia-pine alternative yielded approximately 32% less than the bermudagrass-pine combination. The bermudagrass-pine investment had a present net value of $846 per hectare before taxes, while the serecia-pine alternative yielded only $573 per hectare. Discounted investment costs were 15% greater for the bermudagrass-pine investment, resulting from the greater management effort required for bermudagrass hay production. The IRR generated by these investments ranged from 15.47% for serecia-pine to 16.79% for bermudagrass-pine, lower than the vegetable- and field crop-pine scenarios.

The difference in investment worth between these two forage investments resulted from lower forage production and, consequently, lower revenues from the serecia crop.

However, the total cost of production associated with the serecia-pine intercrop was approximately 13% less than that required for the more intensive bermudagrass-pine investment.

Biomass-Pine Scenario

The single alternative analyzed for biomass-pine intercropping, the sycamore-loblolly investment, showed the least financial promise of those intercrops analyzed, with a discounted before tax net worth of $460 per hectare. Before tax discounted investment costs were $2283, making the biomass-pine investment the least cost intercrop alternative. However, because biomass harvesting systems are still unavailable for general use, investment levels greater than those assumed in this analysis may be required. The analysis results are summarized in Tables 9 and 10.

Discussion of Results

Investment Comparisons

A comparison of investments (Table 9 and Figure 12) suggests that certain crop combinations can provide greater discounted net returns than a conventionally managed pine plantation. At the 13% discount rate all of the eight intercrop investments provided before-tax net revenues exceeding those from the conventional plantation.

TABLE 10

Investment Analysis Results for Intercropped and Conventional Plantation Investments

Investment Alternative	IRR (%)	Benefit/Cost Ratio	Discounted[1] per hectare PNW	Discounted[1] per hectare Costs
<u>Field Crop-Loblolly Pine Investments</u>:				
Before Taxes:				
Soybean-Pine	19.05	1.35	$1156	$3312
Corn-Pine	17.42	1.25	$ 931	$3767
Wheat-Pine	17.18	1.30	$ 880	$2972
After Taxes:				
Soybean-Pine	16.52	1.17	$ 659	$3853
Corn-Pine	15.72	1.11	$ 536	$4233
Wheat-Pine	15.58	1.15	$ 509	$3388
<u>Vegetable Crop-Loblolly Pine Investments</u>:				
Before Taxes:				
Tomato-Pine	20.24	1.16	$1748	$18132
Cucumber-Pine	16.10	1.17	$ 799	$11204
After Taxes:				
Tomato-Pine	17.71	1.10	$ 982	$19433
Cucumber-Pine	15.13	1.11	$ 472	$11891
<u>Forage-Pine Investments</u>:				
Before Taxes:				
Bermudagrass-Pine	16.79	1.39	$ 846	$4501
Serecia-Pine	15.47	1.15	$ 573	$3902
After Taxes:				
Bermudagrass-Pine	15.44	1.10	$ 498	$5013
Serecia-Pine	14.68	1.08	$ 351	$4324
<u>Biomass-Pine Investments</u>:				
Before Taxes:				
Sycamore-Pine	14.80	1.20	$ 460	$2283
After Taxes:				
Sycamore-Pine	14.46	1.15	$ 405	$2621
<u>Monocropped Pine Investment</u>:				
Before Taxes:				
Loblolly Pine	15.69	1.31	$410	$1343
After Taxes:				
Loblolly Pine	15.53	1.24	$349	$1475

[1] Present values computed using a 10% discount rate.

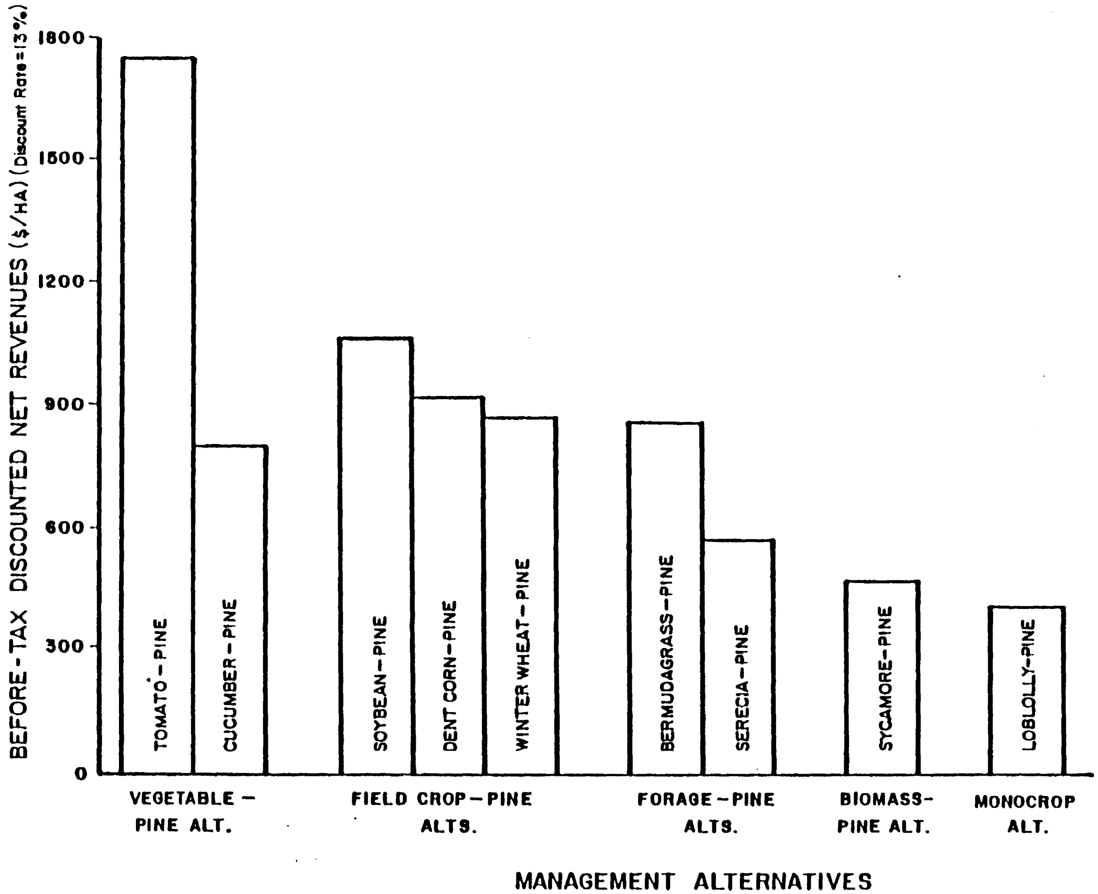

Figure 12: Before-tax comparison of discounted net revenues from the intercropped and conventional plantation investments.

Comparison of the two highest yielding investments, the tomato-pine and soybean-pine combinations, suggests a difference in discounted net worth of more than 50% favoring the tomato-pine combination. However, the internal rate of return for these investments are very similar (Figure 13), with a value of 20.24% for the tomato-pine combination and 19.07% for the soybean-pine combination.

Critical investment differences are revealed when comparing discounted total costs for the two investments, as illustrated in Figure 14. The tomato-pine intercrop required 415% more in discounted total costs than the soybean-pine combination, totalling more than $18,000 per hectare. For this reason, tomato-pine, or any vegetable-pine, intercropping is probably restricted to smaller tracts that can be intensively managed.

The substantially higher investment costs and potential risk associated with tomato-pine intercropping on large acreages imply that the low cost soybean-pine combination is perhaps preferred on large tracts devoted to plantation intercropping. A soybean-pine combination could be incorporated on a much larger scale with less risk and lower per hectare production costs. In addition to the lower investment costs and relatively high rate of return, marketing the soybean crop, or any field crop, would require much less effort.

