To the Graduate Council:

I am submitting herewith a dissertation written by Steven Grady Isaacs entitled *An Enterprise Systems Approach to an Economic Evaluation of In-Row and Between-Row Plant Spacings of Burley Tobacco*. I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Agricultural Economics.

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AN ENTERPRISE SYSTEMS APPROACH TO AN ECONOMIC EVALUATION OF IN-ROW AND BETWEEN-ROW PLANT SPACINGS OF BURLEY TOBACCO

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Steven Grady Isaacs

August 1992

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DEDICATION

This dissertation is dedicated to the author's mother:

Florence M. Isaacs

1935 - 1984

Her presence is missed.

But her love, her influence, and her memory will live on forever.

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ABSTRACT

Satisfying multiple, simultaneous, and often conflicting goals is the crux of farm management, a process defined as "a science of choice and decision-making." Computer technology allows the evaluation of complex interrelationships and multitudes of combinations, scenarios, and iterations on which decisions might be based. Computer technology also facilitates the use of a systems approach to the farm management problem. A systems approach enables researchers to examine interrelated components which more nearly approximates the farm management problem than does the reductionist approach used in classical scientific research which evaluates isolated components.

The farmer attempts to solve the farm management problem of satisfying multiple goals by allocating a set of resources across a system of enterprises to produce goal-satisfying outputs. In a production system composed of multiple interrelated practices and inputs, the farmer must recognize that factors of production may be assembled in many different combinations to attain a specified output objective. Thus, the goal-oriented farmer needs information as to how factors substitute for each other in the production process.

Enterprise budgets provide information regarding production practices, inputs, and price information, yet they do not provide a convenient way of

altering an analysis to match a farmer's specific resources. Although some state extension services offer software versions of their budgets directly to farmers, which relieves the tedium of hand calculations necessary to recalculate budgets to implement revisions, few budget generators have ventured into the field of enterprise systems, which would show the interrelationships among inputs and demonstrate technical and substitutionary relationships.

The purpose of this research was to identify and solve the production problems of a specific enterprise, burley tobacco; to develop a microcomputer spreadsheet-based enterprise planning system; and to demonstrate the optimal plant spacing for several limited resource combinations.

Two field experiments, SPACING and PRODUCTION RUN, were designed to fulfill the first objective. SPACING examined 20 combinations of row and drill spacings in burley cultivar TN 86. The SPACING-AGRONOMIC component of the research examined physical and chemical characteristics, yield, quality, and total value product. A multiple regression total physical product model was used to quantify the relationship between row and drill spacings and per plant yield. Analysis of variance procedures and means separation testing were conducted on each of the variables levels to determine the magnitude, direction, and shape of relationships between the dependent variables and the row and drill treatment variables.

The SPACING-ECONOMIC component evaluated the physical input requirements of 4 of the 20 row and drill combinations. Data collected from two extreme populations and two mid-spaced populations were used to estimate quantitative models to predict input requirements for the remaining 16 treatments. An additional experiment, PRODUCTION RUN, evaluated three different combinations of production practices and management strategies to provide data not collected in SPACING-ECONOMIC. Labor and machinery input data from PRODUCTION RUN were used to validate estimates of input required from SPACING-ECONOMIC. Multiple regression models were estimated from time-and-motion observations of 8 of the 27 production practices. These 8 practices account for 85% of the labor requirement and 50% of the total cost for this enterprise.

The physical and economic data generated by SPACING and PRODUCTION RUN provided the basis for development of the enterprise system model in the STEPS software. The STEPS model was constructed in a Lotus 1-2-3® spreadsheet. As a decision aid, STEPS incorporates information regarding the burley tobacco enterprise into an analytical system which accounts for the interactions and interdependencies of the enterprise. STEPS allows a user not only to see how a plant spacing decision influences net returns, but also to determine the combinations of resources required to produce that net return as well.

Examination of results from 130 solutions of the STEPS model indicates that the optimal plant spacing combination depends on which resource is most limiting. However, results from the SPACING experiment indicate that the optimal plant spacings for all limiting resources except land were considerably different from what is generally used by tobacco farmers.

This study suggests the potential for many burley tobacco producers to improve their net income by transplanting their tobacco at wider spacings and lower plant populations than are currently used. The STEPS software, which demonstrates how product-factor mixes and the associated costs and returns vary with changes in plant spacing, provides information useful to the decision maker planning the burley tobacco enterprise to satisfy farm management goals.

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CHAPTER I

INTRODUCTION

Farmers face economic problems as they attempt to maximize a goal, or more likely a set of goals, subject to resource constraints. Indeed, multiplicity of goals is probably the rule rather than the exception for the farmer/decision maker. Farmers must often balance economic goals of maximizing profit, minimizing risk, and improving net worth with nonpecuniary family or personal goals of increasing leisure time, performing community services, and improving family living standards. Satisfying multiple, simultaneous, and often conflicting goals is the crux of the farm management problem.

Prior to World War II, farm management texts largely regarded this management process as an "art." In the 1950's, Johnson and Haver (1953), Bradford and Johnson (1953), Heady and Jensen (1954), and Bishop and Toussaint (1958) began to formulate the description of the farm management process which persists today. Heady and Jensen (1954) define this process of farm management quite succinctly in their textbook on the subject as "a science of choice and decision-making." Casavant and Infanger (1984) summarize four sets (in addition to their own) of the "steps in an analytical decision" employed in publications from the early 1950's to the late 1970's. These processes, which Casavant and Infanger indicate

may also be known as "functions of management," "the process of management," or "the sequence of decision-making" contain several common elements. Most farm management texts in use today include in their early chapters a listing of the elements or steps in the decision-making process. Although authors do not employ consistent terminology, some of the elements common to each set of steps are **problem identification, information gathering, action,** and **acceptance of responsibility.**

THE SCIENTIFIC APPROACH

Much of the body of agricultural research has been directed toward servicing the second of these common elements: the generation and dissemination of information for the decision-making process. However, the tools to address the farm management research problem have changed over time. Farm surveys and comparative analyses were widely used prior to 1940. With the development of production economics as a field of study in the 1940's and 1950's, production and cost functions and budgetary analysis were the predominant tools of the trade. Operations research and its associated mathematical programming tools found their way from military and business applications to agriculture in the 1960's and 1970's (Keller 1987). The tools of the past have been enhanced by the availability of the computer technologies of the past two decades to allow evaluation of complex interrelationships and multitudes of combinations, scenarios, and

iterations not readily available to previous researchers, change agents, or farmers. One trend to emerge from this technological advancement has been the increased interest in a **systems approach** to farm management problems.

The systems approach differs from much classical scientific research in which information tends to be developed and distributed incrementally. The explanation for this incremental approach lies in the reductionist approach to scientific research which subdivides complex systems or problems into separate components and examines the components individually or only a few at a time. Most agricultural research of the past, particularly in the physical sciences, has by necessity tended to concentrate on the study of cause-effect relationships in isolation or near isolation. Resource constraints of time, researcher knowledge and skill, finances, logistics, technology, and statistical or mathematical methods have limited the study of entire sets of complex interrelationships at one time. Additionally, methodological problems such as misspecification, measurement errors, confounding, feedback, and multivariate causation and the paucity of tools to remedy these problems tended to limit the number of relationships that could be evaluated at one time. While a systems approach allows researchers to examine relatively complex subjects, this is not meant to suggest that systems research capability will ever approach the ultimate of complete realism in examining complex problems. Proper scientific

method will always require some level of abstraction from a complex reality to permit a manageable research environment because most nontrivial problems are extremely complex in their totality. Therefore, researchers continue to identify specific problems, to define objectives, to form hypotheses, and then to test these hypotheses within the constraints of the available resources and methodology regardless of the level of complexity of the problem under study.

Notable exceptions to the reductionist approach in the agricultural sciences are operations research, simulation modeling, and systems analysis. From the operations research field, linear programming has found broad use in whole farm planning but may be limited by its assumptions of linearity (no scale economies or diseconomies), additivity (no interaction between activities), and certainty (known and constant parameter estimates) (Hillier and Lieberman 1986). Dent and Anderson (1971) acknowledge the proliferation of mathematical programming techniques to explain the operation, organization, and behavior of farm firms. However, they note that the very precision of mathematical programming techniques can be misleading as "an exact solution to an inadequately defined problem obviously has somewhat limited application."

This discussion is not intended to draw a line between mathematical programming methods and systems research. In fact, mathematical programming remains a significant component of some systems research

projects. A management model of Australian dairy farms (Olney and Kirk 1989) and a biophysical simulation crop production decision model (Dillon, Mjelde, and McCarl 1989) are examples of recent systems applications that retain mathematical programming components.

The trend toward increased use of systems research is observed in disciplinary and cross disciplinary journals. In their comprehensive survey of systems analysis and simulation, Johnson and Rausser (1977) note the "gravitation toward simulation methods and systems concepts". Their work attempts to establish a common nomenclature for this field. Johnson and Rausser define **system** as "a collection of interrelated components or elements with a purpose," a **model** as "a synthetic representation of a system," and **simulation** as "a process of experimenting with models or systems." Their terminology for techniques for demonstrating the operations of systems models is **simulation algorithms** which can be classified as two types: **analytical simulation** and **exploratory simulation**. Analytical simulation is an experimental method based on a systematic search and design pattern, while exploratory simulation is a procedure for monitoring outcomes which result in the absence of systematic rules or design. In addition, Johnson and Rausser classify models as descriptive, explanatory, predictive, or as decision aids depending on the research objective.

The National Research Council (1989) defines a **farming system** as "an overall approach ...derived from a farmer's goals, values, knowledge, available technology, and economic opportunities." The composition of the system is determined by the choice of methods and practices used by the farmer. A **farming practice** is defined as "a way of carrying out a discrete farming task such as a tillage operation, particular pesticide application technology, or single conservation practice;" and a **farming method** is "a systematic way to accomplish a specific farming objective by integrating a number of practices."

Over the last half of the 1980's, Weiss and Robb (1986, 1988, and 1989) articulated a definition of the systems approach similar to that of Johnson and Rausser and discussed its future in the agricultural infrastructure. The Weiss and Robb definition of systems is "to state or pose large-scale problems correctly, to model the relationships in a realistic yet computable manner, and to follow up the system through its life cycle." They recognize the misuses and abuses of systems terminology and concede that "systems" may be used to describe a multidisciplinary team, analytical computer models, philosophical (holistic) approaches, or some combination of these. Weiss and Robb describe a matrix of the systems approach to production agriculture research as a series of vertical disciplinary columns with the real world problem to the left side of the columns and the set of possible solutions to the right of the columns. The path taken from problem

to solution via an analytical computer model defines a unique system which will change as problems change. Finally, Weiss and Robb offer guidelines to the implementation of systems. They reason that the systems approach tends to blur the traditional distinction between research and extension and argue for more integration between the services.

Evidence of attempts toward this integration of research and extension may be found in the development of interactive microcomputer software for farm management problems of a systems nature. Budget Planner (Hoag et al. 1987) and Whole Farm Machine Cost (Robb and Ellis 1990), examples of user-friendly software packages developed by researchers, have well-defined end uses in the general agriculture sector for farmers with access to microcomputers. Applications software such as Lotus 1-2-3® have proven useful for research projects (Werth et al. 1991), as a base for extension service enterprise budgets (Johnson 1991a), and as components in decision aid models (Ralston et al. 1990). The decision aid model, Wheat and Stocker Cattle Analyzer, is a joint publication of the Texas Agricultural Experiment Station and the Texas Cooperative Extension Service demonstrating the integration Weiss and Robb desired.

From these descriptions of systems and simulation methodology the demand is apparent for a systems approach to deal with complex farm management problems at the industry, firm, and enterprise level. Significant efforts have been directed toward national, regional, industry, and firm-level

analyses. This document will focus much more narrowly on the individual farm enterprise system and will develop methodologies for dealing with intraenterprise relationships.

THE ECONOMIC BACKGROUND

The farmer attempts to solve the farm management problem of satisfying multiple goals by allocating a set of limited and unlimited resources across a system of enterprises to produce goal satisfying outputs. This resource allocation problem is planned, implemented, and controlled by the farm management process (Boehlje and Eidman 1984). Harsh, Connor, and Schwab (1981) describe the usefulness of economic concepts as aids in "defining problems," in "determining data and information needs," and in providing "rules for decision-making."

Some of the underlying economic concepts used by the farmer in the decision-making processes are the production function, the principle of diminishing marginal returns, the principle of input substitution, and an understanding of the classification of fixed and variable resources. The farmer attempting to optimize economic goals needs an explicit or implicit understanding of the technical factor-product relationships which exist between combinations and levels of inputs and the amount of physical outputs that result from the production process. This understanding should also include an awareness that the increases in the amount of physical

output resulting from successive additions of an input diminish as the input level increases in the economically relevant range. In a production system composed of multiple interrelated practices and inputs, the farmer must also recognize that the factors of production may be assembled in many different combinations to attain a specified output objective. The goal-oriented farmer needs information as to how factors substitute for each other in the production process. Another important economic concept needed by the decision-maker is an understanding of the classification of fixed and variable resources and the closely associated notion of length of run. In the long run all factors of production are variable, and economic rules of comparing marginal returns to the marginal cost of the additional product apply to the acquisition and application of the variable resources. As length of run shortens and some factors become fixed or limiting, the farmer needs information regarding the marginal productivity of those limiting resources in alternative uses to determine optimal allocation schemes. Identifying the most limiting resource and pursuing strategies to maximize residual returns to that factor permit the grower to maximize overall net returns. This brief listing is obviously not an inclusive accounting of economic concepts required by the decision-maker but does present some idea of the type of information required for development and implementation of an enterprise system.

Information, the second component of the decision-making process, may be available to the farmer from many sources for use in making sound management decisions using the economic concepts just discussed. Information regarding technical responses to production practices and inputs and price information for both factors and product may be available from a variety of sources including universities, agribusinesses, government agencies, the farm press, family and neighbors, and past experiences. A popular tool to assimilate this data in a format which can produce information necessary for making economic decisions is the enterprise budget. Boehlje and Eidman (1984) define an enterprise budget as a projection of costs and returns for some future period. Many university extension services assemble typical livestock and crop budgets for common enterprises using price and production conditions for their states and encourage farmers to revise the budgets to reflect their own conditions and prices. A bound copy of a set of printed budgets has been a typical method of presenting enterprise budgets to county extension agents, lending institutions, and farmers. While published sets of budgets may be beneficial for comparing enterprises, they do not provide a convenient method of altering an analysis to match a farmer's specific resources, technical relationships, or prices. Printed budgets provide an outline for farmers to follow and establish benchmark levels for prices and input/output relationships, but they often require laborious hand calculations to

recalculate budgets to implement revisions. Partial budgeting, which considers only those income and expense items that change with selected revisions, is an alternative to generating entirely new budgets for each change. However, changes in one component may have unforseen consequences in some other enterprise component. Furthermore, printed budgets may not be used as anything more than an accounting entity to sum costs and returns from specified levels of inputs and may lack adequate provisions for considering input interactions. Finally, farmers may not have sufficient information to assess changes in the technical relationships defined by the production function or the substitutionary factor-factor relationships defined by the production possibilities function.

Most university budgets are generated and stored on microcomputer-supported software, and in recent years some state extension services have offered software versions of their budgets directly to end users. University of Tennessee budgets (1990) are compiled in Lotus 1-2-3® spreadsheets and are available to users in all 95 county extension offices which are equipped with microcomputers and Lotus 1-2-3® (Johnson 1991b). University of Georgia (1986) enterprise budgets are compiled in Supercalc® spreadsheets and diskettes of the budgets are included with the printed budgets. The University of Kentucky uses yet a third commercially available spreadsheet program, Quattro Pro®, to assemble enterprise budgets (Trimble, Shurley, and Benson 1990; Shurley, Trimble, and Benson 1990) and makes them

available on diskette to users through a program called KEB90 (Trimble et al. 1990). Examples of alternatives to the spreadsheet based budgeting packages are Budget Planner (Hoag et al. 1988 and Klonsky 1990), a stand-alone microcomputer software program for whole-farm budgeting of up to five crops; and Mississippi State Budget Generator (Spurlock and Laughlin 1987), also a stand-alone microcomputer program capable of producing crop and livestock budgets in single or multiple units. Computerized versions of enterprise budgets alleviate the tedium of hand calculations of individual printed budgets and allow users to change input and output levels and prices to determine net changes in returns to fixed factors. Computerized budgets facilitate "what if" analyses by allowing users to view the results of changes almost immediately. Risk analysis is a significant component of several budgeting packages and is facilitated by incorporating "average," "pessimistic," and "optimistic" prices and/or yields (Georgia and Tennessee); by incorporating a scale of anticipated prices and/or yields (Kentucky and Tennessee); or by allowing percentage changes above or below selected prices and yields (Budget Planner and Mississippi).

While computer technology has enhanced the development and application of enterprise budgeting and has enabled the user to rapidly evaluate changes and combinations of prices and inputs, few budget generators have ventured beyond the interactive accounting stage into the field of enterprise systems. The interrelationships among inputs and the

technical and substitutionary relationships rarely change in computerized university budgets in anything more than a subjective manner (machinery inputs being the notable exception, e.g. Budget Planner, Mississippi State Budget Generator). Growers may indicate their historic yields and input sets, but systematic changes in technical relationships are rarely included in enterprise budgets in spite of the substantial quantity of scientific research directed toward defining these relationships. Currently available computer technology is clearly capable of accounting for these technical and substitutionary relationships within the context of the enterprise budget. The accomplishment of incorporating these complex interrelationships could transform enterprise budgets from predictive accounting tools into tools for analyzing **enterprise systems.**

THE RESEARCH PROBLEM

A recent project at the University of Tennessee conducted jointly by researchers in the Department of Agricultural Economics and Rural Sociology and the Department of Agricultural Engineering (Mundy et al. 1987) attempted to identify, specify, and solve some tobacco production problems using a systems approach. This project identified the harvest, curing, and market preparation practices as having the highest resource requirements (particularly labor and facilities) and as offering the greatest potential for economic improvement. Research projects were designed and carried out to

focus in large part on the nature and flow of the crop from harvest through market preparation. That is, consideration was given as to how a change in harvest technology would influence a curing or market preparation component or vice versa. At the same time, functional results from other work by these same researchers on preharvest production phases were often integrated into the harvest-through-market preparation practices.

Many of the practices which comprise the tobacco enterprise require manual handling of individual plants or leaves. Consequently, burley tobacco production is a labor intensive enterprise requiring 225 to 317 hours per acre; labor inputs account for 52 to 68 percent of variable tobacco production costs (Clauson 1990; Nutt et al. 1990; Clauson and Grise 1989; Johnson 1991a). Previous research (Bosch 1980; Peedin, Davis, and Ross 1979) has demonstrated the potential for reducing the labor requirement per unit of output with wider plant spacings which produce fewer but higher yielding plants. To produce a given level of physical output with lower plant populations, fewer of the heavier yielding plants are required. Fewer plants and leaves to handle suggests the potential for lowering labor requirements and increasing net returns.

An example of an application of the systems approach to a specific plant population experiment is an evaluation of twenty combinations of row and drill spacings of burley tobacco plants that was conducted at the Tobacco Experiment Station in Greeneville, Tennessee from 1985 to 1990

(Mundy, Isaacs, and Hunter 1990). A Tennessee Agricultural Experiment Station workplan was developed for this project, which came to be known as SPACING. SPACING was an expanded version of an earlier University of Tennessee burley tobacco experiment called POPTOP (Mundy 1983) that analyzed economic and agronomic effects of four drill spacings and two topping heights. POPTOP demonstrated a positive relationship between net returns and drill spacings over the entire range of drill spacings evaluated (Bosch 1980). Thus SPACING was conceived to evaluate a wider range of drill spacings and row widths in an attempt to find the optimal plant spacing. SPACING allowed output/input comparisons between all combinations to determine the net returns to the potentially most limiting resource(s): land, labor, non-labor capital, quota, or management. The systems approach was evident in SPACING as consideration was given to virtually every production component from plant bed and field selection through curing facilities and market preparation. The inclusion of nearly all production components was necessary for a complete economic evaluation because plant spacing in the field had an impact on almost every other production or handling phase with respect to resource requirements or handling characteristics. This experiment illustrated how net returns may be affected by changes in many components when one production factor (plant spacing) is changed by the decision maker.

Prior to 1971 the production of burley tobacco in the United States was restricted by historically established acreage quotas for individual farms. These quotas were administered and enforced by the USDA Agricultural Stabilization and Conservation Service (Grise and Griffin 1988). Because these quotas set upper limits on the acreage of tobacco a farmer could produce, land area was usually the farmer's most limiting resource. Therefore, growers attempted to maximize net returns per acre of allotment. This objective was usually realized by maximizing yield per acre. Farmers often sought to attain high yields with high levels of inputs (particularly fertilizer) and high plant populations (generally 9000-10000 plants per acre).

Since 1971 burley tobacco production quotas have been based on poundage allotments established for individual farms. Thus, pounds of quota would seem to be the most limiting resource and farmers would attempt to maximize net return per pound of quota. However, lease and transfer of quota, sharecropping, and sale of quota from one farm to another tend to mitigate the restrictiveness of the quota resource. Furthermore, in some burley producing counties, the underproduction of quotas has resulted in quota values that are very low, often approaching zero price (Isaacs, Mundy, and Fowlkes 1989). Under these circumstances, some other resource, usually labor or barn curing space, may become the most limiting resource.

Many burley production units are of small scale; median production size was reported to be 0.7 acre in a 1983 Tennessee survey (Mundy, Goodman, and Isaacs 1989). A 1989 USDA survey indicated a median production size in Tennessee of 1.0 acres (Capehart 1991b) with 86 percent of growers producing less than 2.1 acres. On average, Tennessee growers used less than six percent of their cropland for burley production (Capehart 1991a). Therefore, land usually has not been a limiting resource since the transition from acreage to poundage quotas. However, burley program changes beginning with the Food and Security Act of 1985 and continuing with the passage of the Farm Poundage Quota Revision Act of 1990 (USDA 1991) have changed some institutional restrictions. Some of the conservation compliance rules may influence field selection and crop rotations creating land limitations for some growers in the mountainous regions of the burley belt. Other changes may promote quota consolidation and land may become a limiting resource for large acreage growers and/or for growers in a long rotation with limited cropland.

In spite of the increasing complexity of identifying the most limiting resource(s), farmers, researchers, and change agents persist in using yield or net returns per unit of land area as a prime determinant of success or failure. For factors of production that tend to be area specific, area yield may be satisfactory, e.g. fertility level, tillage system, or irrigation. However, given the labor intensity of burley tobacco, this approach of maximizing area yield

may be counterproductive for some factors, particularly those that have a significant influence on labor, curing space, or cost per pound of production. A more accurate indicator of optimal plant spacing might be net returns to the labor resource because labor cost per unit of production is a function of the number and size of plants or leaves handled and cured. By similar reasoning, net returns per thousand plants or per hundredweight of quota might be the best decision measures for situations with barn space or quota limitations.