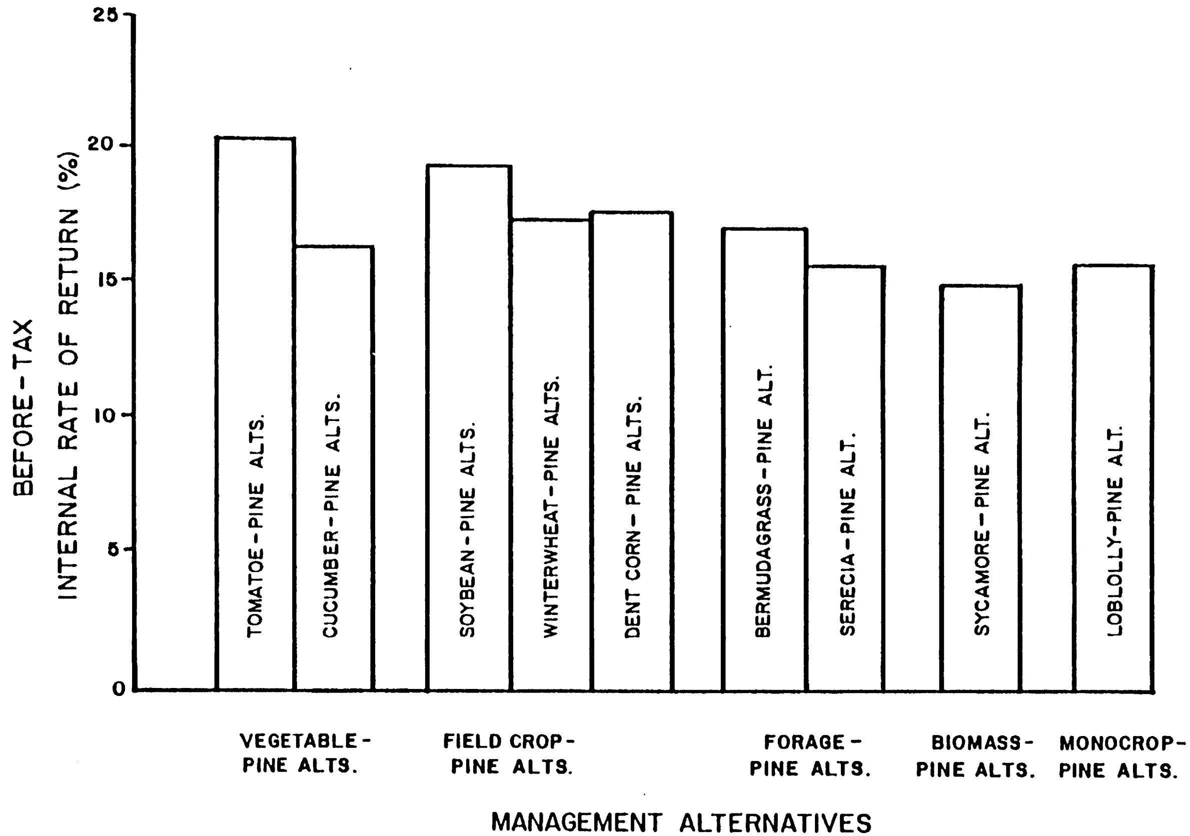

Figure 13: Before-tax comparison of internal rates of return for several intercrop and conventional investment alternatives.

A general comparison of the intercropped and conventional plantation investments using present net value indicates that intercropping typically increased expected before-tax investment revenues. Two other measures of investment potential, the benefit/cost ratio and the internal rate of return, were also evaluated to provide more detailed information about comparative investment potential.

Before-tax benefit/cost ratios for the intercrops ranged from 1.15 for the serecia-pine investment to 1.35 for the soybean-pine combination. The field crop-pine alternatives characteristically developed higher B/C ratios, averaging 1.30 for the three investments considered, while the vegetable-pine alternatives ranked lowest as a group with an average B/C ratio of 1.165. In contrast, the conventional pine investment generated a B/C ratio of 1.31. The high B/C ratio associated with the conventional plantation resulted from the lower establishment costs for this investment and suggests that, in general, B/C ratio values are affected by moderate differences in the cost and revenue functions.

The before-tax internal rate of return (Figure 13 and Table 10) generated by the intercrops ranged from 14.80% for the sycamore-pine investment to 20.24% for the soybean-pine alternative. However, the field crop-pine alternatives as a group generated an average IRR of 17.88%, comparing favorably with the more intensive vegetable-pine combinations with an IRR averaging 16.17%. The conventional pine investment generated an IRR of only 15.69% before taxes and compared poorly with all but one of the intercrop investments (biomass-pine).

The comparisons, when summarized, suggest the following:

1. The conventional plantation is clearly not a superior investment when compared with the intercrop alternatives using criteria such as IRR, present net worth, and benefit/cost ratios.
2. The two most lucrative intercrops, the tomato-pine and the soybean-pine alternatives, differ in terms of investment risk. While before tax discounted revenues for the tomato-pine alternative are superior, discounted total costs may not justify this increased return. The soybean-pine alternative, on the other hand, requires less total investment, while providing high discounted revenues. In addition, IRR and B/C ratio comparisons generally favored the more consistent field crop-pine investments.
3. The intercrop alternative selected by an individual or company will depend primarily on the desired level of risk. The vegetable-pine combinations can gener-

ate greater per hectare revenues over a range of discount rates (Figure 15), but involve substantially greater risk than the field crop-pine intercrops.

<u>Shifts in the Investment Discount Rate</u>

The shape of before-tax present net revenue functions graphed in Figure 15 indicates that, at low discount rates, all eight of the intercrop alternatives analyzed are capable of providing greater returns than the conventional plantation investment. As the discount rate increases, however, this pattern changes and net revenue functions for certain intercrop investments fall below that for the conventional plantation, even when crop prices are held constant. Differences in the shape of these investment curves can be explained, in part, by the effect of discounting on the intermediate returns from agricultural or biomass production. When the discount rate is increased, these revenues fail to offset site preparation and establishment costs, causing discounted net revenues from the investment to decline at a faster rate than the conventional plantation investment. As a result, intercrop investments with high site preparation and establishment costs combined with low annual crop revenues face a greater decline in discounted worth when interest rates shift upward. The more intensive intercrop alterna-

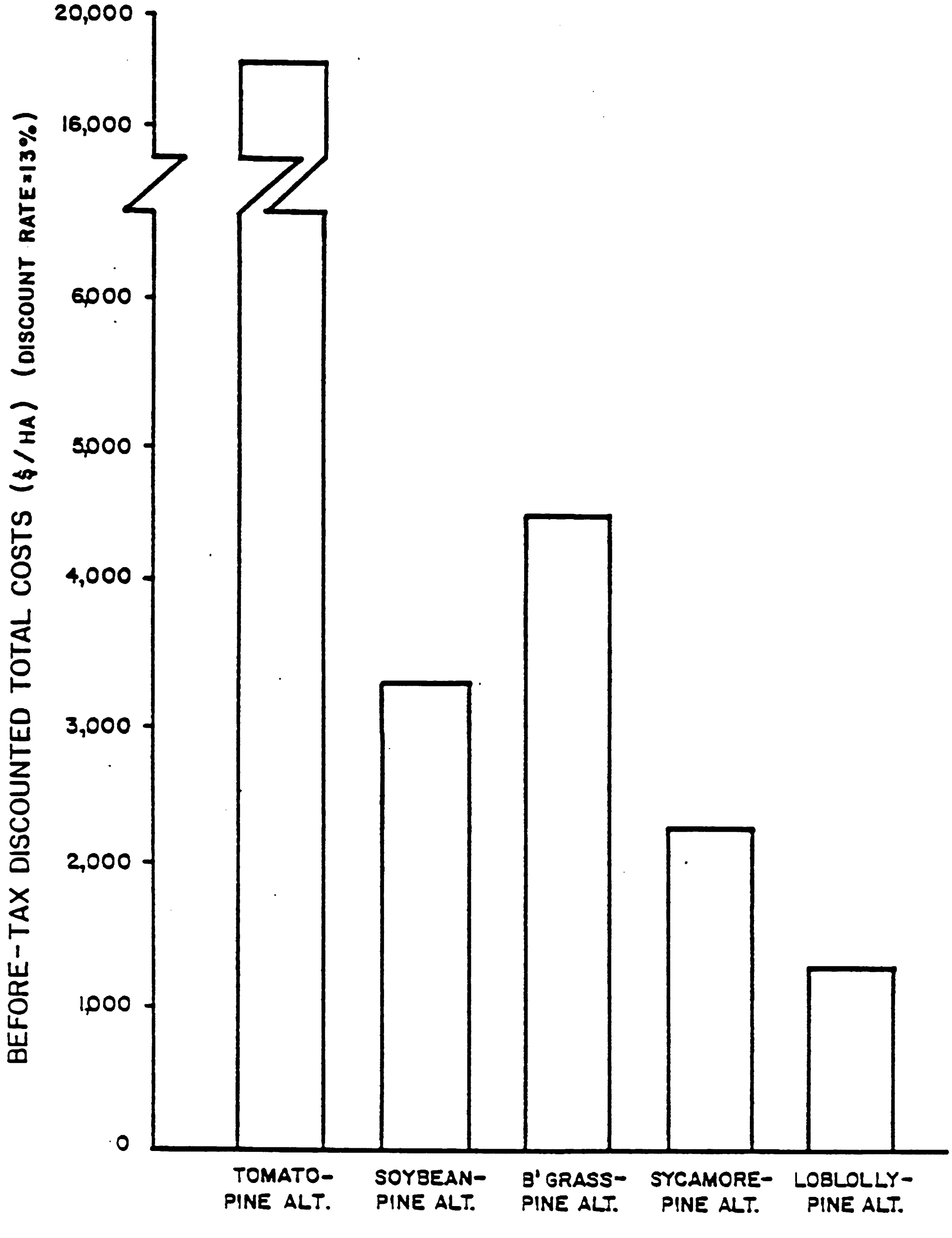

Figure 14: Before-tax comparison of discounted total costs for selected intercrop and conventional plantation investments.

tives are less affected by this rate of decline, but similar problems could be encountered where preparation and establishment costs increase. Situations where these costs can increase, such as clearing and establishing cut-over natural stands, should probably be avoided. Another way to overcome this problem is through the use of double cropping, where two agricultural crops are grown in sequence on the site. Wheat and soybean double crops are commonly grown on the Coastal Plain to increase net revenues from cropping. This practice, while somewhat more intensive than the patterns used in this study, could be used to increase net revenues when discount rates become significantly higher.