The burley tobacco plant spacing problem may be most suitably approached from a systems research perspective. The plant spacing decision is made early in the production process but has significant implications in many later stages of the process. Computerized burley budgets present a framework for incorporating mathematical representations of the factor interrelationships into an enterprise system. For example, such a system has the potential to demonstrate how changes in plant spacings lead to changes in output levels and input requirements throughout the production process. A microcomputer spreadsheet-based enterprise system can be constructed to allow end user interface to exhibit technical and substitutionary relationships resulting from changes in levels and combinations of inputs and changes in production practices. A user-friendly computerized enterprise system permits an economic evaluation of changes in factors of production by enabling a user to predict changes in residual

returns to the resource or set of resources deemed most limiting. Finally, by permitting the user to adjust input levels, prices, and production practices, the user can execute risk and sensitivity analysis within the context of the enterprise system.

OBJECTIVES

Complex economic, biological, and physical systems have generally been examined by looking at variation caused by one, or at most a very few, specific and measurable factor(s) while attempting to hold other factors or components constant, the *ceteris paribus* condition. The obvious flaw in this reductionist method is that most systems are not simply the sum of individual components, each taken one at a time. Beveridge (1980) states that an essential characteristic of a system is "that the whole is greater than the sum of the parts." Keller (1987) concurs that "knowledge about the parts of the system is not sufficient to understand the complete system." Because most agricultural processes are a combination of integrated subsets of many variable factors and tasks (a system), the logical approach to many agricultural decision-making situations is a systems approach.

As previously stated, farm management consists of a set of goals which, given the interrelationships and interdependencies, might easily be described as a system of goals. The farmer generally attempts to satisfy this system of goals by managing a set (or system) of enterprises. Further,

each enterprise is composed of a system of interrelated practices. The general objective of this research was to apply a systems approach to a single enterprise, namely burley tobacco. Specifically the objectives were:

1. To estimate statistically and to test physical and economic factor-product technical relationships and factor-factor substitutionary relationships associated with changes in in-row and between-row plant spacings of burley tobacco.
2. To develop a microcomputer, spreadsheet-based enterprise planning system which incorporates these mathematical relationships into a predictive simulation model of the burley tobacco enterprise. This microcomputer model must be designed to be user-friendly, to be accessible by users with MS-DOS or PC-DOS machines with Lotus 1-2-3® software, and to be adaptable to the inclusion of new technical or economic data.
3. To apply an analytical simulation algorithm as described by Johnson and Rausser to the burley enterprise planning system model to demonstrate the choice of optimal plant spacings for each of several limiting resource situations.

CHAPTER II

LITERATURE REVIEW AND RESEARCH JUSTIFICATION

The examination of previous research relevant to the systems approach of economically evaluating burley tobacco plant spacings encompassed four topic areas: the economic foundations of the farm management problem, the use of systems and simulation analysis techniques in agricultural research, the development of microcomputer-based technologies related to whole-farm or enterprise planning/budgeting processes, and agronomic/economic research projects in tobacco and other field crops. Some of the literature related to the first three of these areas was reviewed in the context of establishing the economic background and scientific approach to the research problem in Chapter I. Therefore, the bulk of this chapter is concerned with a review of the economic and agronomic research related to plant spacing and population studies in several types of tobacco and other field crops.

AGRONOMIC RELATIONSHIPS

Agronomists describe a primary function of agriculture as collecting solar energy and converting it to a useful form by the green leaves on plants (Woodruff 1990). Nutrients and water may be supplemented, but the quantity of solar radiation supplied per unit of land is beyond the control of

the farmer. An acre of cropland receives a given amount of sunlight in a growing season; therefore, the number and spacing pattern of plants on each acre determines the quantity of solar energy available for each plant to use in converting inputs into the desired commodity.

Given these considerations, the attention devoted to plant population and plant spacing studies is not surprising. One recent plant density study in corn production (Nielsen 1988) cited sixteen earlier corn population studies dating from as early as 1905. Ten of these studies indicated that per acre grain yields increased as row widths decreased and drill spacings increased while maintaining a given population per acre. Duncan (1984) attempted to quantify the population-grain yield relationship in corn by identifying the "effect of interplant competition for light, water, and other yield-limiting environmental assets that must be shared." Duncan developed a measure of the geometrical relationships among plants in a planting pattern to describe an inverse relationship between crowding and per plant yields. The log-linear relationship described by Duncan offers an explanation to the observation that as plant populations are increased, area yields increase at a diminishing rate up to a point of maximum yield. When populations are further increased, a decrease in yields occurs. Duncan accordingly described diminishing and negative marginal physical returns to increasing plant numbers:

> At lower than the maximum-yield population, adding more plants overcompensates for the lowered grain yield per plant due to the increased crowding. Above some population, however, the effect of rapidly increasing crowding due to the closer plant spacing cannot be offset by the yield of added plants and grain yield per unit area beyond this point decreases as plant population continues to increase.

Similarly, no shortage of plant population studies exist for soybean production. In a Tennessee study of plant population and row spacing in two soybean varieties, Davis (1981) reviewed agronomic literature related to soybean population research. Davis cited thirty-eight separate studies dating as far back as 1908 which were concerned with interrow and intrarow spacing, population, density, lodging, and equidistance spacings of soybean plants.

In an extension of the Davis work, Parks et al. (1982) estimated polynomial yield response functions for area yield using row spacing and intrarow plant density as explanatory variables. Three-dimensional graphs and plots of isoyield lines were used to illustrate results which correspond to the corn population results. As plant populations were increased, area yields generally increased, reached a maximum, then decreased at extremely high populations.

Agronomic literature abounds with plant population and plant spacing studies for all major and many minor crops. Willey and Heath (1969) reviewed more than fifty population studies across a wide variety of crops to compare and contrast how researchers have attempted to quantify the yield/population relationships. Willey and Heath indicated that mathematical

expression of the yield/population relationships have generally fit one of two categories: **asymptotic**, where, as plant density increases, area yield increases, reaches a maximum, then remains relatively constant at high densities; or **parabolic**, where, as plant density increases, area yield increases, reaches a maximum, then declines at high densities. Crops for which yield is measured by total dry matter production (Willey and Heath cite clover, ryegrass, and fodder rape studies) tend to be best described by the asymptotic relationship; whereas, crops for which yield is measured by reproductive forms (corn, barley, beet, and parsnip studies were cited) tend to conform to the parabolic yield/population relationships described by Duncan and Parks.

In addition to describing the two basic empirical yield/population relationships, Willey and Heath offered three general considerations for plant population research. First, the mathematical expression of the yield/population relationship should, as much as possible, describe the biological processes of plant competition that are involved. Second, plant population should not be defined only in terms of number of plants per unit area (i.e. plant density or population per acre) but also in terms of the geometrical plant arrangements in the field. The terms Willey and Heath use to describe this geometrical relationship are **spatial arrangement** or, in the case of row-planted crops, **plant rectangularity**, which they define as the ratio of the distance between plants within the row to the distance between

the rows. Third, researchers should be aware that growers may be more concerned with how changing populations or plant spacings affects yield per plant than how those changes affect yield per acre.

For many conventional crops, changing plant populations requires little more than purchasing more or less seed and making an adjustment to a planter or drill to change a seeding rate. An exception to this simplistic view may arise if a change in population is accomplished with major changes in row widths or a change from seeding in rows to drill or broadcast seeding. In these cases major capital investment may be required in planting and harvesting equipment, and population/spacing changes may indeed be costly. However, within a fixed set of machinery constraints the cost of population/spacing changes may be minimal, and the attention of the researcher or farmer may be focused predominantly on changes in area yield with little interest in how the yield or other physical characteristics of individual plants respond to changes in populations. Tobacco differs from many conventional crops in terms of value per plant or area unit, labor intensity, facility requirements, and institutional production restrictions. Thus tobacco producers may be more concerned with Willey and Heath's considerations of spatial arrangement and how population changes influence the physical characteristics of individual plants.

TOBACCO POPULATION/SPACING RESEARCH

Tobacco is a major crop in several southeastern states and plant population studies have attracted the attention of agronomists, economists, and engineers. A review of population research in tobacco reveals that researchers have not adequately accommodated the considerations of Willey and Heath. While most crop population studies focus primarily on the technical output relationships between population and area or per plant yields, the input intensive nature of tobacco production calls for the researcher to be attentive to the input and output relationships associated with changing tobacco populations or plant spacings. The concept of spatial arrangement is important in tobacco population/spacing studies because the growth habits of tobacco plants ascribe to what Willey and Heath call plasticity. The physical shape and size of the tobacco plant adapts to the geometry of the space available in a particular planting pattern. This plant growth plasticity presents important considerations for both input requirements and output potential of tobacco plants. Current production practices of burley tobacco require multiple manual handlings of individual plants and/or leaves, particularly in the labor intensive harvest and market preparation phases. Plant size parameters such as weight, stalk diameter, hanging length, leaf number, and dry matter yield have significant implications for labor and facility requirements. All these parameters may be influenced by choice of plant spatial arrangements in the field. A review of

the tobacco population research literature indicates that scientists have not always observed how changes in population and plant spacings could influence changes in land, labor, or facilities requirements simultaneously with changes in yield. Thus, a knowledge of the population/spacing effects on yield alone will not be adequate for assessing the economic question of how population/spacing changes influence net returns to limited resources.

Numerous studies have addressed the question of population and plant spacings in burley and other types of tobacco. Many of these studies were conducted by agronomists and results were presented in terms of technical or physical relationships of output variables. Agronomic studies have identified a positive relationship between plant density and area yield within the population ranges typically used by growers. As plant density increases, yield per acre increases, thus explaining the behavior of farmers under acreage allotment restrictions who planted high populations to maximize yield per acre.

Some of the research in this area also noted the inverse relationship between plant density and yield per plant (Peedin, Davis, and Ross 1979; Bosch 1980; Link and Terrill 1985). Wider spaced plants yield more per plant, but not enough to offset the lower plant numbers. Thus yield per acre falls as plant population per acre falls. However, on a percentage basis the yield per acre decreases substantially less than the corresponding decline in population. Bosch (1980), Peedin, Davis, and Ross (1979), and Atkinson,

Byers, and Fuqua (1971) all cited the importance of this factor in light of the positive relationship between plant density and labor requirement per acre given that labor is the most costly factor of production. Regardless of plant population, each plant must be handled individually several times during the production process. Furthermore, the manner of handling the individual plants is similar regardless of population. Therefore, changes in per acre populations produce closely corresponding changes in the labor requirement per acre. If labor (and possibly other) costs fall more than total value product (TVP) as populations are decreased, the potential exists to improve net returns by handling fewer but higher yielding plants with lower plant populations per acre.

The remainder of this chapter is devoted to: 1) examining the literature which has established these physical and economic relationships, 2) illustrating how the concepts of Willey and Heath concerning spatial arrangements of plants have been heeded, 3) evaluating how the economic components of the population/spacing problem have been handled, 4) identifying the constraints of experimental design or data limitations that have hindered the search for an economically optimum plant spacing, and 5) identifying important components which may have been excluded or were not considered within the scope of earlier studies.

Early Research

One of the earliest recorded observations on tobacco plant spacing is in an 1800 essay on Virginia tobacco production. William Tatham described the typical 18th century production practice of transplanting the tobacco on a four-foot by three-foot grid. Some of the earliest scientific research on the subject was conducted by the USDA in the 1920's. Moss (1931), reporting on flue-cured tobacco research, indicated that growers could increase "yield and net value of crop per acre" by closer spacing and increased fertilization. These results were reported several years prior to any production control programs and in an environment where demand was strong for high quality cigarette leaf. The most extensive tobacco population/spacing experiment prior to World War II was a seven-year flue-cured study at Tifton, Georgia from 1936 to 1942 (Carr and Neas 1951). The study evaluated four plant populations at two fertility rates and three topping practices. Carr and Neas observed that area yields increased as population increased but at a diminishing rate. They referred to other flue-cured work relative to input requirements but reported only output related results (yield, quality, and total value) from their work.

Some of the first research projects at the University of Tennessee Tobacco Experiment Station related to tobacco population/spacing (Click 1990). A Tennessee Agricultural Experiment Station report based on Tobacco Experiment Station research (1940) recommended burley plant

spacings of 12 to 15 inches in 42 inch rows, producing populations of 9957 to 12446 plants per acre. A 1948 Tennessee study involving fertility rates, topping heights and plant spacings found no yield or quality differences from two spatial arrangements (15 x 42 inches and 21 x 30 inches) which generated the same population, 9957 plants per acre. From tests on a new burley variety (Burley 1) in 1949, the Tennessee Agricultural Experiment Station reported yield results of two varieties planted at two populations: 9957 plants per acre, then the recommended standard, and 7965 plants per acre, a 3.75 inches wider plant spacing in the same row width. The wider spacings yielded 10 percent fewer pounds per acre on 20 percent fewer plants per acre. However, no discussion accompanied the results nor were any data reported relative to input requirement differences for the two spacings. Kentucky (1941) burley research conducted in the late 1930's and early 1940's evaluated tobacco planted at the same drill spacing in 36 and 42 inch rows. Average leaf quality, yield per acre, and total value per acre did not differ significantly between the row width treatments; however, the researchers noted that input requirements would differ between the treatments and the additional labor costs associated with the narrower rows would not likely be offset by additional yield.

Modern Burley Research

Since the mid 1960's four significant research projects in four major burley producing states have examined the tobacco population/spacing problem. Atkinson, Byers, and Fuqua (1971) evaluated four population densities in a Kentucky study which also included fertilization rates and irrigation. Peedin, Davis, and Ross (1979) examined nine row width/drill spacing combinations in a three-year North Carolina experiment. Bosch (1980) reported on the first year of a four-year Tennessee experiment which considered four plant populations at each of two topping heights. Most recently, Link and Terrill (1985) included two plant populations and three fertility levels in a Virginia study that evaluated yield and other agronomic characteristics.

The Kentucky study involved an economic and agronomic evaluation of four plant spacings: 12, 16, 20, and 24 inches in a single row width of 39 inches. These spacings produced plant populations of 13400, 10060, 8040, and 6700 plants per acre. The experiment began in 1964 with yield, quality, and labor requirement data being collected for three years. Atkinson, Byers, and Fuqua reported that area yield consistently increased with each population increase, that labor requirements also increased with population increases, but population effects on quality (as expressed by market value per hundredweight) were indeterminate. Partial budgeting techniques were incorporated to evaluate the net effects of added total

value product due to yield increases and added costs resulting from increased labor requirements. The researchers concluded that the value of the additional yields resulting from higher populations was just offset by the cost of the additional labor required to handle more plants; therefore, net returns per acre did not change significantly across the range of populations evaluated. While this project did consider variability in labor requirements, it did not include such population-related input costs as plant beds, barn space, curing sticks, marketing costs, and stalk disposal. Had these additional cost changes been accounted for, net revenue per acre would likely have declined as populations increased. This research was conducted when burley quotas were still administered on a land acreage basis so reporting results on a per acre basis was quite legitimate; however, information as to yield per plant and total or net returns per hour of labor would have been beneficial in explaining the observed relationships.

Peedin, Davis, and Ross included variation in both row width and drill spacing in their 1974-76 burley study conducted at four locations in western North Carolina. In-row spacings of 14, 18, and 22 inches were transplanted in 42, 48, and 54 inch row widths resulting in a population range of 5278 to 10660 plants per acre. These researchers noted the shift in interest toward lower populations following the conversion from acreage to poundage production quotas in 1971. They also acknowledged the significant population/labor relationship by noting that 80 percent of the burley labor

requirement was associated with tasks which involved handling individual or relatively small numbers of plants. Within this environment, experimental objectives were to estimate empirically yield/population relationships on both land area and per plant bases and to estimate labor and input costs of a conventional production system for the individual spacing combinations. Linear regression models using plant population per acre as the explanatory variable were estimated for plant and area yield, and for plant numbers and land area required to produce a 2500-pound quota. Labor and input costs were not observed on an experimental unit basis but rather were estimated as a function of the land area used, the number of plants handled, or the weight of tobacco handled. A North Carolina Agricultural Extension Service burley tobacco budget based on 9000 plants per acre was used to estimate land-related, plant-related, and weight-related production costs. Additional assumptions included no quality differences between spacing treatments and no cost interactions between land, plant number, and weight-related cost items. Given the population/yield relationships defined by their regression equations, Peedin, Davis, and Ross indicated that land-related costs would increase but that plant-related costs (primarily labor) would decrease as wider spacings were used to produce a hypothetical 2500-pound quota. Plant-related costs comprised 70 to 80 percent of total costs so the savings in this area eclipsed the land-related cost increases with the result that residual returns above enumerated costs increased as populations decreased

across the entire range of the study. These results imply that as growers use wider plant spacings they need fewer plants but more land area to produce the same yield. In economic terms, they substitute land and land-related inputs for relatively more expensive labor inputs with the result that net returns to quota and management increase as populations decrease within the range of this study.

The North Carolina experiment captured some important agronomic and economic elements missing in other studies, including the population/yield relationships and the importance of changing labor costs as populations are varied for a given production level. However, it is not without its own limitations. The experiment was designed with the plant rectangularity component included, but the analysis did not account for row width and drill spacing effects separately. Yield equations were estimated using plant populations per acre, ignoring row and drill measurements as explanatory variables even though the researchers acknowledged that two combinations (18 x 42 and 14 x 54 inches) which had the same populations per acre (8294) produced different yields. The combination with the wider drill spacing produced a significantly higher yield per plant. They used this evidence and supporting evidence from other studies (Elliot 1976, Woltz and Mason 1966) to infer that drill spacing had a greater effect on yield than did row width, but did not account for this spatial arrangement factor in their yield equations or in their estimation of input costs. Combinations which

had similar plant populations per acre were assumed to have the same cost structure although the plants would have differed considerably in physical characteristics including yield per plant. Another factor which perhaps could not have been anticipated prior to the design of the experiment, but is nonetheless a serious limitation to the study, is the failure to identify an economically optimum plant spacing. The net returns above costs rose as populations decreased across the entire range of the experiment. This relationship held for increases in both row width and drill spacing although the net return gains were of greater magnitude for changes in drill spacing than for changes in row width. Finally, the scope and objectives of the study were defined within the context of quota as the most limiting resource and results were reported in terms of residual returns to quota and management. A sensitivity analysis was performed to determine the breakeven value of land in the substitution relationship with labor. In the environment that has developed in burley-producing areas since publication of this study, quota may not be the most limiting resource and knowledge of potential returns imputed to labor, land, barn space, or management may be of interest to the decision maker.

Link and Terrill evaluated two drill spacings, 18 and 24 inches, in 42-inch row widths in their three-year Virginia study. Two populations, 8297 and 6223 plants per acre, were produced at three fertility levels. Yield, quality, and levels of selected chemical constituents were the factors of

primary concern; however, Link and Terrill made general references as to how spacing changes might influence labor requirements, production costs, and efficiency. Link and Terrill reported that area yields were 4.7 percent lower at the 24-inch spacing than at the 18-inch spacing although the wider spacing required 25 percent fewer plants per unit of land area. Area yields fell less than proportionally with population because per plant yields increased 26.9 percent at the wider spacing. Link and Terrill discussed the significance of this relatively small yield reduction associated with a large population reduction in the context of the large quantity of labor input that is directly related to plant numbers and the handling of individual plants. They discussed the potential to improve labor efficiency with wider spacings by handling fewer but higher yielding plants to produce the allotted quota. Unlike most previous research, this study found that quality may be influenced by plant spacing. Rather than using value per hundredweight as a proxy for quality, Link and Terrill evaluated the cured tobacco by the group, quality, and color classifications for burley tobacco established by the Agricultural Marketing Service of the USDA (1984). They reported that "the wider spacing resulted in a higher percentage of high quality tobacco with a tendency toward heavier-bodied tobacco and a more desirable color." Consistent with previous studies, Link and Terrill found no significant spacing/fertility interactions for yield variables.

Link and Terrill presented dramatic and straightforward results to illustrate the population/spacing relationship in burley tobacco yields. They succinctly demonstrated the area yield/plant yield relationship and discussed its relevance to labor efficiency. However, they offered no quantitative data on input requirements to substantiate this input/output relationship. Using only two spacing combinations served well to illustrate the basic population/yield relationships, but two combinations did not provide adequate data to establish empirical technical or economic relationships. Link and Terrill presented one of the few tobacco studies to establish a link between plant spacings and quality; however, recent evidence in burley markets (small price differentials between grades) raises the question of whether the subtle group, quality, and color differences they detected would translate into economic differences in the burley auction market.

Data from the first year of a four-year Tennessee Tobacco Experiment Station investigation of burley populations and topping heights were evaluated in a M.S. thesis by Bosch (1980). Four plant spacings were examined at each of two topping heights, "low" and "normal." The plant spacings were 12, 16, 20, and 24 inches in 42-inch rows. These spacings created populations of 12446, 9334, 7467, and 6223 plants per acre. The experiment, named POPTOP (Mundy 1983), was designed to evaluate spacing and topping effects on total value product (TVP), production costs, and net value product (NVP) of the resource(s) of burley producers. Output

data were observed in physical (yield and quality) and economic (total value product) terms. Yield was expressed in pounds per acre and quality was represented by the average seasonal market price corresponding to federal grades assigned to samples from each treatment. Total value product was a function of yield and price and was expressed on a dollars per acre basis. Bosch subdivided the burley production process into 13 stages of production from plant beds through marketing. Input coefficients for 9 of the categories were gleaned from appropriate University of Tennessee production guides and budgets or personal consultation with university or tobacco industry experts. Time-and-motion procedures were incorporated to determine labor requirements for the most labor intensive production stages: transplanting, topping, harvest, and market preparation. These four tasks account for 91 percent of the burley labor requirement under conventional production practices and populations (Isaacs and Mundy 1989). Enterprise budgets were used to assign values to product and factors of production. Net value product was defined as the residual return to a resource (or resources) after all other resources had been paid their market value or opportunity cost. Bosch calculated residual returns to the following resource combinations (units of expression are in parentheses): land and management ($ per Acre), labor and management ($ per Man-Hour), nonlabor capital and management ($ per $100 of Capital), quota and management ($ per 100 lb of Quota), and management alone ($ per $1000 of TVP).

The economic analysis of the Tennessee research included five resource combinations as compared to one in the North Carolina research, but the trends displayed in the results were the same. Net returns to all resources increased as populations decreased across the entire range of the experiment. Bosch conducted an analysis to determine how sensitive the optimal treatment was to changes in input prices and input and output technical coefficients. The sensitivity analysis indicated that although the 24-inch spacing yielded the highest net return, a decrease in labor or nonlabor costs could cause the 20-inch drill spacing to become the optimal treatment. The economic analysis of the Tennessee project was the most thorough of any of the important burley population/spacing studies, but was limited to only one year and failed to have an adequate range to reveal an optimum net revenue spacing. The Bosch analysis was based on only one year of a multi-year experiment and the researcher acknowledged that the year, 1979, was not a typical burley production season. Growing conditions were unusually cool and wet and the experiment was affected by a belt-wide blue mold epidemic which depressed overall yield levels. With data from only the first year of a four-year study and only one location at that time, no attempt was made to estimate empirical relationships between plant populations and yields and the physical input requirements. Also, given the low number of observations generated in one year, no analysis of variance was conducted to determine whether physical and economic

differences between treatments were statistically significant. However, unpublished results from all four years of the POPTOP experiment were reported by Sasscer and Mundy (1985). These results generally supported the findings of Bosch and similarly did not identify the optimal net revenue plant spacing. Net value product increased across the entire range of POPTOP treatments as drill spacings were increased.

Supporting Research - Other Tobacco Types

Several population/spacing studies have been conducted in tobacco types other than burley. Grise and Griffin (1988) offer a discussion of the types of tobacco grown in the U.S. While direct comparisons might not be practical, plant growth habits and some cultural practices are similar enough across types to allow some general comparisons to be made. Also, population/spacing studies share enough similarities to allow comparison of research and analytical methods across types.

A North Carolina flue-cured (Types 11, 12, 13, and 14) study (Chaplin et al. 1968) evaluated drill spacings and row widths in separate experiments. Area yield means from the drill spacing experiment revealed a 20-percent area yield reduction associated with a 44-percent decrease in plant population as drill spacing was increased from 15 to 27 inches in 42-inch rows. In the row width component of the study, drill spacings were held constant and four skiprow patterns were evaluated. Yield per unit of

row length increased as skiprow frequency increased indicating that yield per plant increased and that the plant responded positively to decreased competition. Results were reported for yield, value, and chemical constituents but no attempt was made to account for input requirements differences. The cost of extra land required for wider row spacings was not accounted for as yields and values were reported on a row length basis. Further, while row width and drill spacing were acknowledged as important productions factor, the spatial arrangement question was not addressed.

Woltz and Mason (1966) used data from a three-year North Carolina flue-cured study to estimate empirical relationships using leaf numbers from nine combinations of plant spacing and topping height to explain variation in yield, quality, value, leaf size and shape, and number of suckers. They used leaf population as an explanatory variable because the handling unit in many of the flue-cured tasks of that era was the individual leaf (as opposed to the individual plant in burley production) and the number of leaves handled had a significant impact on labor. Separate quadratic regression models were estimated for five locations, two varieties, and three topping heights. The models explained 92 to 98 percent of the yield variation and were parallel across locations, varieties, and topping heights which implied the leaf number/yield relationships might hold across a wide range of conditions. The fit of the quadratic functional form followed the parabolic pattern later

described by Willey and Heath which suggested that yield increased at a diminishing rate, peaked, and then declined at high populations.

In a series of eleven on-farm tests in North Carolina, Collins, Hawks, and Kittrell (1969) used topping height and plant spacing combinations to generate selected leaf populations per acre. When poundage production quotas were specified as the most limiting factor of production, the lowest leaf number treatment was, in the absence of specific input data, hypothesized to be the most economically efficient. In a Canadian flue-cured study, Elliot (1976) evaluated physical, chemical, and smoke characteristics of population/topping height treatments and presented yield data which confirmed the earlier Carr and Neas and the Woltz and Mason results. Expanding on the Collins, Hawks, and Kittrell and the Woltz and Mason research, Kittrell et al. (1975) collected yield and price data and harvest labor data to compute net returns to four leaf populations. This is the only population/spacing study reviewed that found maximum net returns at anything other than the lowest population tested. Kittrell et al. lowered the leaf population 25 percent below the lowest population used in the Collins, Hawks, and Kittrell study to attempt to find an optimum net revenue population. They found that net returns were highest at their second lowest population because labor requirements did not fall enough to compensate for the yield reduction as populations were reduced to their lowest level.

In a Maryland tobacco (Type 32) study, McKee (1978) acknowledged the population/yield/labor relationship as a justification for his population/fertility study. Like burley, Maryland tobacco is a stalk-cut, air-cured type which has a high labor requirement because of multiple handlings of individual stalks. McKee referred to the laborsaving potential of reduced populations, but his results included only physical and chemical characteristics and area and plant yields. Across a range of four drill spacings (24, 30, 36, and 42 inches) in 42 inch rows, McKee observed a 22 percent decrease in yield per acre associated with the 43 percent decline in plant population per acre from the narrowest to the widest spacing. Average yield per plant increased 37 percent over the same range. Graphical representation illustrated that these yield/population relationships were essentially linear across the range of the data. McKee offered an excellent discussion of the area yield/plant yield relationship and its potential implication for laborsavings; however, his research lacked quantitative support from the input perspective to confirm his suppositions.

Dark tobacco (Types 21 and 22) has also been the subject of population/spacing experiments. Jones and Tramel (1979) evaluated three Virginia dark-fired populations and observed that area yield increased but quality (as reflected by price) decreased at the higher populations. They determined that relatively modest increases in total value product would not be adequate to compensate for the additional inputs required by higher

populations. Similar to other studies, the magnitude of the changes of the input costs was not quantified. A recent Tennessee study on dark-fired tobacco (Miller et al. 1991) revealed similar yield trends but failed to detect quality differentials among six row/drill spacing combinations. An economic analysis is anticipated from the Tennessee study.

A North Carolina flue-cured production cost study (Bradford 1968, Bradford and Nelson 1969, Bradford and Toussaint 1969) provided a thorough economic analysis in a study which included plant populations as a treatment variable. Three production intensities were evaluated in large (approximately 1 acre), replicated, on-farm plots at three locations from 1963 to 1965. Treatment intensity was determined by plant population per acre, topping height, fertilization rates, and sucker control methods; therefore, the results did not directly reflect population differences. However, leaf number (the direct product of plants per acre and topping height) was the independent variable in regression models developed in the study to predict estimates of labor requirements and production costs. Production practices were classified into 15 separate operations. Eleven of these tasks were influenced directly by plant and/or leaf numbers. Direct observation of labor and nonlabor inputs permitted quantification of input requirements and costs by task for each of the three treatment levels. These data facilitated estimation of the functional relationships between production cost components and production variables such as plant

population, leaf number, and yield. Enterprise budgeting, analysis of variance, and linear regression techniques were used to determine cost relationships. Labor costs accounted for 60 percent of variable costs and nearly half of total costs. Labor costs varied directly with treatment intensity on a per acre basis but did not vary significantly on a per pound basis because more intensive treatments produced more pounds of output but also required more labor and nonlabor inputs. Population effects were not directly observed because of confounding due to inclusion of other production-related variables in the three production intensity levels in the nonfactorial experimental design. Yet, this project and the Tennessee burley work (Bosch 1980) were the only tobacco studies found to directly observe both the input and output relationships associated with changes in plant population.

STATEMENT OF RESEARCH JUSTIFICATION

A wide variety of population/spacing studies has been reported over the past 50 years in several types of tobacco including burley. Many of the studies were strictly agronomic, some alluded to economic implications, and a few attempted to observe or estimate economically important relationships. These studies have established a positive relationship between plant density and yield per acre and between plant density and labor requirement per acre. Several studies have noted that as populations

were reduced, total value product declined (due to declining area yields), but total costs declined more than TVP (due primarily to declining labor requirements) with the result that net returns increased as populations decreased. However, no study has unequivocally identified an economically optimal plant spacing for any tobacco type. Previous studies have either lacked the specific input/output coefficients or have failed to explore a wide enough range of populations to satisfy necessary and sufficient conditions for optimization.

This research project was designed to collect input and output data to estimate technical and economic relationships and to permit computation of net return levels for a variety of resource constraint situations. The study encompassed a wider range of population/spacing combinations than had been observed in any previous single study to enable identification of an economically optimal spacing combination.

CHAPTER III

EXPERIMENTAL AND ANALYTICAL PROCEDURE

INTRODUCTION

This chapter includes a description of the burley tobacco production process and the interrelated components which make burley production a farm level enterprise system. The field experiments used to collect primary data on the factor-product relationships of the burley enterprise system are discussed. The analytical procedures used to evaluate the data and the economic framework used to estimate factor-product relationships are also discussed. Finally, the microcomputer-based systems framework used to evaluate the economic relationships are explained.

BURLEY TOBACCO ENTERPRISE SYSTEM

Following the definitions of the National Research Council (1989), the burley tobacco enterprise may be considered as an element of a "farming system." The burley enterprise system is in turn composed of discrete but interrelated "farming practices." Bradford (1968) identified 15 practices which contributed to production costs of flue-cured tobacco while Bosch (1980) classified 13 separate burley production and marketing practices. Peedin, Davis, and Ross (1979) did not identify practices separately but classified costs into land-related, plant-related, or yield-related categories.

This analysis identified 27 farming practices which make up the burley enterprise system. The purpose for this categorization was twofold. First, each practice comprised a unit of observation on which data were collected to allow quantification of the levels of factors of production and their costs. Second, specification of separate practices allowed identification of how changes in population and/or spatial arrangement affected not only the levels of the input requirements but also how the factors substitute for one another in the production process. Some of the 27 practices may be further subdivided into specific operational tasks. Tasks are sub-practice level operations which may or may not be separately observable. Where appropriate, the tasks which comprise a practice are discussed.

Table III-1 is a listing and brief description of 27 farming practices which make up the burley enterprise system used in the SPACING experiment. This enterprise system conforms to Agricultural Extension Service recommendations for burley tobacco production in Tennessee[1] and, with the exception of the cutting and stripping/grading subsystems, is representative of typical production in many burley producing areas in the United States (Clauson and Grise 1989).

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[1]Information related to typical and recommended burley production practices was derived from a variety of published reports by, and oral communications with, personnel in the Agricultural Economics, Agricultural Engineering, Entomology and Plant Pathology, and Plant and Soil Science departments of the University of Tennessee and from the personal experience of the author.

Table III-1. Classification and description of burley tobacco production practices.

Production Practice	Description
PLANT BEDS	
Primary Tillage	Moldboard plow bed site.
Secondary Tillage	Disk and smooth bed site.
Fumigate	Fumigate and seal bed site under polyethylene barrier.
Seed	Fertilize, rake, seed, and cover plant bed.
Pest Control	Scout plant bed and apply pesticides as needed.
Irrigation	Supply supplemental water as needed.
FIELD TASKS	
Primary Tillage	Moldboard plow production field.
Secondary Tillage	Tandem disk production field.
Fertilize	Broadcast blended fertilizer.
Pesticides	Spray application of herbicides, insecticides, and fungicides.
Secondary Tillage	Tandem disk to incorporate pesticides and herbicides.
Pull Plants	Pull seedlings, pack into containers, and load onto wagons.
Transplant	Transplant seedlings into specified row widths and drill spacing. Insecticide application in transplant water.
Cultivate	Two mechanical cultivations for weed control.
Insect Control	One insecticide application with boom sprayer.
Top	Manual removal of terminal bud at early flower stage.
Sucker Control	Mechanical application of chemical growth regulator.
HARVEST	
Drop Sticks	Manual placement of 52" wooden curing sticks into unharvested crop.
Cut and Spear	Manual cutting of plants and placement of 5 or 6 stalks onto curing sticks using a sharpened metal spear to split the stalks. Two-worker crew: one cutter, one spearer.
Load	Load field-wilted sticks of tobacco onto wagons and transport to curing barn.
Hang	Transfer sticks of tobacco from wagon to curing rails in barn.
Disk	Destroy stubble and prepare cover crop seed bed.
Cover Crop	Drill small grain cover crop.
MARKET PREPARATION	
Takedown	Remove cured tobacco from barn onto wagons and transport to striping/grading facility.
Strip/Grade	Use on-stick carousel system to manually remove leaves, sort into three farm grades, and package into bales.
Stalk Disposal	Scatter stripped stalks onto pasture land.
Market	Haul crop to market and monitor sale.

Within four broad categories, specific measurable tasks can be identified. The four general areas are plant bed production, field practices up to harvest, harvest and housing, and market preparation. The practices identified within these four areas may be further partitioned into yet more detailed operational tasks, but these 27 subdivisions represent easily identifiable practices and provide measurable units of observation for labor requirements and other physical inputs. Considerable variation, especially within some practices, exists across the spectrum of burley managers; however, the practices described here comprise a fairly typical burley enterprise. A brief narrative describing the practices and discussing some of the variations farmers use will aid in understanding the technical (production function relationships) and substitutionary (production possibilities) interrelationships among the factors required in the burley production process.

Plant Beds

Conventional plant bed production, which may start before the previous crop season is completed, entails plowing and disking a bed site; treating the site for weed, insect, and disease control with a soil fumigant applied beneath a polyethylene vapor barrier; fertilizing and seeding the bed; and protecting it from insect and disease pests and adverse weather conditions. Approximately 75-100 square yards of plant bed are

recommended for each 8000-plant acre of intended production. A typical plant bed size in Tennessee is 9'x 100' (100 square yards). Plant beds may require 45-75 days to produce seedlings in an occasionally hostile early spring environment, and growers monitor the beds during this period and apply pesticides and/or supplemental irrigation if necessary. Pesticides are generally applied manually (except for large acreage producers) with a hand-pumped, compressed air sprayer. Irrigation technologies span a spectrum from sprinkler buckets to automated semi-permanent overhead irrigation systems. The plant beds are mechanically destroyed by disking or mowing following transplanting to aid in disease and insect control and the plant bed site is seeded to a protective cover crop.

Field Operations

Field operations begin with selection and layout of the field site and primary tillage. Primary tillage is generally accomplished by moldboard plowing and is followed by disking to smooth and prepare the soil for fertilizer and pesticide application. Blended fertilizers, and lime if necessary, are broadcast onto the soil surface. Herbicides, insecticides, and fungicides are tank mixed and applied to the soil surface with a boom sprayer. Additional secondary tillage, usually two passes with a tandem disk, is required to incorporate the fertilizers and pesticides into the soil profile and smooth the soil surface for transplanting.

Pulling plants may justifiably be considered a plant bed task, but because this task is so closely linked to the field task of transplanting it is classified as a field operation. Plants which are large enough to be transplanted to the field (approximately 6-8 inches from the ground to the bud with a stem diameter the size of a pencil) are manually removed from the bed by pulling the plants from the ground one at a time. Plants are grouped, packed into containers, and loaded onto a trailer or truck for transport to the production field. Auxiliary bed site activities may include irrigating the bed before plant pulling to enhance ease of pulling and to minimize root breakage, and irrigation following plant pulling to settle the soil disturbed by the removal of plants and to stimulate regrowth of smaller seedlings.

Transplanting is a semi-mechanized process involving a tractor and a one-row, ferris-wheel type mechanical transplanter and a crew of three workers. Two workers riding on the transplanter place individual seedlings into plant holders which revolve between ground-driven press wheels which secure the seedlings into a furrow. Drill spacing within the row may be varied within a range of six inches to several feet by changing sprockets on the transplanter drive mechanism and/or changing the number of plant holders on the transplanter. For single row transplanters, row width is varied by the distance the tractor is driven from the previously transplanted row. Row width consistency is determined by the skill of the tractor driver

and the uniformity of the soil surface and may vary considerably from farm to farm or even within a given field. Row width uniformity may be enhanced with multi-row transplanters and row markers which score a mark on the soil surface at a fixed distance from the row being transplanted so that the tractor operator has a guide to follow on the ensuing trip through the field.

Several auxiliary tasks are associated with transplanting. The mechanical transplanter applies a small quantity of water (approximately four fl.oz./plant) around the roots of each seedling during the transplanting process. The water is carried on a tractor- or transplanter-mounted nurse tank and periodic stops are required to refill the water tank and load plants onto the transplanter. The transplant water may also serve as a carrier for soil or systemic insecticides which must be added to the nurse tank at refilling. Some growers may add a fourth worker to the transplanting crew to follow the transplanter through the field to replace any plants which may have been damaged, missed, or improperly transplanted.

Controlling weed and insect pests are the major tasks between transplanting and topping. Mechanical cultivation is often necessary to supplement chemical weed control. The number and frequency of cultivations depends on weed pressure and weather conditions, but two cultivations are generally completed before the tobacco is too large to drive through with a tractor-mounted cultivator. Mechanical cultivation may also

be supplemented by manual hoeing. Insect control is accomplished primarily by application of chemical pesticides which may require specialized high clearance equipment, offset sprayers and skiprow planting patterns, custom application, or hand labor.

Topping entails the manual removal of the flower portion of the plant, a few of the uppermost leaves on the plant, and any suckers (succulent secondary buds which develop at the junction of the leaf and stalk) which may be present. Once apical dominance is destroyed by removing the flower, the plant attempts to reproduce seed through the growth of additional suckers. Sucker growth is controlled by the application of one or more chemical growth regulators immediately after topping. These products may be classified by their method of activity as systemic, locally systemic, or contact control measures. Several tank mixes or sequential applications of these products are used by growers in the burley belt. Application methods are as varied as the products, ranging from applying chemicals by hand onto individual plants to custom broadcast applications over the entire crop.

Harvest

The labor intensive harvest season begins two to four weeks after topping. Wooden sticks, approximately 52"x1"x1", are carried into the standing crop and dropped on the ground at a rate of one stick for every five

or six plants. Cutting and spearing is performed by one- or two-worker crews. In a two-worker crew, the first worker grasps the stalk with one hand and uses a tomahawk style "tobacco knife" to cut the stalk clear of the ground just below the bottom leaves. This worker then passes the stalk to the second worker who holds a curing stick vertically with a sharpened metal spear placed on the top end. The second worker orients the stalk horizontally over the spear about 12 to 18 inches from the base end of the stalk and with a downward motion splits the stalk over the stick. Depending on the size of the tobacco and worker preferences, five or six stalks are placed on each stick. Sticks may be driven into the ground or two sticks may be propped together to form a tepee to allow the plants to wilt or field-cure prior to further handling. The procedure for one-worker cutting and spearing is similar to the two-worker method except, as the name implies, all the tasks are performed by a single worker. The stick is driven into the ground so that it will remain standing while the worker cuts the plant with the tobacco knife and spears the stalk onto the curing stick.

Cutting and spearing creates a handling unit consisting of five or six plants, and this handling unit is the focus of interest for labor tasks in the harvest and market preparation phases. Workers pick up sticks of tobacco in the field and manually load them onto tractor-drawn trailers with a capacity of 100 to 200 sticks for transport to the curing barns. At the curing barn the sticks of tobacco must be manually passed from a worker on

the wagon to workers standing on tier rails spaced 4′ horizontally and 4′ to 5′ vertically. The workers standing on the tier rails place each end of the stick on a rail with the stalks of tobacco suspended upside down between the tier rails. To facilitate proper curing, workers must space the sticks uniformly on the tier rails and space the stalks uniformly on the sticks. The tobacco hangs in the barn from 30 to 60 days as the stems and lamina of the leaves lose moisture in an ambient air curing process. Except for opening and closing ventilation doors on the barns no additional labor tasks are required until market preparation.

Curing barns vary in height from one to five tier levels and one worker is required for each tier level; thus, the minimum crew size requirement for housing the crop is determined by the tier height of the curing barn. To haul and hang an acre of burley tobacco, workers must manually load 25000 to 50000 pounds (Duncan et al. 1982) of stalks, leaves, and sticks onto the wagons. Then at the curing barn, workers must manually raise the tobacco vertically 10 to 30 feet onto the curing rails. Attempts at mechanization of this physically grueling task have met with limited success and the limited availability of skilled workers to harvest and house tobacco is often cited by growers as a major production problem.

The final recommended practice in the harvest phase is to establish a cover crop in the production field to prevent erosion, to control weeds, diseases, and insects, and to improve soil organic matter. Disking the field

destroys weeds and crop residue and prepares a seed bed for drilling a small grain cover crop.

Market Preparation

Market preparation tasks begin with the removal of the cured sticks of tobacco from the curing barn in a process that is basically a reverse of the hanging process except that the cured stalks weigh only 20 to 50 percent as much as the green, uncured stalks. Leaves may be stripped from the stalks and sorted into grades at the curing barn or the tobacco may be transported to a stripping/grading facility where supplemental lighting and heat for worker comfort may be provided.

Several different conventional non-mechanized stripping/grading systems are found in the burley producing area. Depending on how the stalk is handled, these conventional manual systems may be classified as relay, non-relay, or on-stick. In both relay and nonrelay systems the stalks are removed from the curing stick prior to stripping/grading, and the worker holds the stalk with one hand and removes the leaves with the other. In relay systems each worker removes one grade from each stalk and passes (relays) the stalk to another worker who removes the next grade. This process continues until 2 to 5 (generally 3) grades have been removed. In non-relay systems each worker removes all farm grades from each stalk and does not pass the stalk to other workers. As the worker removes each

grade, the leaves from that specific grade are deposited into compartments or bale boxes before the leaves of the next grade are removed.

A third stripping/grading method employs the curing stick as a stalk holder. For these on-stick systems farmers use nails, pegs, loops of string, low-hanging tier rails, or a rotating carousel frame to support the sticks while workers use both hands to strip and sort the leaves from the stalks. The stalks remain hanging on the stick in an inverted position just as they do in the curing barn. Workers use a picking motion to strip the leaves and take the stalks from the stick only after all the leaves have been removed.

Regardless of the stripping/grading method, the leaves are packaged for sale by one of three methods: tied into hands for packing onto baskets, bulk packed into 12"x24"x36" bales tied with cotton twine, or arranged into low density loose-leaf burlap sheets. In recent years as much as 95 percent of the burley crop has been sold in bales.

Burley tobacco is marketed at auction sales conducted from late November through January (some major Kentucky markets remain open into March) at commission warehouses across the burley belt. Warehouse operators serve as intermediaries between growers and buyers representing tobacco product manufacturers. Inspectors of the Agricultural Marketing Service of the USDA assign an alpha-numeric grade indicating leaf group, quality, and color of each lot offered for sale. Of the 110 federal grades, 107 have an associated price support level. If buyers do not bid at least one

dollar per hundredweight more than the support price level, then the tobacco is purchased from the grower by burley cooperative associations using funds borrowed from the Commodity Credit Corporation (CCC) of the USDA. CCC loans are repaid when the cooperatives resell the tobacco through industry channels. Annually adjustable assessments are collected from growers and buyers to pay any operating and interest costs and loan repayment shortfalls incurred by the burley cooperatives to insure that the tobacco program operates at no net cost to the federal government. Growers are also assessed a grading fee to offset the cost of operating the USDA inspection service.

Aside from hauling the crop to market, the grower has little labor involved in marketing. In exchange for commissions ranging from four to seven percent of the value of the crop (Tennessee Dept. of Agric. 1991), the warehouse agent furnishes facilities and labor to unload and weigh the crop (in some instances a warehouse agent may arrange to pick up the tobacco at the farm), present it for inspection and sale at auction, and deliver payment to the grower. The grower may monitor the grading and sale of the crop and has right of refusal if not satisfied with the sale price.