Timber Yields

One of the basic concerns associated with this analysis was the possible reduction in timber yield under the wide spacings required for intercrop production. However, PTAEDA/PTAEDAR simulations using this wide pattern suggest that timber revenues from intercropping can be roughly equivalent to those provided under conventional spacings. Typically, the intercropped stand increased veneer log yield by 142%, while pulpwood volumes declined by 179%. Mean stand parameter values from two sample populations comprised of 30 simulation runs show significant differences in mean height,

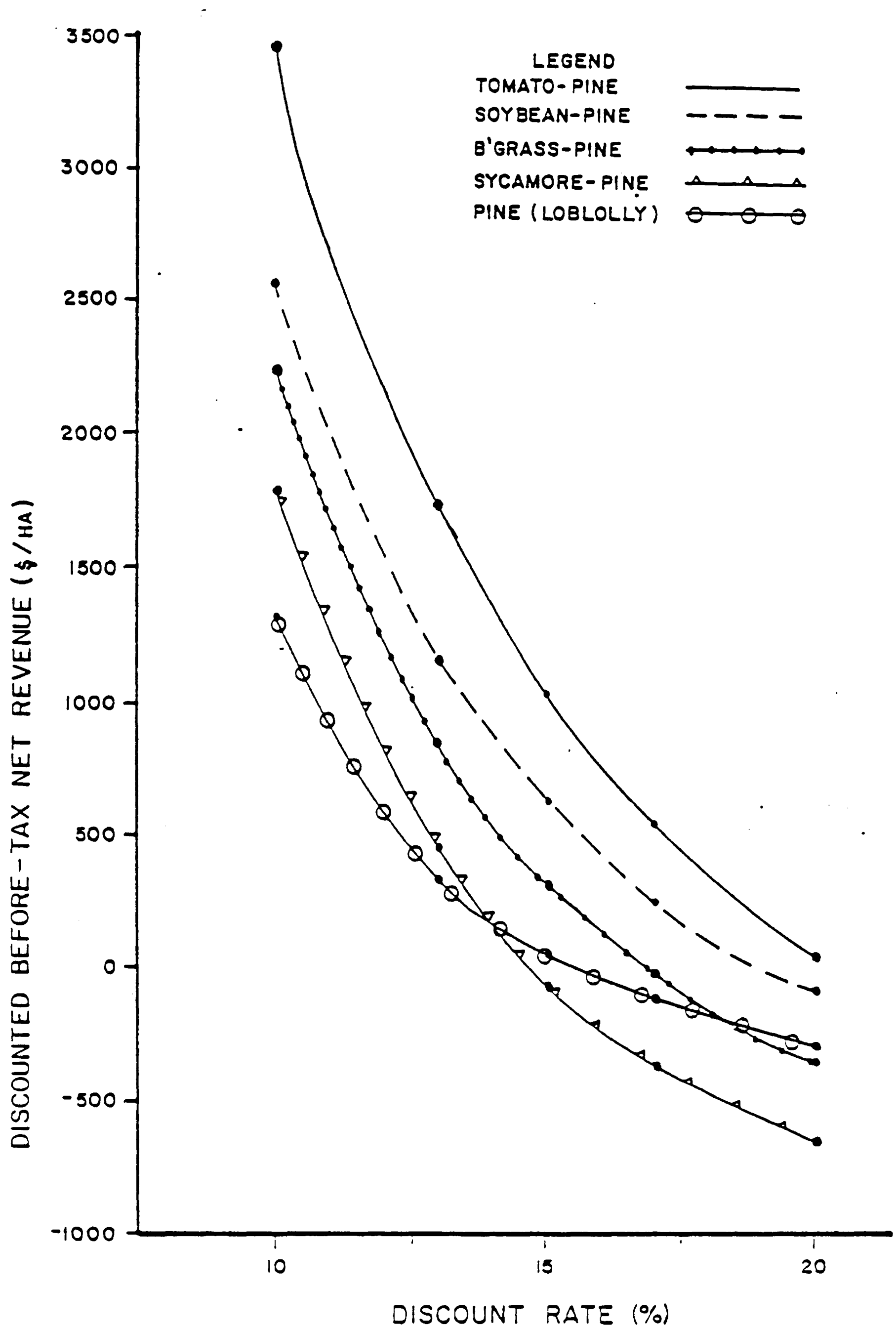

Figure 15: Discounted before-tax net revenue functions of selected intercrop and conventional investments.

diameter, and total volumes as indicated below:

Stand Simulated	Mean DBH (cm)	Mean Height (M)	Mean Total Volume (m^3/Ha)
Intercropped Pine	29.31	17.89	808.1
Monocropped Pine	22.07	16.67	842.0

Average diameter (DBH) in the intercropped stand was approximately 33% larger and mean height increased by 7%. In contrast, per hectare volumes increased from 808.1 m^3 for the intercropped stand to 842.0 m^3 for the monocropped stand as a result of the greater number of trees supported on the monocropped stand. Based on prices for logs delivered at the mill, gross revenue from the intercropped stand were $8444, while the conventional plantation generated $6703 in gross revenues. The costs and revenues associated with each alternative are summarized in Table 11, while product revenue differences are illustrated in Figure 16.

The shift in product mix from pulpwood to veneer under wider spacings are supported by at least two studies. In one widely spaced 15-year-old-stand, loblolly pine grown under 13 m^2 spacings developed an average DBH of 22.6 cm on a SI 75 (25 yrs) site. Four other stands with spacing patterns that ranged from 3 m^2 to 9 m^2, developed significantly smaller diameters, although average height in the five

TABLE 11

Estimated Cost and Revenue Summary for Intercropped and Monocropped Pine Plantations[1]

Product	Units	Volume/Ha	Price[2]	Value/Ha
Monocropped Pine				
Harvest Revenue:				
Pulpwood	Cds	46.50	$ 45.12	$2098.08
Sawlogs	MBF	14.23	197.93	2816.12
Veneer	MBF	8.72	222.94	1943.58
Gross Revenue per Hectare				$6703.27
Harvest Cost:				
Cost per Delivered Cord				$ 23.16
Cords per Hectare				129.32
Total Harvest Cost per Hectare				($2995.20)
Net Revenue per Hectare				$3708.07
Intercropped Pine				
Harvest Revenue:				
Pulpwood	Cds	16.61	$ 45.12	$ 749.44
Sawlogs	MBF	15.15	197.93	2998.19
Veneer	MBF	21.08	222.94	4697.05
Gross Revenue per Hectare				$8444.67
Harvest Cost[2]:				
Cost per Delivered Cord				$ 24.28
Cords per Hectare				125.45
Total Harvest Cost per Hectare				($3046.43)
Net Revenue per Hectare				$5398.24

[1] See Appendix A, Tables 2 and 3 for detailed harvesting cost and revenue summary.

[2] Average price for delivered material in 1983 for North Carolina-quoted from Timber Mart-South.

stands were relatively equivalent. A portion of the trees grown at the 13 m² spacing were of sawlog dimension by age 15 (Balmer et al., 1975). A later study by Harms and Lloyd (1981) of the same stand at age 20 indicates that this trend in stand growth continues late into the rotation. Mean diameter of the stand on 13 m² spacings increased to 24.9 cm at a mean total height of 19.3 m. In addition, the height to live crown for the widely spaced stand was equivalent to that for the closely spaced stands, suggesting that self-pruning characteristics of loblolly pine may not be dependent on spacing parameters.

The simulation results have not been verified by field testing, but do suggest that the intercropping alternative can generate timber products of equivalent or greater worth than timber from conventionally spaced stands.

Sensitivity Analysis

Site Preparation Intensity

Site preparation intensity was modified in this portion of the analysis to determine the financial effect of variation in preparation costs. Three field crop-pine intercrops were subjected to the investment analysis using an assumed site preparation cost of $282. The results of this analysis follow in Table 12.

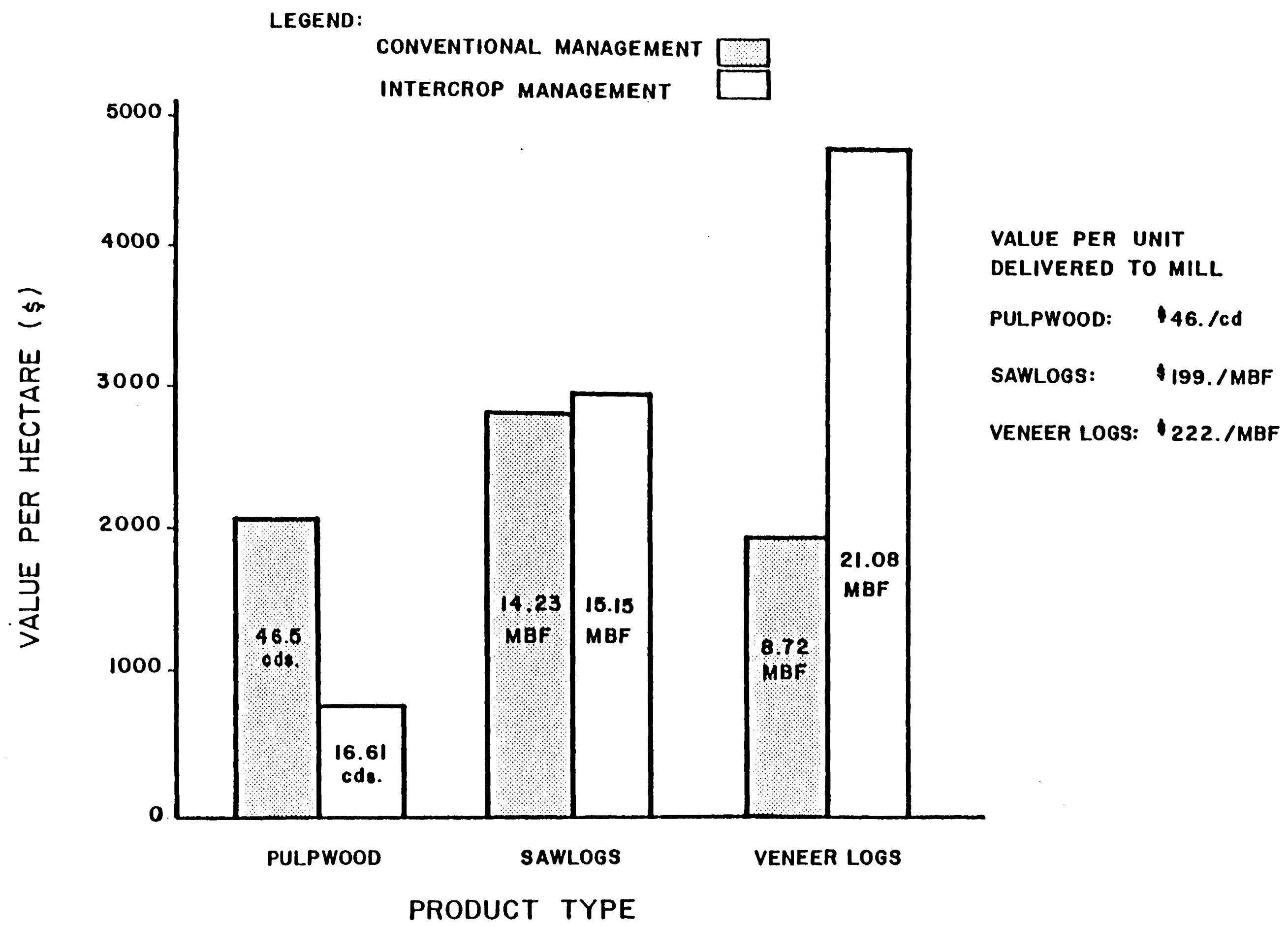

Figure 16: Breakdown of intercropped and conventional plantation yields by product type.

TABLE 12

Intercrop investment characteristics under a low intensity site preparation regime.

Intercrop Investment	IRR (%)	B/C Ratio	Discounted[1] per hectare PNW	Costs
Before Taxes				
Soybean-Pine	26.74	1.55	$1584	$2886
Dent Corn-Pine	22.71	1.41	$1359	$3341
Winter Wheat-Pine	22.42	1.51	$1086	$2766
After Taxes				
Soybean-Pine	22.11	1.32	$1085	$3426
Dent Corn-Pine	20.29	1.25	$ 963	$3807
Winter Wheat-Pine	20.09	1.32	$ 935	$2962

[1] Cost and revenue data computed at a 13% discount rate.

These results support the hypothesis that site preparation costs can critically affect the profitability of an intercrop investment. Where an intensive preparation regime was assumed (ie; cut-over plantation) the intercropped plantation required more investment capital, although before-tax discounted net returns were generally superior to those from a conventional plantation (See Table 9). However, where preparation costs for the intercropped and conventional investments are comparable, discounted net revenues can range as high as $1584 per hectare before taxes (soybean-pine alternative), a 286% increase over conventional plantation returns.

Investment revenue differences imply that old fields and other tracts requiring less preparation will generally provide greater returns from an intercropped plantation investment. In addition, the risk of failure on these old field sites is minimized due to the lower site preparation and establishment costs involved. The lower investment risk, potentially greater revenues, and better site quality comprise three factors that favor these sites over cut-over tracts for plantation intercropping.

Early Rotation Age

Subjecting the intercropped plantation to harvest 5 years early generally reduced investment value. Based on a 13% discount rate, net revenue from three field crop-pine investments subjected to a 20 year rotation ranged from $216 to $492 per hectare before taxes. Analysis results are summarized in Table 13.

A revenue comparison between this alternative and a conventional plantation harvested at age 25 demonstrates significant differences in investment revenue favoring the conventional investment. The decline in investment worth under an early rotation strategy resulted from smaller timber yields and the low product value associated with these yields. The stand parameter and product yield summaries in Table 14 detail these differences.

Pulpwood yield from the 20-year-old intercropped stand was 36% less than that from the conventional plantation, although sawlog and veneer yields were comparable. These product differences were equivalent to a $1393 per hectare lower return from the 20-year-old stand in terms of gross revenue.

Generally, product yields from a widely spaced intercropped stand on a 20 year rotation will not match those from a conventional plantation harvested at age 25. While

TABLE 13

Investment characteristics of an intercropped pine plantation under early rotation management.

Intercrop Investment	IRR (%)	B/C Ratio	Discounted[1] per hectare PNW	Costs
<u>Before Taxes</u>				
Soybean-Pine	17.32	1.13	$ 492	$3667
Dent Corn-Pine	15.17	1.07	$ 269	$4122
Winter Wheat-Pine	14.77	1.07	$ 216	$3327
<u>After Taxes</u>				
Soybean-Pine	15.01	1.06	$ 245	$3964
Dent Corn-Pine	13.96	1.03	$ 123	$4343
Winter Wheat-Pine	13.75	1.03	$ 96	$3499

[1] Cost and revenue data computed at a 13% discount rate.

larger trees are available on the intercropped stand, the greater number of trees harvested from the conventional plantation have a greater effect on per hectare volumes and, subsequently, the value of production.

Comparison of the early rotation yields with those from an intercropped plantation harvested 5 years later reveals significant increases in veneer and sawlog volumes, while pulpwood yield remained relatively constant. The greater veneer and sawlog production for the stand harvested at 25 years contributed to gross revenue differences of $2528 per hectare.

<u>Leased Plantation Option</u>

The leased plantation options were relative profitable. Discounted net revenues ranged from $480 to $378 per hectare and benefit/cost ratios were comparable to that provided by the conventional plantation investment, ranging from 1.24 to 1.20 after taxes. The discounted cost of investment ranged from $1998 to $1912 per hectare after taxes. These lower costs were realized by avoiding crop production during the intercrop period and allowing the leasee to incur the responsibility of production costs. A summary of the analysis results follow in Table 15.

TABLE 14

Stand parameters and product yield for intercropped and conventional plantations under different rotation ages.

Stand Parameter Comparison:

Investment Alternative	Mean Diameter (cm)	Mean Height (m)	Mean Volume (m^3/Ha)
25 yr Monocrop	22.07	16.67	842.00
25 yr Intercrop	29.31	17.89	808.12
20 yr Intercrop	25.30	16.67	550.66

Product Comparison:

Investment Alternative	Pulpwood (cds/Ha)	Sawlog (MBF/Ha)	Veneer (MBF/Ha)
25 yr Monocrop	46.50	14.23	8.72
25 yr Intercrop	16.61	15.15	21.08
20 yr Intercrop	15.62	13.32	9.72

TABLE 15

Investment characteristics of loblolly pine plantation leased for intercropping.