The federally administered production control/price support mechanism (commonly referred to as the tobacco program) sets an upper limit on the pounds of tobacco each farm may offer for sale each year. These production quotas are set annually by the Secretary of Agriculture and

are allocated to individual farms on the basis of historical production patterns. The Agricultural Stabilization and Conservation Service of the USDA administers the tobacco program and facilitates the lease and transfer and/or sale of quotas between farms. Except for certain natural disaster circumstances, all quota transfers must be completed prior to July 1 of each crop year. Growers can market no more than 103 percent of their annual quota allotment. Therefore, some planning and estimation of expected yield levels are necessary to avoid excessive over- or under-production. Excess quota due to under-production may be carried over to the following crop year (up to an equivalent of two years quota). Over-production may be stored and sold on the allotment of the following year; however, growers risk quality degradation with long term on-farm storage.

The preceding discussion of the production process serves to illustrate how plant spacing decisions affect virtually all of the burley production practices. Plant spacing decisions determine not only the number of plants and leaves to be handled but also the size and yield of the plants. Size of the plants is an important consideration, especially for the labor intensive harvest and housing practices. Anticipated plant yield is an important consideration in determining the number of plants required to produce an annual quota level. Plant spacing decisions influence practices from field site selection through market preparation. Observing how choice of plant spacing influences different practices demonstrates how the interrelated

components are combined in an overall approach to define an enterprise system.

THE SPACING EXPERIMENT

The source of most of the primary data for this research was a field experiment conducted at the Tobacco Experiment Station at Greeneville, Tennessee. The experiment, titled *Economic and Agronomic Effects of Selected Row Widths and In-Row Plant Spacings for Burley Tobacco* and referred to as SPACING, was designed and administered by researchers in the Department of Agricultural Economics and Rural Sociology (AERS) and the staff of the Tobacco Experiment Station (TES) of the University of Tennessee. A copy of the SPACING workplan, Tennessee Agricultural Experiment Station Experiment No. H-783-T-11, is available from the author. The tobacco production practices of the experiment were carried out by the field crew of the TES. Input and output data were collected by AERS researchers and TES staff. Records of dates and levels of production practices were maintained on TES field record sheets. Environmental data on rainfall, temperature, relative humidity, and cloud cover were available from TES daily operations records.

The SPACING research consisted of two experimental components. Experiment I was designed to observe physical and chemical characteristics, yield, quality, and total value product from twenty plant spacing

combinations in a replicated, small-plot experiment. Experiment II was designed to measure the physical input requirements of four of the twenty plant spacing combinations in a replicated large-plot experiment. Experiment II generated data concerning economic levels of factors of production, particularly labor, and was referred to as SPACING-ECONOMIC. Although the output variables observed in Experiment I were of economic significance and were expressed in economic terms, this component of the study was referred to as SPACING-AGRONOMIC. SPACING-AGRONOMIC was replicated four times each year from 1985 to 1990. SPACING-ECONOMIC was replicated four times each year from 1987 to 1990. Burley cultivar TN 86 was used as the plant material for both components of SPACING.

EXPERIMENT I: SPACING-AGRONOMIC

Output Variables

Experimental treatment levels in SPACING-AGRONOMIC consisted of five drill (in-row) spacings in each of four row widths. Drill spacing treatments (DRILL) in the experiment were 12, 18, 24, 30, and 36 inches between plants within rows. Each of the five drill spacings were imposed on row widths (ROW) of 36, 42, 48, and 54 inches between adjacent rows. The 20 treatment combinations in SPACING-AGRONOMIC were included in a split-plot experimental design arranged in a randomized complete block with row width treatments as main plots and drill spacing as sub-plots.

These twenty plant spacing combinations produced populations per acre (PPA) ranging from 3227 plants to 14520 plants. Combinations and resulting per acre populations are shown in Table III-2. All of the row width treatments were randomly assigned to each of four replications (REP) and drill spacing treatments were then randomly assigned to all four row width treatments. Eighty experimental units (4 DRILL X 5 ROW X 4 REP) were produced for each of the six years of the experiment for a total of 480 observations. Experimental units were four-row blocks 45 feet long with 30 plants harvested from the center two rows of each plot. Plants on either side of a missing plant were excluded so all harvested plants were subjected to the appropriate drill spacing treatment. Measurements were collected from each experimental unit for actual row width and drill spacings, stalk base diameter, green harvest weight, and green hanging length. Additional agronomic/economic data were collected at market preparation for yield and federal grade for each of three stalk position grades, leaf count per plant, stem/lamina ratio, cured stalk weight and length, percent total alkaloids, percent total nitrogen, and percent nitrate nitrogen.

Table III-2. Plant populations per acre resulting from in-row and between-row plant spacing combinations used in SPACING research project. Greeneville, TN. 1985-90.

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
36	14520	9680	7260	5806	4840
42	12446	8297	6223	4978	4149
48	10890	7260	5445	4356	3630
54	9680	6453	4840	3872	3227

Data Collection

While reasonable efforts were made to transplant seedlings in each plot as near as possible to the specified nominal ROW and DRILL spacings, uneven field conditions, mechanical inconsistencies, and tractor operator error combined to produce spacings that were close to desired nominal spacings but usually were not planted precisely at the specified nominal distances. Actual row widths and drill spacings were randomly sampled at five locations within each plot. Measurements were made to the nearest half inch and a simple mean value was calculated for row and drill spacing for each experimental unit. Actual plant spacings were used to compute an actual plant population per acre. These observed spacings and populations allowed the ROW and DRILL variables to be treated as continuous rather than discrete independent variables in the output models developed later.

Several plant dimension measurements were recorded at harvest. The spatial arrangement of the plants influences not only the yield but also the physical size of the plants. As has been previously indicated, physical plant size at harvest is an important consideration because the entire plant must be manually handled a minimum of six times in the harvest and housing phases. Stalk base diameter measurements were recorded to the nearest sixteenth of an inch for the center stalk of each of six sticks from each plot. The number of plants harvested from each plot and the total weight of the plants and sticks were recorded within 24 hours of cutting and spearing. Vertical hanging length of the inverted plants (from base of the stalk to the tip of the longest leaf) was measured to the nearest half inch.

Additional agronomic/economic data were collected at the market preparation phase of the SPACING-AGRONOMIC experiment. Leaves were stripped from all stalks in each plot and sorted into three stalk position grades. Weights were recorded to the nearest hundredth of a pound for each grade. An inspector of the Tobacco Division of the Agricultural Marketing Service assigned a federal quality grade to each stalk position grade. A total leaf number was recorded from one randomly selected stick in each plot and the stripped stalks from that stick were weighed. The wooden curing sticks from each plot were weighed so that their weight could be tared from the green harvest weight of the plot. The number of

plants in each plot were counted once again because some plants might have been lost during the housing and takedown phases.

Yields were ascertained by dividing total plot weight by the number of plants in each plot to produce a measure of marketable leaf weight per plant. Area yields were determined by multiplying yield per plant for each plot by the actual population per acre observed for that plot. Plant yields were recorded to the nearest hundredth of a pound and area yields to the nearest pound per acre.

The federal grade assigned to each stalk position grade indicated the group, quality, color, and any special factors associated with that lot of tobacco. Five group factors, five quality factors, six color factors, and seven special factors are used to designate 110 standard grades (Burley Stabilization Corporation 1990). All but three of these 110 grades are assigned an official loan advance rate (commonly referred to as a support price) which specifies the price per hundredweight the grower will receive from the burley cooperative if the auction bid does not exceed the loan rate by one dollar per hundredweight. Because higher loan rates are assigned to the more desirable grades, the support price represents a quantitative value measure of the quality of the tobacco. To assign a quantitative value to each experimental unit, a weighted average support price of the three stalk positions was computed for each plot with the weights being the percentage of the total plot in each stalk position grade. Loan advance rates vary from

year to year in absolute terms and in relative differences between grades. To insure that each year of the SPACING experiment was subjected to the same quality standard, federal grades for all years were assigned the support price levels from the 1990 loan schedule.

Physical and chemical leaf characteristics which affect product usability in the manufacturing industry may also be influenced by plant spacings in the field. These factors are of economic importance to the grower if product usability as determined by physical and chemical characteristics affects the price manufacturing companies are willing to pay for the tobacco. Data were collected from SPACING-AGRONOMIC on stem/lamina ratio, levels of certain chemical constituents, and one burning characteristic. Determination of stem/lamina ratios were conducted by the Austin Company, Greeneville, Tennessee on two pound samples from each plot in 1985 and from all stalk position grades within each plot in 1986-89. Tests to determine percentage by weight of total alkaloids, total nitrogen, nitrate nitrogen, and ash were conducted by Philip Morris, U.S.A., Richmond, Virginia, on samples from each stalk position from all plots in 1986 and 1987. Two leaves were removed from each stalk grade position on each plant and were oven-dried, ground, and mixed to provide a 25 gram sample for the chemical analyses.

Data observations from TES experiment field sheets and plot cards were entered in Lotus 1-2-3®, Version 2.01 spreadsheet files. Separate

spreadsheet files were created for each variable for each year. All data manipulation and assignment of classed or continuous independent variables to individual observations was accomplished within the spreadsheets. One example of the data manipulation within a Lotus spreadsheet was the use of a "lookup" feature to assign corresponding support prices to the federal grade designations for each stalk position observation. From the support price and the yield in pounds per grade an average weighted support price was computed for the plot. This feature, along with separate yearly files for grade and yield, facilitated the use of a single loan rate schedule for all years and would allow the files to be updated to reflect potential changes in the support price schedule. The "File Combine" features of Lotus 1-2-3® were used to aggregate observations from across yearly files into a single file and format suitable for further statistical analysis.

Model Construction

To conduct an economic evaluation of burley plant spacings, empirical models to estimate a total physical product function and a product price function were needed to provide estimates of total value product for any possible spacing combination within the range of the data observed in the SPACING experiment. Four hundred eighty observations of yield of marketable leaf per plant (in pounds) and price (from loan advance rates associated with federal grades) were available from the SPACING-

AGRONOMIC experiment. Actual row width and drill spacing measurements, which were available for each yield and price observation, provided continuous rather than discrete observations on treatment and explanatory variables for estimation of total physical product and product price models.

Previous tobacco population/plant spacing research offered conflicting guidance as to choice of functional form for output variable models. Two studies (Bradford and Nelson 1969; Peedin, Davis, and Ross 1979) used linear models for output equations while Woltz and Mason (1966) used a quadratic model. An additional caveat was that none of the previous studies used actual plant spacings as explanatory variables. Rather, they used nominal plant populations or leaf numbers as independent variables. Preliminary analysis of variance procedures and two-dimensional plots of means of yield and other agronomic variables suggested a curvilinear relationship across drill spacings within any row width or across drill spacings for row widths as a group. Plots of the same dependent variables against row width within or across drill spacings suggested a more linear relationship (Mundy and Isaacs 1991). Examination of these plots also suggested that changes in DRILL influenced the agronomic characteristics more than did comparable changes in ROW (Isaacs and Mundy 1991). Peedin, Davis, and Ross (1979) also observed that drill spacing exerted a greater influence on output variables than did row width but estimated their

output equations with population variables only. They acknowledged, however, that two plant spacing combinations producing the same per acre population (18"x42" and 14"x54") produced different plant yields. The wider drill spacing demonstrated a yield advantage over the narrower drill spacing at the same population per acre.

To quantify the relationship between row and drill plant spacings and per plant yields observed in SPACING-AGRONOMIC, the following multiple regression total physical product model was hypothesized:

$$\mathbf{YLDPLT} = f(\mathbf{REP}, \mathbf{YEAR}, \mathbf{ROW}, \mathbf{DRILL}, \mathbf{DRILL}^2) \qquad (3.1)$$

where:

YLDPLT	=	leaf yield in pounds per plant
REP	=	0,1,-1 dummy variable for replications 1-4
YEAR	=	0,1,-1 dummy variable for years 1985-90
ROW	=	actual observed row width in inches
DRILL	=	actual observed in-row drill spacing in inches
DRILL^2	=	quadratic term to reflect the curvilinear relationship observed within actual drill spacings

Previous agronomic research reviewed in Chapter II of this document suggested a positive relationship between the spacing variables (ROW and DRILL) and YLDPLT as the individual plants responded to the decreased competition of wider spacings. If the tobacco plant responded according to the parabolic yield/plant density relationship described by Willey and Heath (1969), the quadratic DRILL^2 term would be expected to have a negative value producing a TPP function which is concave to the DRILL axis.

REP and YEAR were defined by intercept shifting dummy variables R_1, R_2, R_3, and R_4, representing the four replication classes of REP and Y_{85}, Y_{86}, Y_{87}, Y_{88}, Y_{89}, and Y_{90}, representing the six year classes of the experiment. R_4 and Y_{90} were omitted from the regression equation to avoid perfect multicollinearity between these class variables. The REP and YEAR variables were assigned values of +0, +1, or -1 depending on the following conditions:

$R_1 = +1$ if REP = 1, $R_1 = -1$ if REP = 4, $R_1 = 0$ otherwise,

$R_2 = +1$ if REP = 2, $R_2 = -1$ if REP = 4, $R_2 = 0$ otherwise,

$R_3 = +1$ if REP = 3, $R_3 = -1$ if REP = 4, $R_3 = 0$ otherwise,

$Y_{85} = +1$ if YEAR = 85, $Y_{85} = -1$ if YEAR = 90, $Y_{85} = 0$ otherwise,

$Y_{86} = +1$ if YEAR = 86, $Y_{86} = -1$ if YEAR = 90, $Y_{86} = 0$ otherwise,

$Y_{87} = +1$ if YEAR = 87, $Y_{87} = -1$ if YEAR = 90, $Y_{87} = 0$ otherwise,

$Y_{88} = +1$ if YEAR = 88, $Y_{88} = -1$ if YEAR = 90, $Y_{88} = 0$ otherwise,

$Y_{89} = +1$ if YEAR = 89, $Y_{89} = -1$ if YEAR = 90, $Y_{89} = 0$ otherwise.

Estimation of the YLDPLT model with this 0, +1, -1 dummy variable designation generated estimates of the magnitude of a shift in the value of the intercept estimate due to the presence of that particular class variable. The value of any dummy estimator indicated the intercept difference between that class and the mean of all classes in that variable (Suits 1984). Values of the estimators of the excluded classes were determined by the

negative sum of the estimators of the classes of the variables included in the regression.

Seasonal weather differences were such that statistically significant differences were anticipated in YLDPLT between years. Figures displaying the quantity and distribution of rainfall during each of the growing seasons are included in the Appendix. Randomization of treatment plots within replications was conducted to minimize the potential for significant YLDPLT differences between replications due to soil or field differences.

Additional output models of the same functional form as equation 3.1 were estimated for product price (PRICE) and nine other SPACING-AGRONOMIC variables. Previous research had suggested plant population/spacing might influence several plant characteristics whose values are of some importance for labor, facility, or product usability considerations. Green harvest weight of plants (GRNWT) is an important spacing related variable because the labor intensive practices of cutting/spearing, field loading, and hanging are influenced by both the total pounds of green harvested tobacco to be handled and the physical size of the handling unit, the five- or six-stalk stick. Similarly, the base diameter of the stalk (STDIA) is often reported as a measure of plant handling ease or difficulty in the labor intensive harvesting phases because stalk diameter is a indicator of green harvest weight of the plant. Inverted stalk hanging length at harvest (HNGLT) is important with respect to handling ease or difficulty or

with respect to the curing process if some spacings produce plants which extend above or below the fixed vertical space allocated for each tier rail. Leaf number per plant (LEAFNO) is an important contributor to the market preparation labor requirement because individual leaves must be stripped and sorted in the stripping/grading practice. Empirical models were also estimated for several additional physical and chemical variables which might directly influence industry usability and, thus, indirectly affect product price. These included stem/lamina ratio (STEM), percent ash (ASH), percent total alkaloids (ALK), percent nitrate nitrogen (NNI), and percent total nitrogen (TNI).

Eighty observations from each of the six years (1985-90) of SPACING-AGRONOMIC were available for YLDPLT, PRICE, GRNWT, STDIA, and HNGLT. Four years of eighty observations were available for LEAFNO. STEM data were collected from three years of the experiment, and complete data were available on samples taken from the 1986 and 1987 crop years for ASH, ALK, TNI, and NNI. Analysis of variance procedures and means separation testing were conducted initially on each of the SPACING-AGRONOMIC variables levels to determine the magnitude, direction, and shape of relationships between the dependent variables and the twenty combinations of row/drill treatment variables. For estimation of the empirical models of the SPACING-AGRONOMIC variables, the actual observations of row and drill spacing which corresponded to each observation of the

dependent variables were identified as explanatory variables along with the year and replication of each observation.

Models were estimated using all available data observations. In addition to a 6-year model, YLDPLT models were estimated for each year, and an F-test (Intrilligator 1978 and Eastwood 1990) was employed to determine if significant differences existed among coefficients on the row and drill variables across years.

EXPERIMENT II: SPACING-ECONOMIC

Input Variables

Experiment II, SPACING-ECONOMIC, included an evaluation of physical input requirements, particularly for labor, from four of the 20 spacing combinations in Experiment I. The four Experiment II treatments were 12-inch drill spacing in 36-inch rows, 18-inch drill in 42-inch rows, 24-inch drill in 48-inch rows, and 36-inch drill in 54-inch rows. Experience in the POPTOP research (Bosch 1980), as well as other time and motion studies at the University of Tennessee, indicated that large plot size allows workers to establish routine working patterns and improves labor data reliability. Plot sizes in Experiment II were approximately 200 feet long by four rows wide. These plot dimensions produced experimental units in sizes ranging from 0.06 acre to 0.10 acre, eight times larger than their corresponding plot sizes in Experiment I. The large sizes of the Experiment II

plots and their costs in terms of research plot space and experiment station labor resources prevented inclusion of all twenty spacing combinations of Experiment I. Thus the researchers judged that collecting data from the two extreme populations (14520 PPA and 3227 PPA) and two mid-spaced populations (8297 PPA and 5445 PPA) would provide data for estimation of a quantitative model to predict input requirements for the remaining treatments. Machinery and manual labor input data were collected from Experiment II for the most labor intensive practices of the burley enterprise system: transplanting, topping, stick dropping, cutting, loading, hanging, takedown, and stripping/grading.

In addition to SPACING-ECONOMIC, another Tobacco Experiment Station experiment, *Economic Evaluation of Three Large Plot Management Systems for Burley Tobacco*, (UTAES Workplan H-783-T-15), was the source of data on some production practices for which data were not collected in SPACING-ECONOMIC. This experiment, called PRODUCTION RUN, evaluated three different combinations of production practices and management strategies in a nonreplicated experiment using farm-size plots of at least one acre for each treatment. PRODUCTION RUN was a source of primary data for plant pulling and cultivation input requirements and was used to validate estimates of input requirements from SPACING-ECONOMIC.

Machinery and labor inputs for field practices not observed in SPACING or PRODUCTION RUN were considered to be land area specific.

Tillage practices, pesticide and fertilizer application, and establishing a cover crop were assumed constant per unit of land area regardless of plant spacing treatment. Fertilizer and pesticide input rates were also land area specific and were held constant per unit of land across treatments. Input coefficients for these land-related practices were obtained from the burley enterprise budget in the *Guide to Farm Planning* of the University of Tennessee Agricultural Extension Service (UTGFP). Plant bed related inputs (except for plant pulling labor) were not observed directly as part of either of the TES labor studies. Plant bed input coefficients were obtained from the UTGFP and *Producing Tobacco Transplants* (Fowlkes 1989). Based on recommendations from these sources, one 100 square yard plant bed was assumed for each 8000 transplants required.

Other input coefficients provided by UTGFP were marketing costs and labor, operating and long-term interest rates, stick costs and replacement rates, and barn variable and fixed costs. Machinery operating capacities which were not directly observed in the experiments were provided by the UTGFP as were fuel costs, and other variable and fixed machinery costs. Price level for inputs were from the 1991 UT Agricultural Extension Service burley tobacco budget or from a November 1991 telephone survey of East Tennessee agricultural input suppliers.

Table III-3 is a listing of the burley production practices and an indication of the data source used to provide information on the machinery

Table III-3. Data sources for labor input requirements of burley tobacco production practices for enterprise systems analysis.

Production Practice	Data Source
PLANT BEDS	
Primary Tillage	UT Ag Extension *Guide to Farm Planning*
Secondary Tillage	UT Ag Extension *Guide to Farm Planning*
Fumigate	UT Ag Extension *Guide to Farm Planning*
Seed	UT Ag Extension *Guide to Farm Planning*
Pest Control	UT Ag Extension *Guide to Farm Planning*
Irrigation	UT Ag Extension *Guide to Farm Planning*
FIELD TASKS	
Primary Tillage	UT Ag Extension *Guide to Farm Planning*
Secondary Tillage	UT Ag Extension *Guide to Farm Planning*
Fertilize	UT Ag Extension *Guide to Farm Planning*
Pesticides	UT Ag Extension *Guide to Farm Planning*
Secondary Tillage	UT Ag Extension *Guide to Farm Planning*
Pull Plants	PRODUCTION RUN Experiment
Transplant	SPACING-ECONOMIC Experiment
Cultivate	PRODUCTION RUN Experiment
Insect Control	UT Ag Extension *Guide to Farm Planning*
Top	SPACING-ECONOMIC Experiment
Sucker Control	UT Ag Extension *Guide to Farm Planning*
HARVEST	
Drop Sticks	SPACING-ECONOMIC Experiment
Cut and Spear	SPACING-ECONOMIC Experiment
Load	SPACING-ECONOMIC Experiment
Hang	SPACING-ECONOMIC Experiment
Disk	UT Ag Extension *Guide to Farm Planning*
Cover Crop	UT Ag Extension *Guide to Farm Planning*
MARKET PREPARATION	
Takedown	SPACING-ECONOMIC Experiment
Strip/Grade	SPACING-ECONOMIC Experiment
Stalk Disposal	PRODUCTION RUN Experiment
Market	UT Ag Extension *Guide to Farm Planning*

and labor input requirements for each practice. While only 11 of the 27 burley practices were observed directly, data from the burley budget of the UTGFP indicated that these 11 practices accounted for 92 percent of the total labor requirement and 55 percent of the total fixed and variable costs of the burley enterprise. Further, of the practices not directly monitored, land related tasks would not be affected by plant spacings within a given land area. Plant bed requirements were, by assumption, prorated linearly on the basis of the number of transplants required.