Lease Option	IRR (%)	B/C Ratio	Discounted[1] per hectare PNW	Costs
Lease Rate=$40/Ha:				
Before Taxes	16.90	1.49	$809	$1650
After Taxes	15.44	1.24	$480	$1998
Lease Rate=$25/Ha:				
Before Taxes	16.43	1.44	$734	$1650
After Taxes	15.19	1.22	$439	$1964
Lease Rate=$15/Ha:				
Before Taxes	15.78	1.38	$621	$1650
After Taxes	14.85	1.20	$378	$1912

[1] Cost and revenue data computed at a 13% discount rate.

The lease option generated a constant net income over a 10 year period that was unaffected by variations in crop yield. In addition, lease rates as low as $15 per hectare per year were more profitable than the conventional plantation. However, if the additional costs required to prepare a plantation for intercrops are considered, these revenues appear to be unprofitable. Comparison of site preparation regimes (See Appendix A, Table 1) indicates that preparation for an intercropped site typically increased costs by $427 per hectare under the most intensive site preparation regime. Lower planting costs for the intercropped plantation (See Appendix A, Tables 2 and 3) reduces this amount to $326 per hectare. Thus, total lease revenue from an intercropped plantation must, in this case, exceed $326 per hectare to be profitable. Conversion of this value into an annual income stream over a 10 year lease period indicates that an annual lease revenue of $60 per hectare must be realized before the intercrop portion of the investment can break even.

The lease alternative, however, does consider the incidental benefits of intercropping, such as intensive site preparation, annual site fertilization, and early weed control practices that will take place during agricultural and biomass production. Although these factors are currently unquantified, their incorporation is probably complementary to timber production.

SUMMARY AND CONCLUSIONS

This research examined the feasibility of intercropping agricultural and biomass crops with loblolly pine on plantations in the Southeast, with particular emphasis on Virginia and North Carolina. Study focused on the following three topics:

1. Site and plant characteristics relative to forest intercropping,
2. Evaluation of potential intercrop plants, and
3. Analysis of the investment potential of an intercropped plantation.

The following sections summarize the findings of this study relative to these topics.

Site and Plant Characteristics

Intercropped pine plantations should be restricted to fertile soils capable of supporting agricultural crops. Soils with poor drainage, pans, or pH extremes should be avoided. Site selection should also focus on past management history and related factors. Old fields require less site preparation, while cut-over plantations and natural stands contain stumps that will generally hinder agricultural cropping operations. Methods are available for efficiently removing stumps from plantations, but do not work with natural stands where the stumps are randomly placed and costly to remove.

Forest intercropping is most efficient in a plantation setting where agricultural or biomass cropping can be accommodated between uniformly spaced tree rows. Thus, planting rather than direct seeding or natural regeneration is the only method that can be used to establish an intercropped pine site.

Soil conditions prevalent on certain soils in the South can have a significant impact on the success of plantation intercropping. Coastal Plain sites and abandoned agricultural fields have nutrient and erosion problems that can complicate intercrop management. Soil texture, nutrient availability, moisture conditions, and aeration affect not only the soil-plant interactions, but also plant-plant interactions. These factors should be considered when selecting both the plantation site and the intercrop species grown with the pine.

Potential intercrops can compete with the pine for light, moisture, and nutrients. Different planting patterns are useful for controlling intercrop competition, although in some cases a buffer strip between crops may be the only solution. Competition for light can be controlled by orienting the plantation in an East-West direction and by selecting crops of comparable height. Moisture and nutrient competition between the pine and other crops will depend on rooting structure, available moisture, and plant proximity.

Evaluating Available Crops

The four crop groups considered in the evaluation included field crops, high value crops, forages, and biomass. These groupings define different crop markets, management intensities, and product values. In addition, production operations for each crop group are relatively different.

Field crops generally require highly fertile, mildly acid soils that can be tilled and cultivated without erosion or degradation. Common summer crops include corn, soybeans, cotton, and sorghum, while winter crops primarily consist of the small grains. Site preparation requirements can be extensive, although certain tillage practices, particularly no-till, may reduce these requirements on intercropped plantations. Production of these crops involves tillage, planting, cultivation, and harvest. Varying degrees of tillage and cultivation are possible, although the most plausible method for plantation intercropping is probably no-till which minimizes equipment operation and stresses the use of herbicides for cultivation. Conventional and conservation tillage methods do not offer the same advantages and may not be totally adaptable to plantation intercropping. Harvesting equipment is least compatible with conventional plantation spacings, suggesting that wide spacing configurations may be required. Field crops offer the most marketable product and provide relatively high net returns.

High value crops consist of specialty crops, tobacco and peanuts, and vegetables. Tobacco and peanuts require intensive management, large capital outlay, and appropriate soils. In addition, allotments are required from the government for marketing purposes. At best, a lease arrangement with established growers might be considered in lieu of initiating an intercropped plantation with these specialty crops. Vegetable crops can be divided into two marketing categories. Fresh market vegetables require extensive marketing, are subject to high losses from spoilage, and require special packing and transport efforts. These problems severely limit market vegetables as intercrops. Conversely, process vegetables have few marketing problems, being sold to factories in bulk lots. Spoilage is also minimized, due to the fast turn-over rate. For these reasons, process vegetables, particularly tomatoes and cucumbers, are the most plausible high value crops for plantation intercropping. However, production is geographically restricted, while operating costs can be prohibitive. Because conventional tillage is used with most vegetables, an intensive site preparation regime will probably be needed to establish a plantation. Harvesting equipment dimensions would require wider spacings than found on existing plantations.

Forage crops include the legumes and grasses. Legumes typically require neutral to mildly alkaline soils for good production and have proven difficult to establish on the more acid soils common on forest sites. The most promising legume, lespedeza serecia, is not extensively used for hay. The grasses are not as stringent in terms of soil pH, with some suited to a wide variety of soil conditions. Promising grasses include bermudagrass and tall fescue. After establishment, hay fields can remain productive for several years with little maintenance. Hay harvesting requires machinery with operating widths that range from 2 to 3 m. Wide spacings are required for long term hay production on pine plantations. The major problem associated with forage-pine intercropping is the lack of an established market. Lease options may be the most plausible method of economically intercropping forages on pine plantatons.

Biomass-pine intercrops require the least management and generate the least valuable commodity. Biomass wood chips,used primarily for fuel, are difficult to market and have little economic value, except to those using wood fired boilers. Site preparation requirements are less for biomass production, while planting and cultivation efforts will use conventional forestry equipment. Harvesting, however, is not a well developed process and there are currently no biomass harvesters commercially available in the U.S. Before biomass intercropping becomes viable, harvesting technology must become commercially available.

Investment Analysis

Hypothetical intercropping scenarios were developed for eight agricultural and biomass crops interplanted with loblolly pine on a cut-over plantation located in the Coastal Plain of North Carolina. The plantation was configured using an 8x2 m spacing pattern that left approximately 60% of each hectare available for agricultural or biomass crops. Agricultural and biomass production estimates were developed from a variety of sources, notably the North Carolina State Agricultural Extension Division which provided much of the information used to construct budgets specific to intercrop management.

The timber production estimates were obtained using a series of four integrated simulation programs. PTAEDA/PTAEDAR was used to simulate individual tree growth to harvest age from supplied stocking and site information. This information was passed to GENMAC, a generalized machine simulator, to determine the production functions associated with harvesting that particular stand. Finally, costs and revenues for the harvest process were estimated with HSS, or harvesting system simulator.

Estimates from these simulations were used in conjunction with the agricultural and biomass crop budgets in a forestry investment analysis package to determine whether plantation intercropping provided a substantial financial benefit. In addition, investment revenues from a conventionally managed loblolly pine plantation were estimated and compared with returns from the intercropped plantations to determine which management alternative would provide greater investment revenues under similar site and management conditions.

Conclusions drawn from the investment analysis follow:

1. On cut-over plantations, the discounted net revenues from intercropping were substantially greater than returns from a conventional plantation investment, suggesting that intercrop management on plantation sites will increase net revenues. Discounted net revenues from the intercrop investments typically increased with increased management intensity and were maximized using a vegetable-pine intercrop that yielded $1748 per hectare in discounted before tax net revenues.

2. As a result of the high costs associated with crop production, intercropping intensively managed crops, like vegetables, on pine plantations may be restricted to relatively small acreages. However, field, forage, and biomass crops could be interplanted with pines on a large scale without substantial increases in total investment costs. Field crop-pine combinations may be the best alternative for large plantation tracts, because of the consistently high return, low investment cost, and fewer marketing constraints.

3. Upward shifts in the discount rate generally have an adverse effect on less intensively managed intercrop investments. If the discount rate increases, discounted net revenue from these investments will decline at a faster rate than conventional plantation returns.

4. Lowering the cost of site preparation has a correspondingly direct effect on intercrop revenues. Where the cost of site preparation was reduced by $428 per hectare, an equivalent increase in present net worth was realized for each of the three field crop-pine investments tested. These results suggest that site preparation intensity plays a significant role in defining the level of return from an intercrop investment.