Because of its labor and machinery intensive research mission, some of the burley production tasks at the TES would not be considered typical of most burley production. For this reason, a "typical farm" complement of machinery, equipment, and labor was used or was assumed to have been used for most of the burley enterprise practices. For the purposes of calculating machinery requirements and costs, the burley enterprise was assumed to have access to the following machinery complement:

- Tractors (two), 34 and 60 horsepower
- Moldboard plow, 3-14" bottoms, 3-point hitch mounted
- Tandem disk harrow, 8' operating width, 3-point hitch mounted
- Flat Wagons (two), 16'x8', 4-wheel undercarriage
- Hand pumped, compressed air sprayer
- Water tank, 1250 gallon capacity, wagon mounted
- Fertilizer spreader, 600 pound capacity, 3-point hitch mounted
- Field sprayer, 20' boom, PTO pump, 3-point hitch mounted
- Tobacco transplanter, 1-row, 3-point hitch mounted
- Cultivator, 1-row, 3-point hitch mounted
- Cutting equipment, 2 tobacco knives, 2 tobacco spears
- Carousel stripping/grading aid
- Bale press boxes, 3-compartment, compressed air cylinder
- Air compressor, 3 horsepower, electric

Additional production assumptions were that a rectangular-shaped production field with a length four times that of its width was located within one-fourth mile of a four-tier conventionally constructed burley curing barn. A crew size of four workers was considered to be available for all tasks, but all four workers were not used for all tasks. Auxiliary tasks such as planning or giving instructions to workers; hooking up, servicing, adjusting, or repairing machinery; rest and water breaks, or cleanup activities were not consistently observed. Therefore, a multiplier factor of 1.25 (Bosch 1980) was applied to all labor requirement observations to account for these auxiliary tasks. Table III-4 is a listing of the burley enterprise production practices and a description of the observations or assumptions regarding machinery, facility, and other physical inputs as well as the labor complement required for each practice.

Data Collection

To collect data on burley labor and machinery requirements, time-and-motion procedures were conducted on the transplanting, topping, stick dropping, cutting and spearing, loading, hanging, takedown, and stripping/grading practices in the SPACING-ECONOMIC experiment. Each of the four population treatments was replicated four times in each of four years for a total of 64 observations on each practice. Crew size and machinery complements for timed practices were judged to be typical of

Table III-4. Machinery, facility, and crew size assumptions for burley production practices used in SPACING research project. Greeneville, TN. 1985-90.

Practice	Crew Size	Tractor	Equipment	Facilities
PLANT BEDS				
Primary Tillage	1	60 hp	Moldboard plow	Plant bed site
Secondary Tillage	1	60 hp	Tandem disk	"
Fumigate	2	34 hp	16' Wagon	"
Seed	2	34 hp	16' Wagon	"
Pest Control	1		Hand Sprayer	"
Irrigation	1	60 hp	16' Wagon, water tank and pump	"
FIELD TASKS				
Primary Tillage	1	60 hp	Moldboard plow	Field site
Secondary Tillage	1	60 hp	8' Tandem disk	"
Fertilize	1	60 hp	600# Spinner spreader	"
Pesticides	1	60 hp	20' Boom sprayer	"
Secondary Tillage	1	60 hp	8' Tandem disk	"
Pull Plants	4	60 hp	16' Wagon	Plant bed site
Transplant	3	34 hp	1-row transplanter	Field site
Cultivate	1	34 hp	1-row cultivator	"
Insect Control	1	60 hp	20' Boom sprayer	"
Top	2-4			"
Sucker Control	1		Custom application	"
HARVEST				
Drop Sticks	4	34 hp	16' Wagon, sticks	Field site
Cut and Spear	4		Tobacco knives (2)	"
			Tobacco spears (2)	"
Load	4	34 hp	16' Wagon	"
		60 hp	16' Wagon	"
Hang	4	34 hp	16' Wagon	4-Tier barn
		60 hp	16' Wagon	"
Disk	1	60 hp	8' Tandem disk	Field site
Cover Crop	1	60 hp	8' Grain drill	"
MARKET PREPARATION				
Takedown	4			4-Tier barn
Strip/Grade	3		3-Box baler, air compressor, grading carousel	Grading room
Stalk Disposal	2	60 hp	16' Wagon	Pasture land
Market	1		Custom hauler	

what might be found on burley producing farms in Tennessee. Workers employed in timed tasks were selected from the field crew of the TES and were judged to be average to above average in tobacco labor experience and skill. Land and facility resources were judged to be average to above average for the burley belt.

Work crew activities were timed by an AERS or TES observer using a continuous running electronic digital stopwatch on which any designated start/stop or cycle time could be frozen on the display. The only exception to this time-line method was in the stripping/grading practice where workers were self-timed using a sweep hand wall clock to record start/stop times. When using the time-line method, the stopwatch was started at the beginning of a work period and was usually not reset till the end of the work period. All crew actions including start, stop, breaks, changing tasks, changing rows, and auxiliary activities were recorded along with the time at which each activity occurred. In this manner one observer was able to monitor the activities of multiple crews or multiple tasks simultaneously. An example of a portion of a data sheet from a cutting and spearing practice helps to illustrate how the time-line method was employed:

Work Crew Activities. SPACING Experiment. Tobacco Experiment Station

STOPWATCH TIME (min)	CREW ACTIVITY
0.00	Crew A starts cutting TMT 1, Rep C
0.50	Crew B starts cutting TMT 3, Rep C
27.50	Crew A starts water break
30.00	Crew B starts water break
32.50	Crew A returns to cutting TMT 1, Rep C
35.00	Crew B returns to cutting TMT 3, Rep C
55.00	Crew A finishes cutting TMT 1, Rep C
56.50	Crew A starts cutting TMT 2, Rep C
65.00	Crew B finishes cutting TMT 3, Rep C

In this example, Crew A was on task from 0.00 to 27.50 and from 32.50 to 55.00, for a total of 50.00 minutes to cut and spear treatment 1 of replication C. Similarly, Crew B required 59.50 minutes in two separate time periods to complete treatment 3 of replication C. This method of timing precludes having to run multiple stopwatches or having a timer for each crew. One monitor was able to time and record the activities of up to four work crews operating in widely separated areas of the test plot. For some tasks where the monitor might be distracted by rapidly sequencing activities (for instance, several workers changing tasks at or about the same time), workers assisted the monitor by announcing orally when they began, ended, or changed a particular task. Elapsed time per experimental unit was

recorded on a whole plot basis with rest and water break times excluded. Also excluded from direct timing were any machinery adjustment or repair times.

Samples were taken from each plot at market preparation for yield and quality determination. Plant counts were obtained for each plot. Land area per plot was determined by dividing the plant count by the nominal population for the respective treatment. Thus labor data recorded in each plot could be reported on a land area basis (hours per acre) for each population treatment or on a physical output basis (plants, sticks, or pounds per hour). For purposes of model estimation and budgeting analysis, labor was reported in hours per acre for respective population treatments.

Time-and-motion research requires significant attention to detail to obtain usable scientific data. An explanation of some of the procedures employed in collecting data on transplanting, topping, harvest and housing activities, and market preparation practices provides some information on which labor practices and sub-practice tasks were directly observed and how the data were collected.

The time-line method of recording the transplanting practice allowed identification of several sub-practice tasks. These tasks, which varied as to labor requirement across treatments, included in-row time, turn time between rows, and stops for plant and water refills. In-row time began when the transplanter was lowered to the ground to start a new row and

ended when the transplanter was lifted from the ground at the opposite end of the row. Workers were allowed a trial run in the first row of each new treatment to adjust the ground speed of the tractor to the hand-eye coordination and abilities of the workers riding the transplanter. This adjustment was necessary because wider drill spacings permitted faster ground speeds. Turn time was identified as the interval from when the transplanter was raised at the end of a row until the transplanter was lowered to the ground at the beginning of the adjacent row. Notes in the field data sheet crew activity section indicated whether turns included stops for plants and water. "Clean" turn times were those for which the crew finished one row, raised the transplanter, turned 180^{0}, and started back down the adjacent row without stopping for plants, water, or breaks. Stops to refill transplanter trays and the water tank were made at row ends. The frequency of refill stops varied with drill spacings. Times were recorded for refill stops for plants only and for both plants and water. To compute a labor requirement per acre from these timed tasks, some assumptions regarding field size and shape, water tank capacity and application rate, and transplanter tray capacity were necessary. The transplanting labor requirement computations were based on a rectangular one-acre field with a 4:1 ratio of length to width. A one-acre field of these dimensions is 416' long by 104' wide and the number of rows varies from 35 when row width is 36" to 23 rows when row width is 54". Field shape and the resulting row

length and number of rows varies widely from farm to farm. The choice of a 4:1 field shape was not based on scientific evidence or survey data but casual observation indicated this is not an unusual field shape. The transplanter applied four fluid ounces of water to each transplant from a 55-gallon nurse tank and each of the two plant trays on the transplanter carried 400 seedlings. The transplanting crew size was a tractor driver and two workers riding on a one-row transplanter. Table III-5 is a listing of the transplant, refill, and turning requirements associated with a 4:1 rectangular-shaped one-acre production field for each of the four SPACING-ECONOMIC population treatments.

Because of some experiment-related labor tasks, not all turns or refill stops could be considered "clean" times; that is, some turns and stops included research labor such as changing sprockets on the transplanter to set different drill spacings when moving from plot to plot. Activities which included research labor were deleted from labor requirement calculations. Over the four years of the SPACING-ECONOMIC experiment, 148 "clean" turns were identified which could positively be associated with particular population treatments. Analysis of variance of mean values by treatment and by year indicated significant differences between treatments but not between years. Therefore, the turn times observations were grouped across years to determine average turn time for each treatment.

Table III-5. Number of transplants, turns, and plant and water refill stops required for four plant spacing combinations in a 4:1 rectangular-shaped 1-acre burley tobacco field.

Plant Spacing	Transplants	Turns[a]	Plant-and-Water Refills[b]	Plant-only Refills
12"x36"	14520	35	9	9
18"x42"	8297	30	5	10
24"x48"	5445	26	4	3
36"x54"	3227	23	2	2

[a](N - 1) Where N = number of rows in field
[b]Water tank capacity of 55 gallon, application rate of 4 fl.oz./plant. Transplanter capacity of 800 seedlings.

"Clean" refill times could not always be associated with a particular treatment because refill stops often occurred between plots. This plot association was not important because the frequency, not the duration, of refills was affected by population treatment. One would not expect the elapsed time required to refill the trays and water tank to be any greater for a 12"x36" treatment than for a 36"x54" treatment. However, for a given land area, the number of refill stops was obviously greater for the higher population treatments (see Table III-5). Only 15 "clean" observations on plant-and-water refills and 20 observations of plant-only refills were obtained over the duration of the experiment. Given the paucity of actual observations on refill times and the absence of need to link the observations to specific treatments, all refill observations were grouped together to

determine average labor requirements for plant-and-water or plant-only refill practices. These refill times could then be added to other transplanting sub-practices on the basis of how many refills were required for each treatment.

The final determination of transplanting labor requirement was the summation of row time, turn time, and refill time. Row times were observed directly for each treatment, replication, and year for a total of 64 observations. Average turn times and the number of turns associated with each treatment were computed and added to row time observations as was a constant refill time for the specified number of plant-and-water or plant-only refills for each population treatment.

The other timed practices in SPACING-ECONOMIC were not as complex as the transplanting with respect to timing multiple tasks. Auxiliary tasks, if present at all, did not pose the intertreatment variability found in the transplanting practice. The topping labor requirement, for instance, was observed by recording the elapsed time required to top each plot, multiplying elapsed time by crew size, and dividing by plot size to determine labor hours per acre. Topping labor was observed in only two of the four years. In 1988, a four-worker crew topped all plants in each plot before moving on to the next plot. In 1989, a four-worker crew was again employed but each worker acted alone to top all the plants in a plot. Workers rotated across all four treatments to avoid a worker/treatment confounding of labor data. Because only two years of topping labor data were observed, the number of

observations was 32 rather than 64 as in the other SPACING-ECONOMIC labor practices.

Stick dropping labor was observed for all four years of the SPACING-ECONOMIC experiment. In 1987-89, stick dropping was observed as part of the cutting/spearing practice but was identified separately on the time-line data sheets. In 1990, the stick dropping was timed as a separate practice from cutting/spearing. Four two-worker crews were employed for stick dropping and cutting/spearing. Crews were rotated across treatments so that each crew harvested one plot of all four treatments. All four rows in each plot were harvested. Workers used the typical burley method of harvesting two rows at a time; this two-row combination is called a stick row. Crews were given the correct number of sticks (± 5%) for the plots they were to harvest. Sticks were counted in advance and placed at the row ends in a loose pile on the ground. No times were recorded for transporting sticks to the field or placing sticks at the row ends. Manual stick dropping time was measured from when the workers picked up the sticks which had been previously deposited at the ends of the plot until they returned to the beginning of the row to start the cutting/spearing operation. Because of a lack of experience with drill spacing wider than 20 inches, some crews experienced difficulty in properly spacing the sticks in the wider drill spacings. Consequently, crews occasionally had to redistribute sticks in

the rows as they were cutting. This redistribution time was captured in the cutting labor.

The two-worker cutting/spearing method was the standard practice used at the TES so workers were experienced in this practice. Workers placed five stalks on each curing stick in the 18"x42", 24"x48", and 36"x54" treatments. Because the relative stalk size was smaller in the narrowest drill spacing, six stalks were placed on each stick in the 12"x36" treatment. Cutting/spearing time was recorded from the time the first stalk was cut until the last stalk was speared in each stick row. Cutting/spearing operations proceeded in one direction through the field so that the stubble of the harvested stalks were turned toward the midday sun to prevent sun scald on the leaves. Therefore, when workers finished a stick row they walked back to the original starting point to begin the next stick row. This walking time was not included in the cutting/spearing time because workers used this time to obtain plant counts for the plots. Cutting/spearing labor requirement was the sum of the elapsed time to cut the two stick rows multiplied by the two-worker crew.

Field loading of SPACING-ECONOMIC plots was performed by four-worker crews, one to four days following cutting/spearing. The crew consisted of a tractor driver, two workers on the ground who picked up the tobacco from both stick rows in each plot as the tractor and wagon were driven alongside the plot, and a worker on the wagon who took the sticks of

tobacco from the workers on the ground and packed them onto the wagon. Workers rotated among tasks because the picking up and packing jobs required substantial exertion and the driving job was viewed as a rest break from the other more strenuous tasks. The timed portion of the loading task began when the first stick of tobacco in a plot was picked up off the ground and ended when the last stick in the plot was packed onto the wagon.

Field-to-barn transport time and distance varied considerably in the SPACING-ECONOMIC experiment as it does on typical farms. The transport component of the labor requirement was calculated on the basis of the following assumptions: crew of four workers, one-fourth mile transport from field to barn, an average transport speed of 7.5 miles per hour (loaded speed: 5 MPH, empty speed: 10 MPH), and a round trip capacity of 300 sticks with two tractors and two wagons.

Hanging tobacco in the 4-tier curing barns at the TES was accomplished by a four-worker crew, one worker on the wagon handing the sticks of tobacco to the first of three workers standing directly overhead on the tier rails. The workers passed the tobacco up through the tier rails to fill the curing barn. The timed observations on hanging labor began when the first stick of a plot was picked up by the worker on the wagon and ended when one of the workers on the tier rails announced he had hung and spaced the last stick in the plot. After completing the hanging tasks for an individual plot, the crew installed a string marker which hung between

adjacent plots to insure that plots would remain separated when workers began the takedown procedure. Because the plot marking was not a normal hanging labor task, these times were excluded from the labor computations.

Removing the cured tobacco from the barn was essentially a reverse of the hanging process. Times were recorded by plot as four-worker crews removed the tobacco from the barn and packed the sticks on TES transport vehicles. No transport times were included for moving the tobacco away from the curing barn because the stripping/grading facility was assumed to be in or adjacent to the curing barn.

Elapsed times per plot for stripping/grading ranged from a half hour to nearly three hours. No attempt was made to identify any sub-practice tasks, and timing precision to the nearest minute was deemed adequate. Therefore, the stripping/grading practice was self-timed by the work crew using a sweep hand wall clock mounted in the stripping/grading room. One worker in the three-worker crew was assigned responsibility for recording the beginning and ending times of each work period and the treatment and replication number of the plot for that period. All stripping/grading tasks were included in the timed work period: carrying unstripped tobacco into the grading room; stripping and sorting leaves into three farm grades; loading, pressing, and tying bales; stripping stalks from the stick; depositing the stripped stalks into disposal receptacles; and depositing the sticks into storage receptacles. The stripping/grading method employed in the

SPACING-ECONOMIC experiment was an on-stick approach using a rotating carousel frame to hold four sticks of tobacco while workers used both hands to strip and sort the leaves. The carousel stripping/grading system is described and compared to conventional methods in *The Carousel System for Stripping and Grading Burley Tobacco* (Isaacs, Mundy, and Fowlkes 1986). Although the carousel system was not widely adopted across the burley belt, it was the standard market preparation system employed by the TES during the years of the SPACING-ECONOMIC experiment.

The PRODUCTION RUN experiment was the source of labor and machinery input data for three burley enterprise practices: plant pulling, cultivation, and stalk disposal. The large plot sizes of the PRODUCTION RUN experiment provided an opportunity to observe a farm-size crew in some production activities which, due to research or plot size considerations, were not observed directly in the SPACING-ECONOMIC experiment.

In the PRODUCTION RUN experiment, a 3-worker crew pulled plants from the TES plant beds, packed them into 900 to 1000 plant capacity wooden containers, and loaded them onto vehicles for transport to the production field. Timed intervals of plant pulling ranged from 2.25 to 4.92 hours for the 3-worker crews. Plant numbers were obtained from field counts after the PRODUCTION RUN plots were transplanted. A plant pulling

rate in worker-hours per 1000 plants was determined from a simple mean of eight observations from the PRODUCTION RUN in 1987-1989.

Cultivation labor requirements were obtained from timed observations of first and second cultivations of the 1987 PRODUCTION RUN experiment. Timed observations consisted of in-row and between-row turn times. For each cultivation, 28 single-row observations of elapsed in-row times were recorded. Twenty-five "clean" turn times were also recorded for each experiment. First and second cultivations were observed separately because slower cultivating speeds are necessary in earlier cultivations to prevent damaging the smaller tobacco plants. Cultivating labor and machinery requirements for plant spacing combinations were calculated using the observed in-row and turn times, previously stated assumptions about field shape and size, and a 34-hp tractor and one-row cultivator. Observed data provided the equipment operating speed and elapsed turning times between rows. Length and number of rows, and the number of turns per acre for each population treatment were based on the assumed 4:1 rectangular-shaped one-acre field. Labor and machinery requirements were calculated separately for first and second cultivations because of observed differences in operating speeds and turn times.

Stalk disposal labor and machinery requirements were observed in the 1988 and 1989 PRODUCTION RUN experiments. Labor to remove the stalks from the sticks and load them onto transport vehicles was recorded as

a component of the stripping/grading practice; however, hauling and scattering the stalks in a pasture field adjacent to the stripping/grading facility was timed separately. Labor and machinery requirement calculations for the stalk disposal practice was based on average elapsed times observed in PRODUCTION RUN and assumed a 2-worker crew, a 60-hp tractor and a 16' farm wagon.

The reliability and consistency of input data from three sources (SPACING-ECONOMIC, PRODUCTION RUN, and UTGFP) was insured because the two experimental data sources were designed, supervised, and observed by the same researchers from the AERS department and the TES. Also, labor operations in both experiments were performed by workers from the same TES labor pool; often the same workers were employed in both experiments. The third data source, the *Guide to Farm Planning*, is based on University of Tennessee cultural recommendations for burley tobacco which were followed in the management of the standard, nonexperimental practices in SPACING-ECONOMIC and PRODUCTION RUN.

All labor and machinery requirements were described in terms of worker- or machine-hours per acre (HRAC) for inclusion in the model estimation and budgetary analysis portions of this research. Some of the practices were observed in experimental units of a specified land area (i.e. plot size in acres per plot) while other practices were observed in plant related units (i.e. number of plants or sticks per plot). Observations of labor

operations were recorded in minutes of elapsed time and were converted to HRAC by one of the following formulas.

$$\text{HRAC} = \frac{(\text{ET} \times \text{CS})/60}{\text{PS}} \qquad (3.2)$$

$$\text{HRAC} = \frac{(\text{ET} \times \text{CS})/60}{\text{PN}} \times \text{PPA} \qquad (3.3)$$

where:

HRAC = labor or machinery requirement in hours per acre
ET = elapsed time to perform labor operation in minutes
CS = crew size to perform labor operation in number of workers
60 = constant to convert elapsed time to hours
PS = plot size in acres
PN = number of plants per plot
PPA = number of plants per acre for selected plant spacings

Raw labor data from the Work Crew Activities data sheets were entered in Lotus 1-2-3® spreadsheet files. Just as for SPACING-AGRONOMIC, separate spreadsheet files were maintained for each practice and each year. All data manipulation to convert observations to common units and account for auxiliary activities were performed in each spreadsheet file. The "File Combine" features of Lotus 1-2-3® were used to aggregate labor practice data across the burley enterprise or across years into a format suitable for statistical analysis.

Model Construction

Input coefficients for the practices in the burley enterprise system were derived from one secondary and two primary data sources as indicated in Table III-3. The coefficients obtained from the UTGFP and the PRODUCTION RUN experiment were linearly prorated to the burley enterprise on a land area, yield, or plant population basis. Only 8 of the 27 burley enterprise practices were observed directly in the SPACING-ECONOMIC experiment (three others were observed directly in PRODUCTION RUN). Using the UTGFP as a benchmark, these 8 practices accounted for 85 percent of the labor requirement and 50 percent of total fixed and variable costs. The SPACING-ECONOMIC labor requirements observed and reported in worker-hours per acre were designated as follows:

TPL = Transplanting labor requirement including plant and water refills and row end turn times.

TOP = Labor requirement to manually remove flowers and top leaves of plants.

DRP = Labor requirement to distribute appropriate number of curing sticks in preharvested tobacco.

CUT = Labor requirement to manually cut the plants and spear them onto the curing sticks.

LOD = Labor requirement to field load sticks onto farm wagons for transport to curing barns.

HNG = Labor requirement to hang the sticks of tobacco in conventional 4-tier curing barn.

TDN = Labor requirement to takedown the cured tobacco from the curing barn prior to market preparation.

GRD = Labor requirement to strip the leaves from the stalks, sort them into three grades, and package them into bales.