5. Lease options are a viable alternative to intercrop management on plantation sites. Earnings are unaffected by variations in crop production, while total investment costs are comparable to costs incurred on conventional plantations. However, costs associated with establishing the site for intercropping may limit lease arrangements to old field sites or other tracts that can be prepared cheaply.

6. Management for early rotation is not an economic alternative on intercropped stands under the assumptions of this analysis. Timber harvested from a 20-year-old intercropped stand did not generate enough revenue to overcome establishment and management costs under a 13% discount rate. The IRR generated by early rotation intercrop plantations was consistently less than revenues from the conventional and intercropped plantations managed for a 25 year rotation

The analysis also indicated that a shift in product type from pulpwood to veneer and sawlogs can be expected on widely spaced intercropped plantations. For companies interested in only a single product, like pulpwood, intercrop management would probably be unacceptable. However, for the company that produces multiple products, this alternative would be a valid and, in some cases, more profitable alternative. The capacity of a company to handle the diverse yield provided from intercropped plantations is a requirement that must not be overlooked. The revenues that could be generated under plantation intercropping can only be realized by a company capable of handling a diversity of products from the site, ranging from agricultural or biomass to veneer and sawlogs. Companies unable to market these products should avoid plantation intercropping as a management alternative.

Future Research

The potential of plantation intercropping depends on the direction and extent of future research. For this reason, several topics are suggested for future researchers.

One critical research topic is the relationship between site preparation and crop tillage. No-till methods may reduce the need for heavily prepared sites and, as a result, increase the earning potential of the intercrop. In addition, these studies could determine what effect intercropping has on crop yields and the extent of intercrop competition occurring between pine and various agricultural crops.

The effect of intercrop spacing on pine growth should also be examined to determine whether tree form or self-pruning characteristics are affected. Parallel studies to determine the effects of tillage and crop production on seedling growth and mortality levels should also be considered.

One problem that must be addressed is the effect of cropping practices on pine growth over time. To adequately determine the investment worth, these effects should be quantified. Studies indicate that fertilizer, cultivation, and weed control can increase pine growth. Whether the annual crop production would reduce these effects and to what degree should be addressed in the immediate future.

Some of these studies will involve field testing and long term research. However, some of the more important work could be initiated at a low cost and be completed within a reasonable time frame. Results from this short term research could be used to support long range experiments aimed at optimizing plantation intercrop production.

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Appendix A

SITE PREPARATION REGIMES AND LOBLOLLY PINE CROP BUDGETS

TABLE 1

Site Preparation Regimes[1]

Operation	Cost per Ha	Passes Required	Total Cost per Ha
Vegetable-, Forage-, or Field Crop-Pine Intercropping:			
Chop	$126.24	1	$ 126.24
Burn	29.31	1	29.31
Stump Removal	124.90	1	124.90
Rake/Pile	103.36	1	103.36
Burn (Windrows)	29.31	1	29.31
Disc	96.02	2	192.04
Rake/Pile (Fine)	103.36	1	103.36
Total Cost per Hectare			$ 708.52
Biomass-Pine Intercropping:			
Chop	$126.24	2	$ 252.48
Rake/Pile	103.36	1	103.36
Disc	96.02	1	96.02
Total Cost per Hectare			$ 451.86
Pine Monocrop:			
Chop	$126.24	2	$ 252.48
Burn	29.31	1	29.31
Total Cost per Hectare			$ 281.79

[1] Costs from Kluender (1983) and Industrial Sources.

TABLE 2

Crop Budget for Intercropped Loblolly Pine

Category	Unit	Price	Quantity	Value per Ha
Establishment[1]:				
Custom Plant	Ha	$112.00	0.4	$ 45.50
Lob. seedlings	Hd	3.00	6.50	19.50
Total Establishment Cost				$ 65.00
Harvest[2]:				
Production[3]:				
Pulpwood	Cd	$ 45.12	16.61	$ 749.44
Sawlogs	MBF	197.93	15.15	2998.19
Peelers	MBF	222.94	21.08	4697.05
Total Receipts				$8444.67
Operating Inputs:				
Contract haul	Cd	$ 9.72	125.45	$1219.40
Mach. fuel and lube	Ha			212.30
Machinery repair	Ha			219.53
Total Operating Cost				($1625.78)
Capital Cost:				
Feller-buncher invest.		0.13	$444.08	$ 57.73
Skidder investment		0.13	680.31	88.44
Loader investment		0.13	274.00	35.62
Total Interest Cost				($ 181.79)
Ownership Cost:				
Feller-Buncher	$			$ 238.28
Skidders	$			292.72
Loader	$			104.25
Total Ownership Cost				($ 635.25)
Labor Cost:				
Feller-buncher labor	Hr	$ 8.75	15.61	$ 136.57
Skidder labor	Hr	8.13	31.22	253.78
Loader labor	Hr	12.00	15.61	187.61
Total Labor Cost				($ 577.96)
Net Return from Harvest Operation				$5398.24

1 Establishment in year 0. Prices from Reisinger (1983).
2 Adapted from HSS simulation results.
3 Average 1983 prices for North Carolina from Timber Mart-South.

TABLE 3

Crop Budget for Monocropped Loblolly Pine

Category	Unit	Price	Quantity	Value per Ha
Establishment[1]:				
Custom Plant	Ha	$112.50	1.0	$ 112.50
Lob. seedlings	Hd	3.00	16.7	50.10
Total Establishment Cost				$ 162.60
Chemical Release[2]:				
Aerial herb. release	Ha	$ 85.00	1.0	$ 85.00
Total Chemical Release Cost				$ 85.00
Harvest[3]:				
Production[4]:				
Pulpwood	Cd	$ 45.12	46.50	$2098.08
Sawlogs	MBF	197.93	14.23	2816.12
Peelers	MBF	222.94	8.72	1943.58
Total Receipts				$6703.27
Operating Inputs:				
Contract haul	Cd	$ 9.72	129.32	$1256.99
Mach. fuel and lube	Ha			190.22
Machinery repair	Ha			194.38
Total Operating Cost				($1641.59)
Capital Cost:				
Feller-buncher invest.		0.13	$434.00	$ 56.42
Skidder investment		0.13	655.54	85.22
Loader investment		0.13	265.69	34.54
Total Interest Cost				($ 176.18)
Ownership Cost:				
Feller-Buncher	$			$ 231.45
Skidders	$			284.16
Loader	$			101.20
Total Ownership Cost				($ 616.81)
Labor Cost:				
Feller-buncher labor	Hr	$ 8.75	15.15	$ 132.42
Skidder labor	Hr	8.13	30.30	246.36
Loader labor	Hr	12.00	15.15	181.80
Total Labor Cost				($ 560.62)
Net Return from Harvest Operations				$3708.07

[1] Establishment in year 0. Prices from Reisinger (1983).
[2] Chemical release in year 7. Prices from Reisinger (1983).
[3] Adapted from HSS simulation results.
[4] Average 1983 prices for North Carolina from Timber Mart-South.

TABLE 4

Timber Product Haul Cost Assumptions

Average Haul Distance:	50 miles (one way)
Rate:	$1.70 per loaded mile
Load Size:	
Biomass Chips	22 Mg
Tree Lengths	8.75 Cords
Cost per Cord per Trip = $ 9.72	

TABLE 5

Percentage of Diameter Class Falling into a Given Product Category

DBH (cm)	*---------- Percentage by Product --------*		
	Pulpwood[1]	Sawtimber[2]	Peeler[3]
12-17	100%	0%	0%
20	68	32	0
23	47	53	0
25	7	93	0
28	2	49	49
30	0	50	50
33	0	43	57
35	0	35	65
38	0	30	70
41	0	25	75
>41	0	25	75

[1] Trees 13 cm to 20 cm DBH to a 8 cm top.
[2] Trees 20 cm to 28 cm DBH to a 15 cm top.
[3] Trees 28 cm DBH and larger to a 20 cm top.

Appendix B

CROP BUDGETS FOR AGRICULTURAL AND BIOMASS INTERCROP COMPONENTS

TABLE 1

Crop Budget for Intercropped No-Till Dent Corn[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Corn	Mg	$ 93.00	4.12	$383.05

Total Receipts				$383.05
Operating Inputs:				
Lime, bulk	Mg	$ 28.60	0.45	$ 12.87
Seed corn	Kg	110.00	0.30	33.00
0-60-60, bulk	Mg	192.50	0.14	26.95
Dry fert. spread	Ha	13.60	0.60	8.16
30% N sol'n.	Mg	157.52	0.32	49.15
Custom N application	Ha	12.97	1.20	15.56
Herbicide[2]	Ha	87.89	0.60	52.73
Insecticide and Nematicide	Ha	22.72	0.60	13.63
Tractor fuel	Ha			5.97
Tractor repair	Ha			2.18
Machinery fuel	Ha			6.02
Machinery repair	Ha			10.72

Total Operating Cost				($236.94)
Capital Cost:				
Annual operating cap.		0.13	$101.28	$ 13.17
Tractor investment		0.13	32.78	4.26
Machinery investment		0.13	182.05	23.67

Total Interest Cost				($ 41.10)
Ownership Cost:				
Tractor	$			$ 3.71
Machinery	$			28.10

Total Ownership Cost				($ 31.81)
Labor Cost:				
Machinery labor	Hr	$ 6.00	2.24	$ 13.56

Total Labor Cost				($ 13.56)
Net Return to Land, Management, and Overhead				$ 59.55

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

[2] Includes pre- and post-emergent herbicides.

TABLE 2

Crop Budget for Intercropped Winter Wheat[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Wheat	Kg	$ 0.14	1824	$255.36

Total Receipts				$255.36
Operating Inputs:				
Lime, bulk	Mg	$ 28.60	0.45	$ 12.87
Seed wheat	Kg	0.32	56.25	18.00
10-20-20, bulk	Mg	210.54	0.15	31.58
Dry fert., spread	Ha	13.60	0.60	8.16
Ammonium Nitrate	Mg	231.00	0.15	33.50
Herbicide	Ha	6.40	0.60	3.84
Tractor fuel & lube	Ha			4.33
Tractor repair	Ha			1.68
Mach. fuel & lube	Ha			5.28
Mach. repair	Ha			6.67

Total Operating Cost				($125.91)
Capital Cost:				
Annual operating cap.		0.13	$ 63.07	$ 8.20
Tractor investment		0.13	25.27	3.29
Machinery investment		0.13	137.88	17.92

Total Interest Cost				($ 29.41)
Ownership Cost:				
Tractor	$			$ 15.03
Machinery	$			21.88

Total Ownership Cost				($ 36.91)
Labor Cost:				
Machinery labor	Hr	$ 6.00	2.24	$ 13.44

Total Labor Cost				($ 13.44)
Net Return to Land, Management, and Overhead				$ 49.69

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

TABLE 3

Crop Budget for Intercropped No-Till Soybeans[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Soybeans	Kg	$ 0.27	1290.00	$348.30
Total Receipts				$348.30
Operating Inputs:				
Lime, applied	Mg	$ 28.60	0.50	$ 14.30
Soybean seed	Kg	0.20	66.00	13.20
0-20-20, bulk	Mg	144.10	0.20	29.40
Dry fert. spread	Ha	13.60	0.60	8.16
Pre-Emerg. Herb.	Ha	32.26	0.60	19.36
Post-Emerg. Herb.	Ha	29.10	0.60	17.46
Insecticide	Ha	8.57	0.60	5.14
Nematicide	Ha	84.14	0.60	50.48
Tractor fuel & lube	Ha			3.97
Tractor repair	Ha			1.80
Mach. fuel & lube	Ha			4.73
Machinery repair	Ha			11.03
Total Operating Cost				($178.43)
Capital Cost:				
Annual operating cap.		0.13	$178.95	$ 23.26
Tractor investment		0.13	32.78	4.26
Machinery investment		0.13	142.97	18.59
Total Interest Cost				($ 46.11)
Ownership Cost:				
Tractor	$			$ 3.71
Machinery	$			26.48
Total Ownership Cost				($ 30.19)
Labor Cost:				
Machinery labor	Hr	$ 6.00	2.15	$ 12.98
Total Labor Cost				($ 12.98)
Net Return to Land, Management, and Overhead				$ 79.99

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

TABLE 4

Crop Budget for Intercropped Tomatoes[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Tomatoes	Mg	$ 99.00	27.00	$2673.00

Total Receipts				$2673.00
Operating Inputs:				
Tomato plants	Hd	$ 0.90	130.00	$ 117.00
Lime, applied	Ha	64.25	0.60	38.55
10-20-20, bulk	Mg	210.54	0.35	73.69
Dry fert. spread	Ha	13.60	0.60	8.20
Ammonium Nitrate	Mg	247.50	0.27	66.83
Nematicide	Ha	74.13	0.60	44.48
Herbicide	Ha	46.95	0.60	28.17
Fungicide	Ha	13.34	12.00	160.13
Insecticide	Ha	11.86	8.00	94.89
Custom harvest	Mg	34.10	27.00	920.70
Custom haul	Mg	6.60	27.00	178.20
Tractor fuel & lube	Ha			115.95
Tractor repair	Ha			44.98
Machine repair	Ha			23.48

Total Operating Cost				($1915.25)
Capital Cost:				
Annual operating cap.		0.13	$137.41	$ 17.86
Tractor investment		0.13	406.12	52.80
Machinery investment		0.13	586.67	76.27

Total Interest Cost				($ 146.93)
Ownership Cost:				
Tractor	$			$ 46.03
Machinery	$			52.36

Total Ownership Cost				($ 98.39)
Labor Cost:				
Machinery labor	Hr	$ 6.00	15.87	$ 95.22
Other labor	Hr	6.00	14.83	88.96

Total Labor Cost				($ 184.18)
Net Return to Land, Management, and Overhead				$ 328.30

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

TABLE 5

Crop Budget for Intercropped Cucumber (Pickling)[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Cucumbers, pickling	Mg	$175.85	8.44	$1484.17
Total Receipts				$1484.17
Operating Inputs:				
Hybrid seed	Kg	$ 22.00	1.35	$ 29.65
Lime, applied	Ha	64.25	0.60	38.55
10-10-10, bulk	Mg	167.65	0.55	92.21
Dry fert. spread	Ha	13.60	0.60	8.20
Sidedress N	Kg	0.66	20.25	13.35
Insecticide	Ha	15.60	2.50	39.00
Nematicide	Ha	81.50	0.60	48.90
Fungicide	Ha	29.90	2.00	59.80
Herbicide	Ha	37.00	1.20	44.40
Custom harvest	Mg	90.10	8.44	760.55
Tractor fuel & lube	Ha			33.40
Tractor repair	Ha			13.81
Machine repair	Ha			7.71
Total Operating Cost				($1189.53)
Capital Cost:				
Annual operating cap.		0.13	$ 56.02	$ 7.28
Tractor investment		0.13	207.47	26.97
Machinery investment		0.13	249.70	32.46
Total Interest Cost				($ 66.71)
Ownership Cost:				
Tractor	$			$ 23.49
Machinery	$			22.17
Total Ownership Cost				($ 45.66)
Labor Cost:				
Machinery labor	Hr	$ 6.00	6.47	$ 38.80
Total Labor Cost				($ 38.80)
Net Return to Land, Management, and Overhead				$143.47

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

TABLE 6

Crop Budget for Establishing Intercropped Lespedeza.

Category	Units	Price	Quantity	Value per Ha
Operating Inputs:				
Lespedeza seed	Kg	$ 2.10	17.00	$ 35.32
Inoculant	Ha	3.00	1.00	3.00
Lime, applied	Mg	28.60	2.25	64.35
10-20-20, bulk	Mg	213.84	0.15	56.65
Dry fert. spread	Ha	13.60	0.60	8.16
Tractor fuel & lube	Ha			6.94
Tractor repair	Ha			2.75
Machinery repair	Ha			1.20
Total Operating Cost				($178.37)
Capital Cost:				
Annual operating cap.		0.13	$ 46.48	$ 6.04
Tractor investment		0.13	41.28	5.37
Machinery investment		0.13	36.96	4.80
Total Interest Cost				($ 16.21)
Ownership Cost:				
Tractor	$			$ 4.68
Machinery	$			5.46
Total Ownership Cost				($ 10.14)
Labor Cost:				
Machinery labor	Hr	$ 6.00	1.65	$ 9.91
Total Labor Cost				($ 9.91)
Net Return to Land, Management, and Overhead				($214.63)

TABLE 7

Crop Budget for Intercropped Lespedeza

Category	Units	Price	Quantity	Value per Ha
Production:				
Lespedeza	Mg	$ 77.00	4.40	$338.80
Total Receipts				$338.80
Operating Inputs:				
10-20-20, bulk	Mg	210.20	0.27	56.75
Dry fert. spread	Ha	13.60	0.60	8.16
Baler Twine	Kg	1.45	8.65	9.49
Tractor fuel & lube	Ha			21.82
Tractor repair	Ha			8.25
Machinery repair	Ha			14.45
Total Operating Cost				($118.91)
Capital Cost:				
Annual operating cap.		0.13	$ 40.73	$ 5.29
Tractor investment		0.13	124.30	16.16
Machinery investment		0.13	167.58	21.79
Establishment inv.		0.13	47.00	9.91
Total Interest Cost				($ 53.15)
Ownership Cost:				
Tractor	$			$ 14.08
Machinery	$			25.46
Establishment[1]	$			47.00
Total Ownership Cost				($ 86.54)
Labor Cost:				
Machinery labor	Hr	$ 6.00	8.46	$ 50.70
Other Labor	Hr	$ 6.00	1.33	8.00
Total Labor Cost				($ 58.76)
Net Return to Land, Management, and Overhead				$ 38.30

[1] A 5 year production period assumed.