The input coefficients for the eight labor practices observed in the time-and-motion portions of the SPACING-ECONOMIC experiment were

obtained from multiple regression models for each of the labor practices. The four treatments in SPACING-ECONOMIC consisted of four drill spacings in each of four row widths. Determining the separate effects of ROW or DRILL on labor requirements was impossible due to the confounding of each ROW treatment being associated with a different DRILL treatment and vice versa. Therefore, population per acre (PPA) was used as an explanatory variable rather than ROW and DRILL. Plots of labor requirements of the various practices against PPA revealed a generally linear relationship. The following model was estimated for each of the labor practices observed in SPACING-ECONOMIC:

$$\mathbf{HRAC} = f(\mathbf{REP}, \mathbf{YEAR}, \mathbf{PPA}) \qquad (3.4)$$

where:

HRAC	= labor requirement for each of the eight SPACING-ECONOMIC practices in worker-hours per acre
REP	= 0,1,-1 dummy variable for replications 1-4
YEAR	= 0,1,-1 dummy variable for years 1987-90
PPA	= nominal plant population per acre for each treatment

The labor intensive nature of tobacco production and the substantial number of labor practices that include handling of individual plants and/or leaves suggest a positive relationship between plants per acre and labor requirement per acre. In addition to seasonal weather differences, work crew composition was not consistent across all years of the experiment;

that is, due to TES field crew turnover, the same set of workers were not used across the four years of the experiment. For these reasons, statistically significant differences were not unexpected in labor requirements across years. Randomization of treatment plots within replications and rotation of crews across all treatments was conducted to minimize the potential for labor requirement differences due to replication effects.

Just as in the SPACING-AGRONOMIC models, REP and YEAR variables were categorized by intercept shifting dummy variables R_1, R_2, R_3, and R_4, representing the four replications and Y_{87}, Y_{88}, Y_{89}, and Y_{90}, representing the four years of the experiment. R_4 and Y_{90} were omitted from the regression equation to avoid perfect multicollinearity between these class variables. The same 0, +1, -1 pattern used in SPACING-AGRONOMIC to designate the presence of class variables was used in the labor requirement equations to generate dummy variable estimators whose values represent the difference of that class from the mean value of all classes of that variable.

SYSTEMS ANALYSIS

The Systems Approach

Systems research efforts in agriculture have often been directed toward large-scale interdisciplinary problems (Weiss and Robb 1986, 1988, and 1989) of at least a whole-farm scope and often of state, national, or international magnitude. Dent and Blackie (1979) suggested that systems are composed of hierarchal layers of autonomous subsystems and sub-subsystems. They further indicated that the number of layers included in any study depends on the judgement and goals of the researcher. Combining this notion of Dent and Blackie with the National Research Council (1989) definition of farming systems, methods, and practices, the burley enterprise system may be envisioned as a sub-system of a whole-farm system of interdependent enterprises.
The burley sub-system may then be further subdivided into interdependent sub-subsystems, namely the 27 farming practices identified in Table III-1.

The whole-farm system might legitimately be considered a subsystem or sub-subsystem of an even larger agricultural system. Similarly, at the other end of the spectrum, the burley practices might be considered a system composed of machinery, labor, climate, soils, and plant subsystems. This discussion demonstrates the need for researcher judgement to

determine how far up or down the hierarchal layers of systems to proceed with the evaluation.

The burley enterprise systems analysis developed to evaluate the results of the SPACING and PRODUCTION RUN experiments was narrower than a whole-farm systems analysis because it examined only one farm enterprise. However, the analysis was considerably broader than factorial experiments common to the physical sciences. Not only were the direct physical and economic implications of yield and total revenue variations associated with changes in plant spacing evaluated, but also the indirect effects on resource requirements and production practices were considered in the analysis. Although only one enterprise was evaluated, the technical coefficients and the analytical methods used in the tobacco enterprise analysis would conceivably be of use in a broader whole-farm analysis of resource requirements and usage, anticipated income potential, and short- and long-run planning.

Economic Framework

The tobacco producer making a plant spacing decision must integrate the technical input/output relationships and the respective values of the inputs and outputs into an economic decision framework. The farmer with a short-run goal of maximizing the residual return to the fixed factors of production can establish the optimal point of enterprise operation by

determining the optimal amount of input to apply or by determining the optimal level of output to produce. Choice of approach depends on the information available to the decision-maker. Either the input or output approach to the optimization problem generally results in the same decision (Doll and Orazem 1978). Individual burley producers are rarely in a market position to exert any influence on product or factor prices; therefore, an assumption of perfect competition in factor and product markets is legitimate for the enterprise optimizing decision maker.

The production function describes the technical relationship between the output of an enterprise and the levels of variable and fixed inputs and, therefore, is an integral component of both the output and input approaches to economic optimization. In a perfectly competitive market, the shape of the production function defines the shape of the total value product relationship for the input approach through the mathematical relationship:

$$TVP = TPP \times P_Y \qquad (3.5)$$

where:

- **TVP** = total value product, the total dollar value of the production of an enterprise at any input level.
- **TPP** = total physical product, the production function, the technical input/output relationship describing the output produced for any levels of input
- P_Y = the price of the output, known and constant in perfect competition.

Similarly, the production function provides information to develop the total cost function necessary for optimization using the output approach. Whereas the production function (and associated average and marginal

product functions) expresses output as a function of input quantities, the cost functions (total, average, and marginal) generally express cost as a function of output. However, because costs are simply input quantities multiplied by input prices, cost functions and production functions are inversely related. The total cost function is the inverse, or mirror image in a graphical sense, of the physical production function.

Both optimization schemes compare the change in benefits resulting from a change in output to the change in cost due to changing input(s). That is, both approaches use marginal analysis to determine the optimal production level. For the input approach, these marginal changes are measured in terms of the change in value of the product associated with a change in input(s), the marginal value product (MVP), and the change in cost of the input, marginal factor cost (MFC), which in the case of perfect competition in the factor market is the price of the input(s). The input approach evaluates changes in benefits and costs in terms of units of input. The objective of the decision-maker using the input approach is to maximize net value product:

$$NVP = TVP - TFC \qquad (3.6)$$

where,

NVP = net value product, or the residual return to the fixed factor(s)
TVP = total value product
TFC = total factor cost of the variable factor(s).

NVP is at a maximum when MVP and MFC are equal[1]. In other words, input is added until its contribution to TVP just offsets the cost of the additional input. With the input approach the farmer is making a decision about the level of input to use.

The output approach to enterprise optimization uses the total revenue function (TR), the total cost function (TC), and the associated marginal functions, marginal revenue (MR) and marginal cost (MC), to determine the output level which maximizes residual net return (NR) to fixed resources where:

$$NR = TR - TC \tag{3.7}$$

For example, in a perfectly competitive product market with output being increased, MR is the price of an additional unit of output while MC is the additional cost of producing that unit of output. The output approach uses information about these incremental changes in value of output and the cost of producing additional output to determine the economically optimal output level according to the following decision rule:

$$MR = MC \tag{3.8}$$

That is, output is increased as long as the added value of the increased output exceeds or equals the cost of producing the additional output[2].

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[1] MVP = MFC are the first order conditions for maximizing NVP using the input approach. The second order conditions are that MVP must be positive and decreasing in mathematical magnitude.

[2] MR = MC are the first order conditions for maximizing NR using the output approach. The second order conditions are that MC is positive and increasing in mathematical magnitude.

While the input approach decision rule indicates the optimal amount of input to use, the output approach indicates the optimal output to produce.

The optimal input/output combination for a given production function and set of product and factor prices is the same regardless of whether the input approach or the output approach is used. Several methodologies are available to solve or illustrate the optimization problem. The accounting method uses arithmetic values for costs and returns to determine the highest NVP or NR. For more than the simplest of problems a computer may be necessary to complete the necessary calculations. A geometrical method serves to graphically illustrate relative differences between costs and returns and permits visual inspection of direction and magnitude of trends but may lack the precision to determine optimal solutions and is limited to a two or three dimensional analysis. A mathematical method uses calculus to determine the precise rates of change of choice variables but requires detailed knowledge of the underlying physical and economic relationships to define an optimal solution.

The information generated in the SPACING research and the analytical framework provided by the enterprise budgeting component of the UTGFP suggested the input approach and a computer algorithm for determining the optimal plant spacing for burley tobacco. For expositional purposes, plant spacing might be considered as an input to the burley enterprise. More precisely, each spacing represents a bundle of variable inputs which is

combined with a set of fixed resources to produce an output, burley tobacco. The model represented by equation (3.1) describes the functional relationship between spacing and physical output per plant. The estimation of this production function provided the information about the TPP relationship between plant spacing and yield. Federal support price level was identified as the dependent variable in the model for estimating the impact of plant spacing on output quality. Thus, the PRICE model provided the product price information needed to translate TPP into TVP by equation 3.5. The burley enterprise budget of the UTGFP provides the framework for determining the TFC of the bundle of inputs associated with each spacing. The burley budget categorizes inputs into variable and fixed components; however, the format of the budget allows inclusion of different resource combinations into the TFC classification so that NVP may be computed to any of several resources and/or resource combinations which may be perceived as the fixed or most limiting resource(s).

The profit maximizing burley producer will combine multiple factors of production in such a manner as to maximize the NVP of those resources. Extending the input approach NVP maximizing decision criterion into multiple resource space, the decision rule becomes:

$$\frac{MVP_{x_1}}{MFC_{x_1}} = \frac{MVP_{x_2}}{MFC_{x_2}} = \ldots\ldots = \frac{MVP_{x_n}}{MFC_{x_n}} \geq 1 \qquad (3.9)$$

This equation implies that all resources are added until the value of their marginal contribution just equals the cost of their acquisition.

The quantity and quality of resources available to burley producers may vary considerably. Thus, how producers interpret the results of this study will vary with respect to the resources they possess. For example, a producer whose most limiting resource is barn space would likely be interested in maximizing the net value product to that resource after paying the explicit or implicit costs of the other factors of production.

The factors of production considered in the burley enterprise analysis were land, labor, quota, capital, barn space, and management. How these factors are classified as to fixed versus variable (limited versus unlimited) depends on the length of run or point in the production process being considered and the perceptions and planning horizon of the producer. To provide analytical flexibility, procedures were developed to compute NVP for various limiting resource situations. All factors except management were assigned an explicit or imputed cost[3] for resource scenarios where that input was considered to be a variable factor of production available in unlimited divisible quantities at that price. Because the cost of the management resource is difficult to quantify, the residual return to management was included with each of the first five factors. To compute the NVP of each factor plus management, the explicit or imputed cost of all

[3]Annual costs assigned to factors of production were: Land-$100/ac, labor-$5.25/hr, quota-$0.10/lb, capital-11.0%, and barn space-$217.5/ac.

of the other factors were subtracted from TVP. The residual return was expressed in terms of dollars per unit of the respective factors: $/acre of land, $/hour of labor, $/pound of quota, $/one hundred dollars of capital cost, and $/1000 sticks of barn capacity. To determine return to management alone, all other factors were paid their respective costs and the residual return was assigned to management in terms of NVP per $100 of TVP because dollars are the only homogenous unit of expression (Heady and Dillon 1961). Expressing a return to management in terms of any other unit of production implies a return to that factor.

Construction of STEPS

The analytical tool created to generate residual return levels to various limiting resource situations for selected plant spacing combinations was a personal computer, spreadsheet-based software program called STEPS. STEPS is an acronym for **S**oftware for **T**obacco **E**nterprise **P**lanning **S**ystem. The software was developed in a Lotus 1-2-3® electronic spreadsheet and was based on the format used in the University of Tennessee Guide to Farm Planning (UTGFP). Because all Tennessee County Extension offices and many computer literate farm managers have Lotus 1-2-3®, STEPS was not developed to be a stand-alone software program, but rather would require a user to have access to an IBM-compatible personal computer and Lotus 1-2-3®, Version 2.0 or later. Another reason for not developing a stand-alone

software package was the desire to incorporate periodic revisions to reflect changes in output and input prices and to be able to include additional information about functional relationships for other input and output associations.

STEPS incorporates the Lotus-based **DATA** file which is used by University of Tennessee extension economists to provide annual updates of input and output prices for all the enterprise budgets in the UTGFP. This DATA file contains a listing of approximately 215 product and factor prices for all enterprises in the UTGFP as well as fixed and variable cost data for 126 machinery items which may be used in one or more of the enterprises. These prices are updated annually and new enterprise budgets are generated based on current or anticipated price levels for that year. The price schedule used in this analysis was for the 1991 crop season.

The organizational arrangement of STEPS within the Lotus 1-2-3® spreadsheet is depicted in Figure III-1. This pattern is the same general design followed in the computerized component of the field crop and livestock budgets of the UTGFP. This general design consists of using the "File Combine" features of Lotus 1-2-3® to integrate an individual enterprise file (e.g. CORN.WK1, BURLEY.WK1, etc.) with a data file of input items and their current prices (DATA.WK1).

The BURLEY.WK1 budget file provided the basic framework of the STEPS program; however, some revision was required within specific

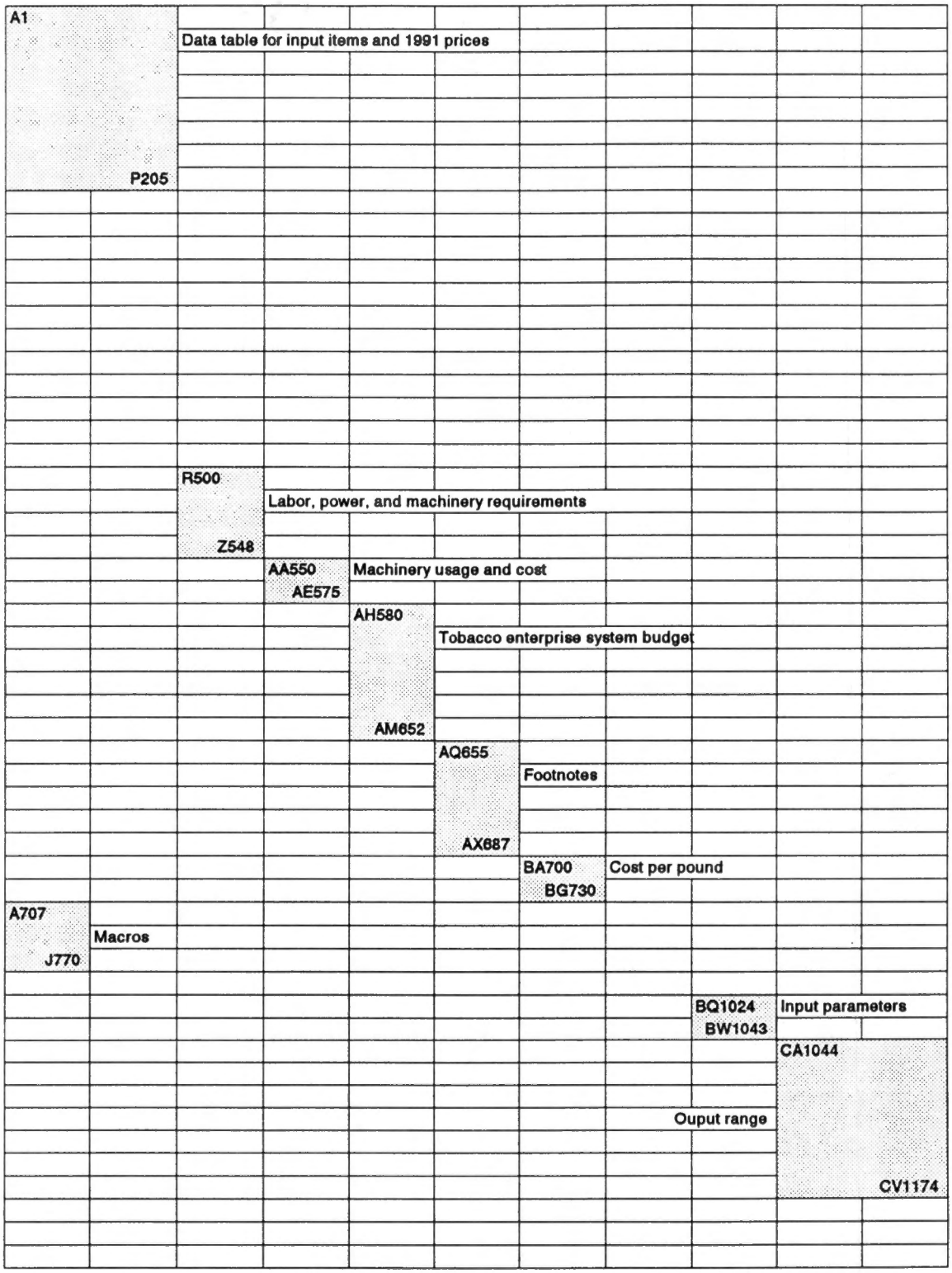


Figure III–1. Diagram of the names and location within Lotus 1–2–3 spreadsheet of components of STEPS (Software for Tobacco Enterprise Planning System). Locations designated by cell addresses of upper left and lower right cells of each component.

components to accommodate the additional enterprise detail resulting from the SPACING research. The diagonal positioning of separate components within the spreadsheet allowed insertion or deletion of rows and/or columns within each component without altering other components. To economize on file size, inputs and prices from enterprises other than tobacco were deleted from the data table after it was "File Combined" with the burley spreadsheet. Also, some machinery items which were not included in the DATA.WK1 file were added to the machinery cost section of the DATA table. The STEPS program consists of the modified data file and the modified burley budget merged into a single Lotus 1-2-3® spreadsheet file named STEPS.WK1.

When the STEPS file is retrieved into an active Lotus 1-2-3® session, an instruction screen and customized menu tree appear on the monitor. The user may select from menu choices to move to various components of STEPS. For the analysis of the SPACING project, an input **PARAMETERS** screen (Figure III-2) was developed to allow for user-determined changes in drill and row spacing, labor overhead factor, and field-to-barn distance and transport speed. Other input levels and prices can be modified by working directly within the STEPS components. The PARAMETERS component includes the models to estimate yield per plant and formulas to compute plant population per acre, the number of rows in a 4:1 rectangularly shaped field, and the number of 9'x 100' plant beds required per acre at the

USER SELECTED PARAMETERS FOR BURLEY TOBACCO BUDGET		
	DRILL	xx
	ROW	xx
Population per Acre for Selected Row and Drill Spacings:		xxxx
Yield per plant (pounds)		x.xx
Multiplier Factor for Labor Overhead		x.xx
Number of Rows in a 4:1 Rectangular Acre		xx
Number of Sticks per Acre:		xxxx
Average Field to Barn Transport Distance:	MILES	x.xx
Average Field to Barn Transport Speed:	MPH	x.x
Number of 9' by 100' Plant Beds per Acre:	BEDS	x.x

Figure III-2. Input parameter screen in STEPS (Software for Tobacco Enterprise Planning System). Shaded cells are user determined, other cells are calculated within the spreadsheet.

specified population.

The labor, power, and machinery requirements component (**LABOR**) from the UTGFP burley budget was modified in STEPS to include the 27 production practices identified in Table III-1. Table III-6 is an example of format for the LABOR table to be generated for any spacing combination within the range of the SPACING experiment. Equipment items typed in all capital letters indicate that machinery and labor requirements for those practices were determined from the UTGFP. The LABOR component of STEPS is designed to indicate the tractor size, machinery and equipment,

TABLE III–6. Burley tobacco production practices. Tractor and equipment requirements, machinery usage, and labor requirements.

Drill-Row Spacing: xx in X xx in Plant Population per Acre: xxxx plants

PRACTICE	TRACTOR	EQUIPMENT	MACHINE TIME (hr/ac)	MANUAL LABOR (hr/ac)
PLANT BED				
Plow	60 hp	PLOW, 3-14",MOUNTED	x.xx	x.xx
Disk	60 hp	TANDEM DISK, 8',MOUNTED	x.xx	x.xx
Fumigate	34 hp	16' Trailer	x.xx	x.xx
Seed	34 hp	16' Trailer	x.xx	x.xx
Spray	----	HAND SPRAYER	x.xx	x.xx
Water	60 hp	16' Trailer, Water Tank	x.xx	x.xx
FIELD				
Primary Tillage	60 hp	PLOW, 3-14",MOUNTED	x.xx	x.xx
Disk	60 hp	TANDEM DISK, 8',MOUNTED	x.xx	x.xx
Fertilize	60 hp	FERT SPREADER,SPINNER,600#	x.xx	x.xx
Apply Pesticides	60 hp	SPRAYER, WITH BOOM	x.xx	x.xx
Disk, 2 passes	60 hp	TANDEM DISK, 8',MOUNTED	x.xx	x.xx
Pull Plants	----	Hand, @1.27 hr/M plants	----	x.xx
	60 hp	16' Trailer	x.xx	----
Transplant	34 hp	1-Row Transplanter	x.xx	x.xx
	60 hp	16' Trailer	x.xx	----
Cultivate	34 hp	1-Row Cultivator	x.xx	x.xx
Cultivate	34 hp	1-Row Cultivator	x.xx	x.xx
Insect Control	60 hp	SPRAYER, WITH BOOM	x.xx	x.xx
Top	----	Hand	----	x.xx
Sucker Control	----	Custom Applicator	----	----
HARVEST				
Drop Sticks	34 hp	16' Trailer	x.xx	x.xx
Cut	----	2 Knives, 2 Spears	x.xx	x.xx
Load	34/60 hp	2 Tractors, 2-16' Trailers	x.xx	x.xx
Transport	34/60 hp	2 Tractors, 2-16' Trailers	x.xx	x.xx
Hang	34/60 hp	2 Tractors, 2-16' Trailers	x.xx	x.xx
Disk	60 hp	TANDEM DISK, 8',MOUNTED	x.xx	x.xx
Seed Cover Crop	60 hp	GRAIN DRILL, 14X7"	x.xx	x.xx
MARKET PREPARATION				
Takedown	----	Hand	----	x.xx
Strip & Grade	----	Carousel, Baler, Compressor	x.xx	x.xx
Stalk Disposal	60 hp	16' Trailer	x.xx	x.xx
Market	----	CUSTOM HAULER	----	x.xx
		TOTAL HOURS	xx.xx	xxx.xx

and manual labor required for each task. Machine time represents the elapsed time required to perform each task while the manual labor requirement incorporates crew size and the user-determined overhead labor factor. The manual labor requirement for the eight tasks observed directly in the SPACING-ECONOMIC experiment is estimated by the eight labor models (from equation 3.4) which are included in the LABOR component of STEPS. Four of the labor requirements are based on coefficients from the PRODUCTION RUN experiment, and the remainder of the labor requirement coefficients are provided by the UTGFP.

While Table III-6 represents the format for the component of STEPS which determines the technical machinery and labor coefficients, Table III-7 is a sample format of the STEPS component which sums the machinery usage from the labor, power, and machinery table by machinery item. This component (**MACHINERY**) uses price information from the DATA table to determine variable, fixed, and interest costs for each machine. The variable cost component for machinery consists of repairs and, for machines with engines: fuel, filters, and lubricants. Repair cost per hour of use is estimated as a percentage of new cost divided by the anticipated life of the machine in hours of use. Estimates for variable cost per hour of use were obtained from the data table of the UTGFP. The MACHINERY component of STEPS uses the "lookup" feature of Lotus 1-2-3® to locate the appropriate machine item and associated variable cost per hour in the DATA table and multiplies

Table III-7. Burley tobacco machinery usage and costs.

Drill-Row Spacing: xx in X xx in Plant Population per Acre: xxxx plants

MACHINE	TOTAL USAGE (hr/ac)	VARIABLE COST ($/ac)	FIXED COST ($/ac)	INTEREST COST ($/ac)
TRACTOR, 60H.P.	x.xx	x.xx	x.xx	x.xx
TRACTOR, 34H.P.	x.xx	x.xx	x.xx	x.xx
PLOW, 3-14",MOUNTED	x.xx	x.xx	x.xx	x.xx
TANDEM DISK, 8',MOUNTED	x.xx	x.xx	x.xx	x.xx
HAND SPRAYER	x.xx	x.xx	x.xx	x.xx
Water Tank and Pump	x.xx	x.xx	x.xx	x.xx
FERT SPREADER,SPINNER,600#	x.xx	x.xx	x.xx	x.xx
SPRAYER, WITH BOOM	x.xx	x.xx	x.xx	x.xx
TOBACCO TRANSPLANTER, 1-ROW,	x.xx	x.xx	x.xx	x.xx
CULTIVATOR, 1-ROW	x.xx	x.xx	x.xx	x.xx
GRAIN DRILL, 14X7"	x.xx	x.xx	x.xx	x.xx
TRAILER 16'	x.xx	x.xx	x.xx	x.xx
Cutting Equipment	x.xx	x.xx	x.xx	x.xx
Grading Carousel	x.xx	x.xx	x.xx	x.xx
Baler, 3-Compartment	x.xx	x.xx	x.xx	x.xx
Air Compressor	x.xx	x.xx	x.xx	x.xx
TOTAL		$xxx.xx	$xxx.xx	$xxx.xx

that cost by the total usage in the tobacco enterprise to determine the variable machinery cost per acre. The machinery fixed cost component consists of straight line depreciation over the useful life of the machine, insurance cost at $12 per $1000 dollars of average value, and an annual maintenance charge for machinery storage space based on the square feet of storage space required. The machinery interest cost is based on one-half the new cost of the machine at the prevailing interest rate with the cost prorated over the hours of useful life. Just as for variable cost, the MACHINERY component of STEPS "looks up" the appropriate machine item and associated fixed and interest costs per hour in the DATA table and multiplies them by the hours of use in the tobacco enterprise to determine

the costs per acre for selected plant spacings. The MACHINERY cost component also sums across machinery items to provide total variable, fixed, and interest cost per acre for the tobacco enterprise. As for the LABOR component, all-capital letters indicate items found in the original UTGFP; mixed-letters indicate machinery items added to the DATA table from other sources. Another modification to the UTGFP burley budget was to assume the use of two different size tractors in the burley enterprise.

The tobacco enterprise **BUDGET** is the component of STEPS which integrates agronomic and economic relationships specified in other components of the spreadsheet into an enterprise planning system. The plant bed component (Table III-8) estimates the variable costs of one 9'x 100' plant bed, and the decision formula in the PARAMETERS component of the enterprise planner determines how many plant beds are required per acre at the user-determined population. Table III-9 is the format for an enterprise budget. Each line in the budget is dependent on the values, models, or formulas which reside in the previously discussed components of the STEPS software. By changing values in the PARAMETERS screen or DATA table, an infinite number of enterprise alternatives are available to the user of STEPS.

To evaluate the economic implication of the relationships identified in the SPACING research, STEPS was executed for all even-valued plant spacing combinations within the range of the study. That is, every even-

Table III–8. Burley tobacco estimated variable costs for one 9'x100' plant bed

ITEM	DESCRIPTION	UNIT	QUANTITY (#/bed)	PRICE ($/unit)	AMOUNT ($/bed)
Seed	Hybrid 1/12 oz.	pkg	x.xx	x.xx	x.xx
Fertilizer	4-16-4	cwt	x.xx	x.xx	x.xx
Gas Cover	103'x10.5', 3 mil	ea	x.xx	x.xx	x.xx
Bed Cover	100'x9', Polyester	ea	x.xx	x.xx	x.xx
Insecticide	Di-Syston 5G	oz	x.xx	x.xx	x.xx
Fungicide (2)	Ridomil 2E	qt	x.xx	x.xx	x.xx
Fumigant	Methyl Bromide	lb	x.xx	x.xx	x.xx
Applicator	Prorated 3 Years		x.xx	x.xx	x.xx
				TOTAL	xx.xx

valued in-row spacing from 12" to 36" was paired with every even-valued row width from 36" to 54". This pairing resulted in 130 row/drill combinations. To execute this number of enterprise plans and store the results from all plans, a Lotus 1-2-3® macro (a set of stored commands) was included in STEPS to insert each of the 130 spacing combinations into the PARAMETER screen, recalculate the enterprise system, and store the results in the output component of the spreadsheet. Data from the output range was manipulated so that tabular and graphical results could be assembled.

The BUDGET component of STEPS computes total revenue, costs, and returns to selected resources or resource combinations for user-determined plant spacings. The total physical product on a land area basis is the product of the yield model and the plant population which result from the specified plant spacing. Total value product (revenue) is determined using TPP (yield) times the product price from the DATA table. Variable and

TABLE III-9. Burley tobacco estimated revenue, costs, and residual returns to six potentially limiting resource combinations.

Drill-Row Spacing: xx in X xx in Plant Population per Acre xxxx plants

ITEM	DESCRIPTION	UNIT	QUANTITY (#/ac)	PRICE ($/unit)	AMOUNT ($/ac)
REVENUE	Tobacco	lb	xxxx	x.xx	xxxx.xx
EXPENSES, Variable					
Transplants	9'x100' Plant Bed	ea	x.x	x.xx	xx.xx
Fertilization	5-10-15	cwt	x.x	x.xx	xx.xx
	Nitrogen	lb	x.x	x.xx	xx.xx
	Lime	ton	x.x	x.xx	xx.xx
Insecticide	Orthene 75SP	lb	x.x	x.xx	xx.xx
Fungicide	Ridomil 2E	qt	x.x	x.xx	xx.xx
Herbicide	Prowl 4E	pt	x.x	x.xx	xx.xx
Sucker Control	Royal MH-30	gal	x.x	x.xx	xx.xx
	Custom Spraying	ac	x.x	x.xx	xx.xx
Cover Crop	Wheat	bu	x.x	x.xx	xx.xx
Grading	Cotton Twine	lb	x.x	x.xx	xx.xx
Market Fees	4.5% + $1/cwt				xx.xx
Hauling	To Market	cwt	x.x	x.xx	xx.xx
Program Costs	NNC, Grading Fees	cwt	x.x	x.xx	xx.xx
Assessment	1/2% of Gross	cwt	x.x	x.xx	xx.xx
Machinery	Fuel/oil, repairs	ac	x.x	x.xx	xx.xx
			TOTAL VARIABLE EXPENSES		xx.xx
			NET RETURN ABOVE VARIABLE EXPENSES		xx.xx
EXPENSES, Fixed					
Machinery	Depr, Insc, Storage	ac	x.x	x.xx	xx.xx
Tobacco Sticks	Prorated 8 Years	ea	xxxx	x.xx	xx.xx
Barn	Conventional, 4-tier	ea	x.x		xx.xx
			TOTAL FIXED EXPENSES		xx.xx
			TOTAL VARIABLE AND FIXED EXPENSES		xx.xx
			NET RETURN TO QUOTA, LAND, LABOR, CAPITAL, AND MANAGEMENT		xx.xx
EXPENSES, Interest					
Variable Capital	6 Months	$	x.x	x.xx%	xx.xx
Fixed Capital	Machinery	ac	x.x	x.xx%	xx.xx
Fixed Capital	Barn	ea	x.x	x.xx%	xx.xx
			TOTAL INTEREST EXPENSE		xx.xx
			NET RETURN TO QUOTA, LAND, LABOR, AND MANAGEMENT		xx.xx
EXPENSES, Labor		hr	xx.xx	x.xx	xx.xx
EXPENSES, Quota		lb	xxxx	x.xx	xx.xx
EXPENSES, Land		ac	x.xx	xx.xx	xx.xx

NET RETURN: To Land and Management	$/ac	xx.xx
NET RETURN: To Labor and Management	$/hr	xx.xx
NET RETURN: To Quota and Management	$/cwt	xx.xx
NET RETURN: To Capital and Management	$/$100 of total cost	xx.xx
NET RETURN: To Barns and Management	$/1000 sticks of capacity	xx.xx
NET RETURN: To Management	$/$100 of total value product	xx.xx

fixed expense items are derived from a variety of sources in other components of STEPS and are classified in a format based on the UTGFP burley tobacco budget. Net value product for various resources are computed as the residual return to specified resources after the cost of all other factors of production have been deducted from the total revenue. Various net revenue measures are indicated in the enterprise budget by their location within highlighted boxes. Net return above variable expenses represents the revenue left to pay for capital costs, fixed machinery and facilities, quota, land, labor and management. Similarly, net return to quota, land, labor , capital, and management represents the residual revenue to pay to these resources after paying for variable expenses and the annual fixed cost of machinery and facilities. Following the same pattern, the other net return values represent the residual return to that factor, or set of factors, after the cost of all other factors has been deducted from total revenue.

The final six net revenue measures in the enterprise budget represent various resource situations which burley farmers might perceive as their fixed or most limiting resource(s). Thus, users of STEPS may evaluate the results of various enterprise plans from the perspective of their resource availability situation. From an analytical perspective, STEPS allows a large number of enterprise plans to be evaluated to determine: 1) economically optimal plant spacing combinations for selected resource limitations, 2) the

rate of change in net return levels as plant spacings are varied, and 3) the nature and magnitude of resource substitutions as plant spacings change. From an expository perspective, STEPS and SPACING provide data for tabular and graphical illustration of the potential economic implications of a wide range of burley plant spacing alternatives.

CHAPTER IV

RESULTS AND CONCLUSIONS

This study was designed to allow application of a systems research approach to the burley tobacco enterprise to determine physical and economic factor-factor and factor-product relationships associated with changes in in-row and between-row plant spacings of the burley tobacco plants. Additional objectives were to develop a microcomputer software tool to incorporate these mathematical relationships into a predictive simulation model of the burley enterprise, and to apply an analytical simulation algorithm to the burley model to demonstrate the choice of optimal plant spacings for each of several limiting resource situations.

Chapter III included descriptions of the physical and economic experiments used to generate the primary data for estimating the mathematical representations of the physical and economic relationships and the procedure for estimating and testing the relationships. Chapter III also included a description of the STEPS software used to integrate the physical and economic relationships into an economic model. This model could be solved for a wide range of in-row and between-row plant spacings and a variety of other input levels and prices. This chapter will:

1. Present summary tabular data for mean values and means separation tests of the parameters observed in the SPACING experiments.

2. Specify the functions estimated for those parameters and indicate whether the treatment variables were significant contributors to the variability of the parameters.

3. Review and elaborate on the incorporation of the estimated relationships into the burley enterprise system via the STEPS software.

4. Present and interpret results from 130 iterations of the STEPS software in tabular and graphical formats to illustrate how economically optimal plant spacing decisions may be determined.

INITIAL SPACING-AGRONOMIC RESULTS

As indicated in Chapter III, physical and economic data were collected for 12 different parameters from the SPACING-AGRONOMIC experiment for each of the twenty row-drill spacing combinations listed in Table III-2. The initial stage of the data analysis was to determine the mean values by year and across years for each of the treatment combinations, to determine whether means for combinations were significantly different from each other, and to identify any general relationships associated with the treatment variables. Table IV-1 is a list of variables on which data were observed in the SPACING-AGRONOMIC experiment. Complete data were collected over the entire six-year life of the experiment for six of the twelve variables. Various logistical, managerial, and administrative situations limited data collection of the remaining variables to less than the full six years of the experiment. Tables IV-2 through IV-13 follow the format of Table III-2 in listing the mean values by treatment across row widths and across drill

Table IV-1. Variables observed in the SPACING-AGRONOMIC experiment of the SPACING research project. Greeneville, TN. 1985-90.

Variable Name	Variable Description	Method of Measurement	# Years	N
YLDPLT	Cured leaf yield, lb/plant	Plot yield/plot plant number	6	480
YLDAC	Cured leaf yield, lb/ac	YLDPLT * nominal population/acre	6	480
GRNWT	Green harvest weight, lb/plant	Total plot weight/plot plant number	6	480
STDIA	Stalk base diameter, in/plant	Mean measurement of center stalks from each stick in plot	6	480
HNGLT	Inverted plant length, in/plant	Mean measurement of end stalks from each stick in plot	6	480
PRICE	Weighted average support price, $/cwt	1990 loan rate for each federal quality grade by stalk position	6	1440
LEAFNO	Number of leaves per plant, #/plant	Mean number of leaves from one plant from each stick in plot	4	320
STEM	Stem-lamina ratio of cured leaf, % by weight	Weight of stem and lamina portions of leaf in 2 lb sample from each plot	3	240
ALK	Total alkaloids in ground sample, % by weight	Concentration of total alkaloids in 25g sample from each stalk position grade	2	480
ASH	Ash in burned sample, % by weight	Ash residual in 25g sample from each stalk position grade	2	480
NNI	Nitrate nitrogen in ground sample, % by weight	Concentration of nitrate nitrogen in 25g sample from each stalk position	2	480
TNI	Total nitrogen in ground sample, % by weight	Concentration of total nitrogen in 25g sample from each stalk position	2	480

Table IV-2. Mean yield in pounds per plant (YLDPLT) for in-row and between-row plant spacing combinations. Mean yields across row widths and drill spacings. SPACING research project. Greeneville, TN. 1985-90.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(lb/plant)			
36	0.27	0.37	0.45	0.52	0.56	0.43 a
42	0.31	0.38	0.48	0.55	0.60	0.46 b
48	0.30	0.41	0.50	0.56	0.60	0.48 c
54	0.32	0.44	0.53	0.57	0.61	0.49 c
Drill Mean[2]	0.30 a	0.40 b	0.49 c	0.55 d	0.59 e	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-3. Mean yield in pounds per acre (YLDAC) for in-row and between-row plant spacing combinations. Mean yields across row widths and drill spacings. SPACING research project. Greeneville, TN. 1985-90.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(lb/ac)			
36	3955	3695	3200	2989	2664	3301 a
42	3732	3213	2946	2727	2478	3019 b
48	3286	3043	2729	2389	2179	2725 c
54	3095	2892	2518	2194	1961	2532 d
Drill Mean[2]	3517 a	3211 b	2848 c	2575 d	2320 e	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-4. Mean harvest weight in pounds per plant for (GRNWT) in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1985-90.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(lb/plant)			
36	3.41	4.44	5.14	5.90	6.11	5.00 a
42	3.66	4.43	5.35	5.97	6.24	5.13 a
48	3.54	4.68	5.48	6.00	6.34	5.21 ab
54	3.70	5.08	5.86	6.10	6.26	5.40 b
Drill Mean[2]	3.58 a	4.66 b	5.46 c	5.99 d	6.24 d	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-5. Mean base stalk diameter in inches (STDIA) for in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1985-90.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(in/plant)			
36	1.17	1.31	1.39	1.44	1.44	1.35 a
42	1.22	1.29	1.34	1.45	1.49	1.36 a
48	1.18	1.31	1.39	1.48	1.45	1.36 a
54	1.22	1.36	1.44	1.46	1.48	1.39 b
Drill Mean[2]	1.20 a	1.32 b	1.39 c	1.46 d	1.47 d	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-6. Mean inverted hanging length of wilted plants 24-48 hours post harvest in inches per plant (HNGLT) for in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1985-90.

	Drill Spacing (in.)					
Row Width (in.)	12	18	24	30	36	Row Mean[1]
			(in/plant)			
36	62.9	63.4	61.5	63.3	61.6	62.6 a
42	61.8	60.9	60.9	61.9	61.7	61.4 ab
48	60.2	61.4	60.7	61.6	60.3	60.8 b
54	60.1	62.7	61.5	59.7	58.9	60.6 b
Drill Mean[2]	61.3 a	62.1 a	61.1 a	61.6 a	60.6 a	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-7. Mean price in dollars per pound[1] (PRICE) for in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1985-90.

	Drill Spacing (in.)					
Row Width (in.)	12	18	24	30	36	Row Mean[2]
			($/lb)			
36	1.51	1.51	1.54	1.54	1.56	1.53 a
42	1.52	1.50	1.52	1.52	1.52	1.51 a
48	1.53	1.52	1.52	1.54	1.51	1.52 a
54	1.54	1.50	1.54	1.56	1.56	1.54 a
Drill Mean[3]	1.52 ab	1.51 b	1.53 ab	1.54 a	1.54 a	

[1]Prices were determined using 1990 federal support price levels assigned to quality grades for each of three stalk position grades.
[2]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[3]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-8. Mean number of marketable leaves per plant (LEAFNO) for in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1987-90.

	Drill Spacing (in.)					
Row Width (in.)	12	18	24	30	36	Row Mean[1]
			(#/plant)			
36	19.7	20.3	20.8	21.8	21.3	20.8 a
42	19.1	20.1	21.3	21.7	21.3	20.7 a
48	19.0	21.5	22.6	21.9	22.1	21.4 a
54	19.0	21.0	22.4	21.8	21.8	21.2 a
Drill Mean[2]	19.2 a	20.7 b	21.8 c	21.8 c	21.6 c	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-9. Mean percentage by weight of stem in leaf samples[1] (STEM) from in-row and between-row plant spacing combinations. Means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1987-89.

	Drill Spacing (in.)					
Row Width (in.)	12	18	24	30	36	Row Mean[2]
			(%)			
36	21.6	20.4	19.8	19.5	19.0	20.1 a
42	20.9	20.0	19.4	18.2	18.4	19.5 b
48	21.4	19.6	19.0	18.5	18.9	19.4 b
54	20.7	19.4	18.6	18.4	17.9	19.0 b
Drill Mean[3]	21.1 a	19.8 b	19.2 c	18.7 c	18.6 c	

[1]The remaining percentage is the lamina volume by weight of the leaf sample.
[2]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[3]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-10. Mean percentage by weight of total alkaloids (ALK) in cured leaf samples for in-row and between-row plant spacing combinations and means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1986-87.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(%)			
36	3.07	3.37	3.31	3.48	3.44	3.33 a
42	3.51	3.51	3.67	3.55	3.70	3.59 b
48	3.23	3.26	3.36	3.40	3.45	3.36 a
54	3.26	3.32	3.63	3.34	3.39	3.39 a
Drill Mean[2]	3.29 a	3.36 ab	3.49 b	3.44 ab	3.50 b	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-11. Mean percentage by weight of ash (ASH) from cured leaf samples for in-row and between-row plant spacing combinations and means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1986-87.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(%)			
36	17.93	18.10	18.77	19.00	18.19	18.40a
42	18.01	18.58	18.54	17.97	18.47	18.31a
48	18.89	18.81	18.53	18.27	18.51	18.60a
54	18.01	18.72	18.72	18.92	18.58	18.60a
Drill Mean[2]	18.21a	18.55a	18.64a	18.54a	18.44a	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-12. Mean percentage by weight of nitrate nitrogen (NNI) in cured leaf samples for in-row and between-row plant spacing combinations and means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1986-87.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(%)			
36	0.36	0.44	0.42	0.38	0.33	0.39 a
42	0.40	0.36	0.38	0.37	0.39	0.38 a
48	0.39	0.38	0.38	0.37	0.36	0.38 a
54	0.36	0.38	0.37	0.39	0.37	0.37 a
Drill Mean[2]	0.38 a	0.39 a	0.39 a	0.38 a	0.36 a	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

Table IV-13. Mean percentage by weight of total nitrogen (TNI) in cured leaf samples for in-row and between-row plant spacing combinations and means across row widths and drill spacings. SPACING research project, Greeneville, TN. 1986-87.

Row Width (in.)	Drill Spacing (in.) 12	18	24	30	36	Row Mean[1]
			(%)			
36	4.14	4.32	4.27	4.07	4.17	4.19 a
42	4.08	4.13	4.12	4.21	4.14	4.14 a
48	4.28	4.16	4.20	4.22	4.20	4.21 a
54	4.21	4.13	4.30	4.23	4.23	4.22 a
Drill Mean[2]	4.18 a	4.18 a	4.22 a	4.18 a	4.19 a	

[1]Row means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.
[2]Drill means with different letters are significantly different by Duncan's multiple range test at the $\alpha = 0.05$ probability level.

spacings for the 12 variables. Duncan's multiple range test for significant differences between means at the .05 probability level are indicated for means grouped across row widths and across drill spacings. Duncan's tests for differences among the twenty treatment variables were conducted and are available from the author; however, to prevent unnecessary detail, they were omitted from the tables.

Mean yield results are included in Tables IV-2 and IV-3. Typically tobacco yields from agronomic studies, on-farm demonstrations, and farm statistical series are presented in terms of yield per acre, although plant populations may vary considerably from region to region or over years as cultural practices are modified. As discussed previously, the intrinsic relationship between plant population and production costs (particularly labor) suggests that yield per plant is an important measurement standard for decision makers to consider. The presentation of the two yield tables illustrates the importance of considering yield per plant (YLDPLT) as well as yield per acre (YLDAC). Subsequent results in this chapter will indicate a general inverse relationship between net returns and YLDAC and a positive relationship between net returns and YLDPLT over a substantial range of the data and limiting resource situations. Therefore, a farmer selecting a plant spacing solely on the basis of one of these two yield parameters might select a less than economically optimal production practice. That is, the optimum agronomic yield (per acre or per plant) may not be the optimum

economic yield. This dilemma concerning choice of optimization variable is explored more fully in the discussion of net value product (NVP) results later in this chapter.

Two notable trends may be observed in Table IV-2. First, the rate of change in YLDPLT diminished as drill spacing was increased within each of the row spacings. Second, the increases in YLDPLT associated with changes in drill spacing were greater than the changes associated with comparable changes in row width, particularly at the lower end of the range of drill spacings. Similar trends were observed in two other measures of plant size: green harvest weight per plant (Table IV-4, GRNWT) and base stalk diameter at harvest (Table IV-5, STDIA). These results were not surprising and support earlier cited research in tobacco and other field crops which indicated that plant size and yield per plant increased as the spatial arrangement of the plants was widened to allow individual plants less competition for light, water, and other environmental assets.

Examination of both YLDPLT and YLDAC results revealed other trends that support earlier findings. As YLDPLT increased as drill and row spacings were increased, YLDAC decreased because the increase in plant yield was not enough to offset the reduced number of plants associated with the wider plant spacings. The increases in YLDPLT were the reason that the YLDAC declines were not proportional to the declines in plant population per acre. This nonproportional decline in YLDAC was noted in several previous studies

but the actual YLDPLT values and their positive but diminishing trends were not reported. The results of this study revealed an 8.3% decrease in YLDAC for a 25% reduction in plant population per acre (8000 PPA to 6000 PPA). For comparison, Link and Terrill (1985) observed a 4.7% decrease in YLDAC over this same range of populations in their study. Over the entire range of the SPACING study, YLDAC declined 50.4% as population per acre was reduced 77.7%.