TABLE 8

Crop Budget for Establishing Intercropped Bermudagrass[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Bermudagrass	Mg	$ 77.00	2.70	$207.90

Total Receipts				$207.90
Operating Inputs:				
Custom Sprigging	Ha	$197.00	0.60	$118.60
Lime, applied	Mg	28.60	2.25	64.35
0-25-25, bulk	Mg	213.84	0.15	32.08
Dry fert. spread	Ha	13.60	0.60	8.16
30% N solution	Mg	157.52	0.27	42.72
Baler Twine	Kg	1.45	7.07	10.27
Tractor fuel & lube	Ha			23.00
Tractor repair	Ha			14.70
Machinery repair	Ha			18.26

Total Operating Cost				($337.64)
Capital Cost:				
Annual operating cap.		0.13	$354.47	$ 46.08
Tractor investment		0.13	221.13	28.75
Machinery investment		0.13	241.84	31.44

Total Interest Cost				($106.27)
Ownership Cost:				
Tractor	$			$ 15.03
Machinery	$			21.88

Total Ownership Cost				($ 36.91)
Labor Cost:				
Machinery labor	Hr	$ 6.00	7.78	$ 46.70
Other Labor	Hr	$ 6.00	1.00	6.00

Total Labor Cost				($ 52.70)
Net Return to Land, Management, and Overhead				($325.62)

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

[2] A 10 year Bermudagrass production period assumed.

TABLE 9

Crop Budget for Intercropped Bermudagrass[1].

Category	Units	Price	Quantity	Value per Ha
Production:				
Bermudagrass	Mg	$ 77.00	5.93	$456.64
Total Receipts				$456.64
Operating Inputs:				
Lime, applied	Mg	$ 28.60	0.34	$ 16.06
0-20-20, bulk	Mg	144.10	0.40	57.93
Dry fert. spread	Ha	13.60	0.60	8.16
30% N solution	Mg	157.52	0.60	80.34
Baler Twine	Kg	1.45	10.89	15.79
Tractor fuel & lube	Ha			34.11
Tractor repair	Ha			12.91
Machinery repair	Ha			20.58
Total Operating Cost				($245.88)
Capital Cost:				
Annual operating cap.		0.13	$ 78.98	$ 10.27
Tractor investment		0.13	194.37	25.27
Machinery investment		0.13	241.75	31.43
Establishment inv.		0.13	36.18	4.20
Total Interest Cost				($ 71.67)
Ownership Cost:				
Tractor	$			$ 22.03
Machinery	$			36.72
Establishment[2]	$			36.18
Total Ownership Cost				($ 94.93)
Labor Cost:				
Machinery labor	Hr	$ 6.00	13.24	$ 79.41
Other Labor	Hr	$ 6.00	2.22	13.34
Total Labor Cost				($ 12.98)
Net Return to Land, Management, and Overhead				$ 31.18

[1] Adapted from NC State Agricultural Extension Crop Budget for 1983.

[2] A 10 year Bermudagrass production period assumed.

TABLE 10

Crop Budget for Intercropped Sycamore as Biomass[1].

Category	Units	Price	Quantity	Value per Ha
<u>Establishment</u>:				
Operating Inputs:				
Custom plant	Ha	$ 99.50	0.60	$ 59.90
Sycamore seedlings	Hd	18.00	26.00	468.00
10-20-20, bulk	Mg	210.54	0.20	42.11
Fert. Application	Ha	13.60	0.60	8.16
Total Establishment Cost				($578.17)
<u>Harvest[2]</u>:				
Production[3]:				
Biomass chips	Mg	$ 17.50	15.00	$262.50
Total Receipts				$262.50
Operating Inputs:				
Harvester operation	Hr	$ 40.00	1.29	$ 51.60
Chip-fwdr. operation	Hr	33.35	1.29	43.00
Total Operating Cost				($ 94.60)
Capital Cost:				
Operating capital		0.13	$ 94.60	$ 12.26
Harvester investment		0.13	50.00	6.50
Chip-fwdr. investment		0.13	25.00	3.75
Total Interest Cost				($ 22.51)
Ownership Cost:				
Harvester	$			$ 22.03
Chip-forwarder	$			10.88
Total Ownership Cost				($ 32.91)
Labor Cost:				
Machinery labor	Hr	$ 6.00	1.29	$ 7.74
Total Labor Cost				($ 7.74)
Net Return to Land, Management, and Overhead				$104.74

[1] Adapted from Marley (1982), Chaffin and Montgomery (1983), and Frederick (1984).

[2] A 10 year biomass production period assumed with harvest in years 3, 6, and 10.

[3] Green weight measurement used for production.

Appendix C

CROP BUDGETS FOR LEASE OPTION AND EARLY ROTATION ANALYSES

TABLE 1

Crop Budget for Intercropped Loblolly Pine Plantation Under Early Rotation (20 yr) Management.

Category	Unit	Price	Quantity	Value per Ha
Establishment[1]:				
Custom Plant	Ha	$112.00	0.4	$ 45.50
Lob. seedlings	Hd	3.00	6.50	19.50
Total Establishment Cost				$ 65.00
Harvest[2]:				
Production[3]:				
Pulpwood	Cd	$ 45.12	15.62	$ 704.77
Sawlogs	MBF	197.93	13.32	2636.43
Peelers	MBF	222.94	9.72	2166.98
Total Receipts				$5508.18
Operating Inputs:				
Contract haul	Cd	$ 9.72	87.44	$ 849.92
Mach. fuel and lube	Ha			327.86
Machinery repair	Ha			466.94
Total Operating Cost				($1644.72)
Capital Cost:				
Feller-buncher invest.		0.13	$561.00	$ 72.93
Skidder investment		0.13	859.43	111.73
Loader investment		0.13	346.12	45.00
Total Interest Cost				($ 229.66)
Ownership Cost:				
Feller-Buncher	$			$ 301.02
Skidders	$			369.79
Loader	$			131.70
Total Ownership Cost				($ 802.51)
Labor Cost:				
Feller-buncher labor	Hr	$ 8.75	19.72	$ 172.55
Skidder labor	Hr	8.13	39.44	320.65
Loader labor	Hr	12.00	19.72	237.03
Total Labor Cost				($ 730.23)
Net Return from Harvest Operation				$2101.06

[1] Establishment in year 0. Prices from Reisinger (1983).
[2] Harvest at age 20. Adapted from HSS simulation results.
[3] Average 1983 prices for North Carolina from Timber Mart-South.

TABLE 2

Crop Budget for Intercropped Loblolly Pine Plantation Under Lease Arrangement.

Category	Unit	Price	Quantity	Value per Ha
Establishment[1]:				
Custom Plant	Ha	$112.00	0.4	$ 45.50
Lob. seedlings	Hd	3.00	6.50	19.50
Total Establishment Cost				$ 65.00
Lease Revenues[2]:				
Annual Lease Pmt.	Ha	$ 40.00	1.0	$ 40.00
Total Annual Lease Revenue				$ 40.00
Harvest[3]:				
Production[4]:				
Pulpwood	Cd	$ 45.12	16.61	$ 749.44
Sawlogs	MBF	197.93	15.15	2998.19
Peelers	MBF	222.94	21.08	4697.05
Total Receipts				$8444.67
Operating Inputs:				
Contract haul	Cd	$ 9.72	125.45	$1219.40
Mach. fuel and lube	Ha			212.30
Machinery repair	Ha			219.53
Total Operating Cost				($1625.78)
Capital Cost:				
Feller-buncher invest.		0.13	$444.08	$ 57.73
Skidder investment		0.13	680.31	88.44
Loader investment		0.13	274.00	35.62
Total Interest Cost				($ 181.79)
Ownership Cost:				
Feller-Buncher	$			$ 238.28
Skidders	$			292.72
Loader	$			104.25
Total Ownership Cost				($ 635.25)
Labor Cost:				
Feller-buncher labor	Hr	$ 8.75	15.61	$ 136.57
Skidder labor	Hr	8.13	31.22	253.78
Loader labor	Hr	12.00	15.61	187.61
Total Labor Cost				($ 577.96)
Net Return from Harvest Operation				$5398.24

[1] Establishment in year 0. Prices from Reisinger (1983).
[2] A 10 year lease period assumed. The analysis also considered annual lease revenues of $15 and $25 per hectare.
[3] Adapted from HSS simulation results.
[4] Average 1983 prices for North Carolina from Timber Mart-South.

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