A fourth measure of plant size, inverted hanging length at harvest (Table IV-6, HNGLT), did not follow the trends just described. No statistically significant differences were observed for changes in drill spacing and trends across row widths were not consistent. Casual observation of the plants at harvest suggested that wider spaced plants grew shorter but had longer top leaves than the more closely spaced plants. Thus, when the plants were harvested, speared onto sticks, and inverted into their curing positions, the longer top leaves of the shorter plants offset the additional stalk length of the closer spaced plants. The result is the absence of hanging length differences noted in Table IV-6.

The PRICE variable was used as a proxy for quality evaluation of the spacing treatments. Values in Table IV-7 represent the means of weighted average support prices for each stalk position grade in the SPACING treatments. Few significant differences were noted and no substantial trends associated with drill or row spacings were suggested. These results

are consistent with most of the previous tobacco spacing studies which failed to find economically significant quality differences associated with plant spacing variations.

Other physical plant measures included the number of marketable leaves (Table IV-8, LEAFNO) and stem-lamina ratio (Table IV-9, STEM). Leaf number is generally positively correlated to yield per plant and is also an important consideration in determining total labor requirement as leaves must be individually removed from the stalk and sorted during the market preparation task. LEAFNO tended to increase with wider drill spacing within any row width up to the 24- to 30-inch drill spacings where it stabilized. No significant differences were noted across row widths within any drill spacing, again reinforcing the previously stated notion that drill spacing was a more significant factor than row width for some plant parameters. Proportion of stem to lamina in the cured leaf is of interest to manufacturers of finished tobacco products because the lamina is the portion of the leaf which is more desirable in most manufacturing processes. Results reported in Table IV-9 suggested the percentage by weight of stem in leaf samples declined at wider row and drill spacings.

The final four tables in this initial series report results from standard industry chemical analyses: Table IV-10, percent total alkaloids (ALK); Table IV-11, percent ash (ASH); Table IV-12, percent nitrate nitrogen (NNI); and Table IV-13, percent total nitrogen (TNI). The values presented are the

means of weighted average results from two years of the SPACING study. Except for a weak trend toward higher alkaloid levels as drill spacing was increased within row widths, no significant differences were detected as a result of the chemical analyses.

RESULTS FROM MODEL ESTIMATES

SPACING-AGRONOMIC Variables

The previous section included results from the initial stages of the SPACING-AGRONOMIC experiment for the nominal row-drill treatment variables. The nominal treatment levels and the factorial treatment arrangement of Tables IV-2 through IV-13 provided an acceptable format for the initial stages of the analysis and for tabular presentation of mean values. However, additional information was collected on the treatment variables for the model estimation stages of the analysis. As has been previously indicated, actual row and drill spacing measurements were collected for each of the nominal treatment variables. These actual observations of row and drill spacing, which corresponded to the observations of the twelve SPACING-AGRONOMIC parameters, were used as the independent variables to estimate the models for eleven of the twelve variables listed in Table IV-1. The remaining variable, YLDAC, was not observed directly but rather was arithmetically determined by multiplying YLDPLT by the corresponding plant

population per acre. Results from the ordinary least squares estimation of the models are presented in Table IV-14.

The first five of the models (YLDPLT, GRNWT, STDIA, HNGLT, and LEAFNO) estimate parameters which assess the physical size or yield potential of the tobacco plants. The coefficient estimates for the treatment variables generally support the trends observed in the initial stages of the analysis. Namely, that the treatment variables, in-row spacing (DRILL) and between-row spacing (ROW) positively influence most plant size variables. Furthermore, significant negative values on the quadratic term ($DRILL^2$) suggest that the effects of DRILL diminish at wider drill spacings. The relative values of the DRILL and ROW estimates support the earlier observation that drill spacing contributes more to changes in plant-size parameters than does row spacing. Values for DRILL in the YLDPLT, GRNWT, and STDIA models are larger than values for ROW by approximately a factor of ten. Estimates for the HNGLT model support initial observations that treatment variables had little or no influence on the inverted hanging length of the harvested plants. Although the ROW term was statistically significant, a change of a tenth of an inch for each one inch change in row spacing is of no practical significance to a farmer considering vertical tier spacing in curing barns. Drill spacing contributed positively (but at a diminishing rate) to leaf number per plant (LEAFNO). Row spacing was not a significant contributor to LEAFNO.

Table IV-14. Multiple regression coefficient estimates for parameters observed in SPACING-AGRONOMIC experiment. SPACING research project, Greeneville, TN. 1985-90.

Model[b]	Variable[a]											
	Intercept	Y85	Y86	Y87	Y88	Y89	Y90	ROW	DRILL	$DRILL^2$	F-value	R^2
YLDPLT (lb/plt)	-0.12 (-4.39)	0.09 (15.97)	0.03 (4.93)	-0.11 (-18.76)	0.06 (9.63)	-0.10 (-17.5)	0.03 (5.74)	0.003 (8.64)	0.026 (12.75)	-0.0003 (7.04)	230.1	0.84
GRNWT (lb/plt)	-0.44 (-1.16)	1.55 (19.78)	0.11 (1.35)	-1.63 (-20.88)	0.53 (6.79)	-0.98 (-12.53)	-0.43 (-5.50)	0.023 (4.45)	0.293 (10.55)	-0.004 (-6.66)	153.0	0.78
STDIA (in/plt)	0.76 (16.22)	0.15 (15.46)	-0.06 (-6.53)	-0.13 (-13.29)	0.08 (8.47)	-0.02 (-2.02)	-0.02 (-2.08)	0.002 (3.61)	0.032 (9.46)	-0.0004 (-6.28)	89.67	0.68
HNGLT (in/plt)	65.03 (26.05)	9.66 (19.05)	1.23 (2.42)	-9.10 (-17.92)	4.77 (9.41)	-7.97 (-15.72)	1.40 (2.76)	-0.103 (-3.10)	0.117 (0.65)	-0.003 (-0.78)	84.45	0.66
LEAFNO (#/plt)	12.76 (8.59)	NA[c]	NA[c]	2.48 (10.84)	-0.39 (-1.70)	-3.07 (-13.43)	0.98 (4.28)	0.037 (1.76)	0.491 (4.75)	-0.008 (-3.83)	36.13	0.51
PRICE ($/lb)	1.49 (32.47)	-0.04 (-4.49)	-0.04 (-4.38)	0.03 (3.32)	-0.06 (-6.27)	-0.004 (-0.44)	0.11 (12.2)	0.0003 (0.51)	0.0004 (0.12)	0.00001 (0.20)	19.98	0.32
STEM (%)	27.00 (24.15)	NA[c]	NA[c]	-2.17 (-15.37)	2.35 (16.65)	-0.18 (-1.27)	NA[c]	-0.059 (-3.83)	-0.323 (-4.12)	0.004 (2.82)	63.35	0.69
ALK (%)	3.13 (10.33)	NA[c]	-0.45 (-16.9)	0.45 (16.9)	NA[c]	NA[c]	NA[c]	-0.0005 (-0.14)	0.018 (0.83)	-0.0002 (-0.42)	44.99	0.34
ASH (%)	16.69 (17.79)	NA[c]	1.77 (21.3)	-1.77 (-21.3)	NA[c]	NA[c]	NA[c]	0.012 (0.95)	0.107 (1.62)	-0.002 (-1.52)	66.63	0.75
NNI (%)	0.38 (6.14)	NA[c]	0.02 (2.74)	-0.02 (-2.74)	NA[c]	NA[c]	NA[c]	-0.0008 (-0.93)	0.004 (0.85)	-0.0001 (-1.03)	4.74	0.18
TNI (%)	4.03 (20.85)	NA[c]	-0.20 (-11.5)	0.20 (11.5)	NA[c]	NA[c]	NA[c]	0.004 (1.40)	-0.001 (-0.06)	0.00002 (0.07)	20.71	0.49

Table IV-14 (cont.)

[a] Variables Y85-Y90 are intercept shifting dummy variables for years 1985-90. ROW, DRILL, and $DRILL^2$ are between-row, within-row, and a quadratic term for within-row spacing. T-values are indicated in parentheses.

[b] Models are defined as follows:

YLDPLT is cured leaf yield in pounds per plant,
GRNWT is green harvest weight in pounds per plant,
STDIA is stalk base diameter at harvest in inches per plant,
HNGLT is inverted plant length in inches per plant,
PRICE is the average federal support price per pound,
LEAFNO is the number of leaves per plant at market preparation,
STEM is the percentage by weight of the stem component of the cured leaf,
ALK is the percentage by weight of total alkaloids in cured leaf,
ASH is the percentage by weight of ash residue remaining following combustion of cured leaf,
NNI is the percentage by weight of nitrate nitrogen in cured leaf,
TNI is the percentage by weight of total nitrogen in cured leaf.

[c] Data were not collected for that year of the experiment.

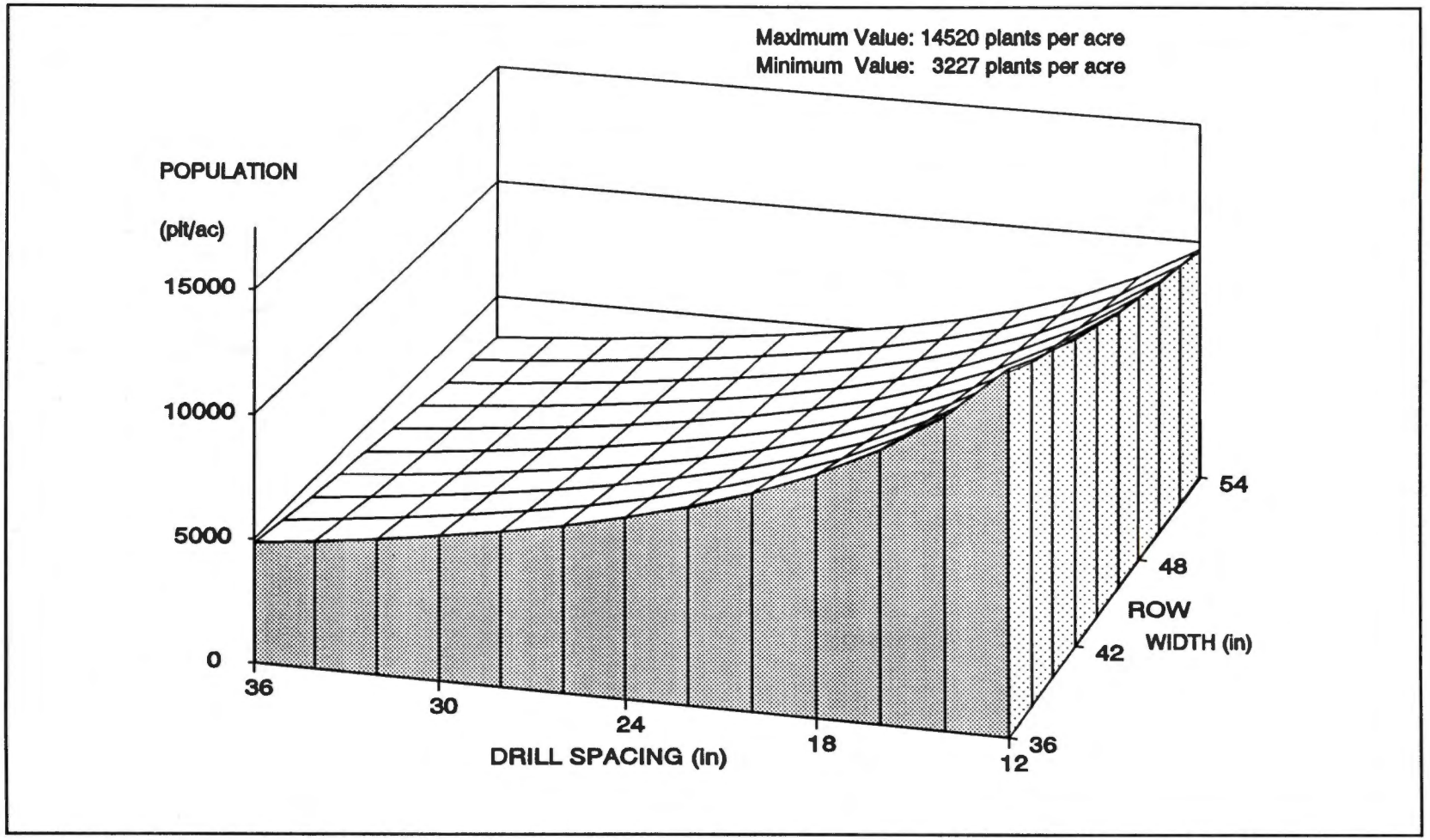


Figure IV-1. Plant population per acre for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

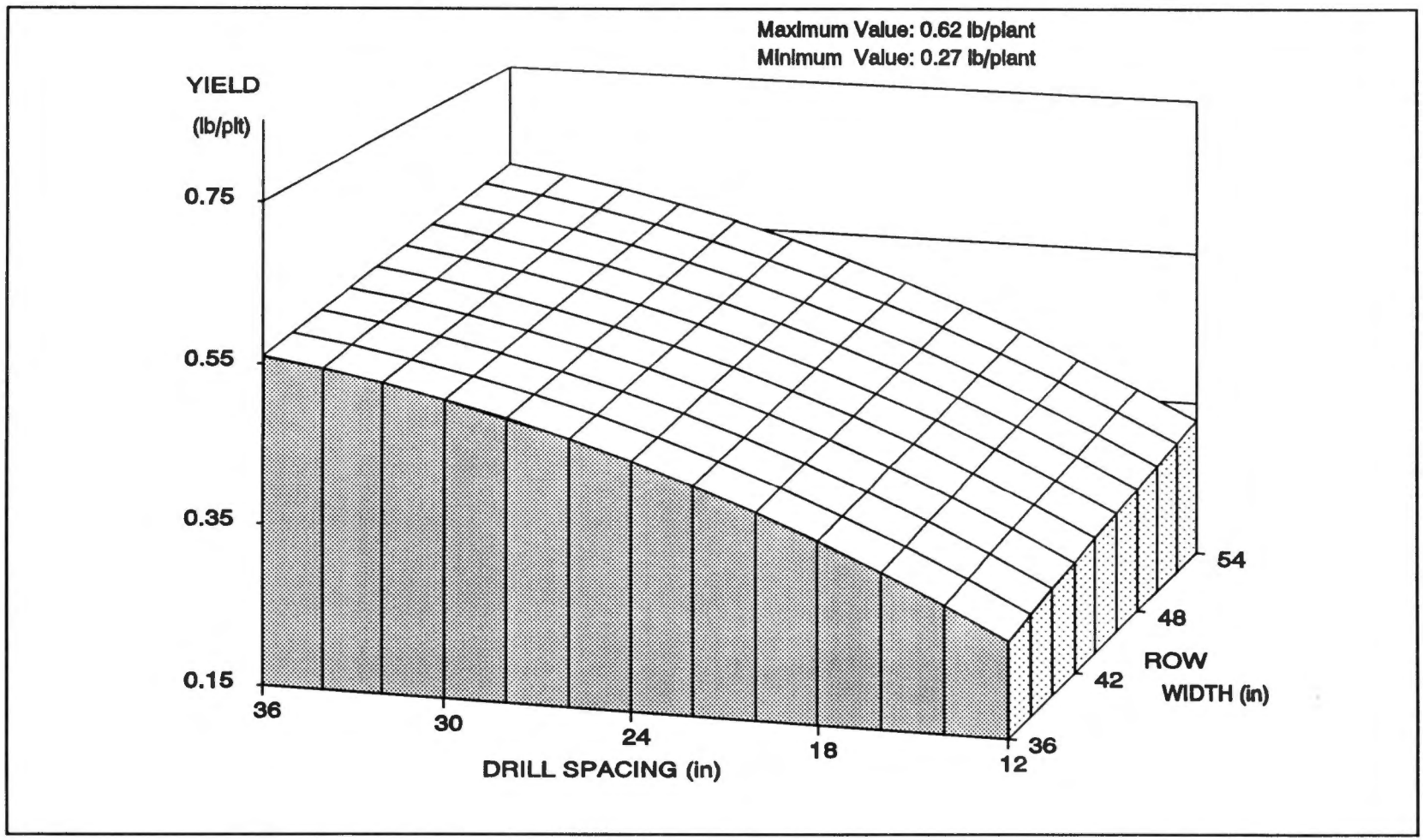


Figure IV-2. Predicted yield in pounds per plant for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

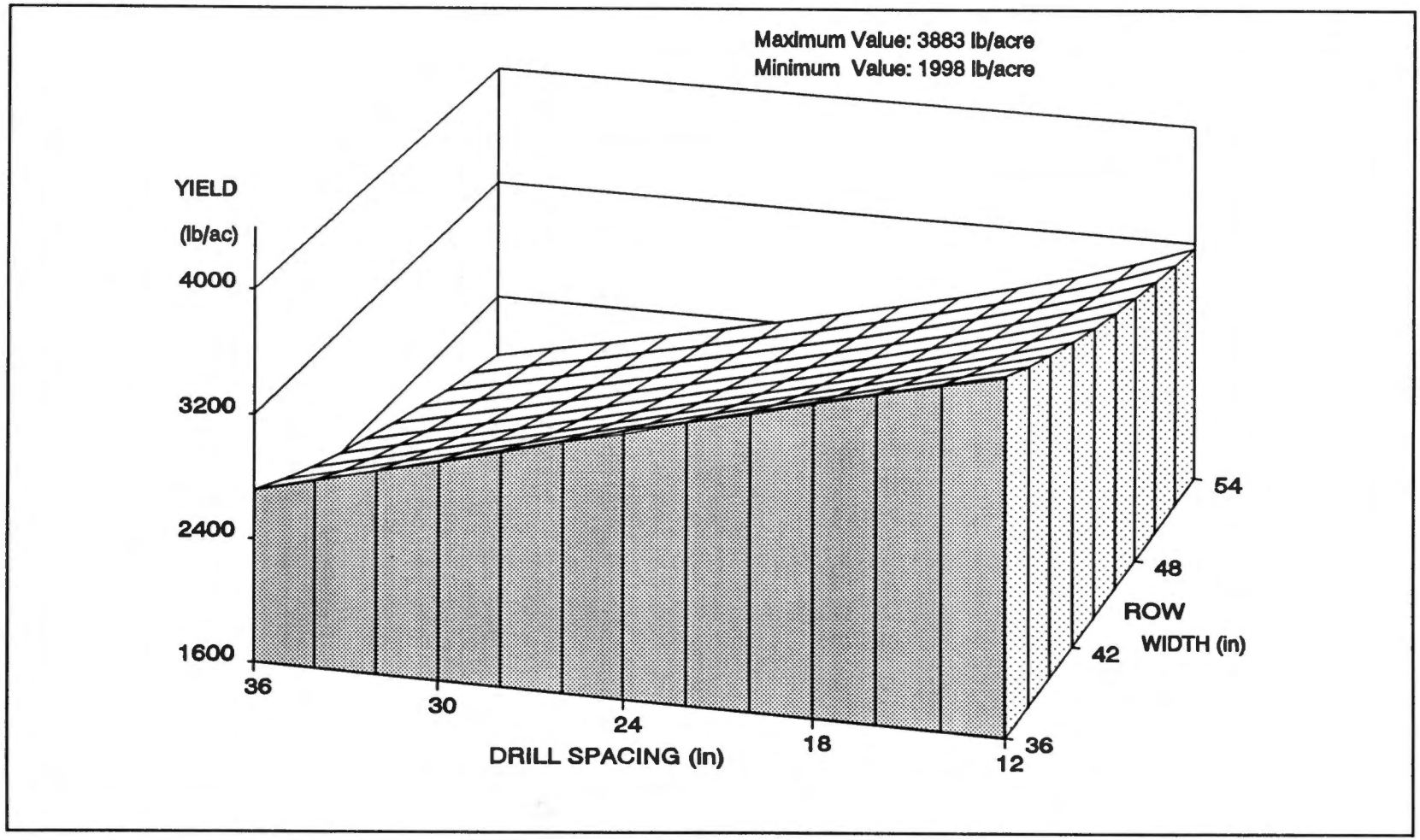


Figure IV-3. Predicted yield in pounds per acre for burley tobacco planted in 12- to 36- inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

Plant populations per acre for 130 possible spacing combinations within the range of SPACING are plotted in Figure IV-1. Corresponding predicted results from 130 solutions of the plant yield equation are plotted in Figure IV-2. The products of YLDPLT and PPA are plotted in a predicted YLDAC graph in Figure IV-3. The three figures display previously discussed results which indicate that YLDPLT increases as plant spacings increase and area populations decrease. The YLDPLT increases are proportionally less than the PPA decreases with the result (illustrated in Figure IV-3) that YLDAC decreases as spacings increase but not proportionally with the PPA decreases. Tabular data from which Figures IV-1, IV-2, and IV-3 were generated are presented in Appendix Tables A-1, A-2, and A-3.

Additional statistical tests were conducted on the YLDPLT model to determine if seasonal yield differences were due to seasonal variation in the influence of the row and drill variables. That is, did the coefficients on the ROW and DRILL variables vary statistically over the years of the experiment or were they relatively stable regardless of year-to-year variation in growing conditions. Ordinary least squares equations were estimated for YLDPLT by year for each of the six years of the experiment. F-tests of the ROW, DRILL, and $DRILL^2$ coefficients across all years indicated that ROW coefficients differed significantly but DRILL and $DRILL^2$ coefficients did not differ significantly across the six years of the experiment. In pairwise comparisons of the DRILL coefficients, no seasonal differences were detected. The DRILL

variable accounts for nearly ten times more variability in YLDPLT than does the ROW variable. Therefore, stability in the DRILL variable is a strong indicator that the relative influence of spacing on plant yield changes very little from seasons associated with high yields to those associated with low yields. This is an important result given that intercept shifting coefficients on the YEAR variables indicated that YLDPLT varied as much as ± 0.10 pound per plant. That level of variability represented the potential for a ± 20 percent seasonal yield variation.

SPACING-ECONOMIC Variables

Data relative to the primary input factors (land, curing facilities, machinery, fertilizer and chemicals, and labor) were collected in the SPACING-ECONOMIC portion of the field experiments. Land requirements on a per plant basis varied arithmetically with the spatial arrangement of the tobacco plants. Wider spaced plants obviously required more square feet of the land resource per plant than did the narrower spaced plants. The widest plant spacing required 13.5 ft^2/plant and the narrowest spacing required 3.0 ft^2/plant. On a per acre basis, each acre of tobacco required an acre of land. Land requirements for plant bed space were not observed directly but were calculated on the basis of one 9'x100' conventional plant bed per 8000 transplants. Thus, plant bed requirements varied from 1.8 to 0.4 beds per acre. To account for access space around the plant beds, the land area

requirement of 900 ft^2 of plant bed per 8000 transplants was doubled to 1800 ft^2 in the STEPS software.

Curing space requirements per plant did not vary as plant spacings were changed except for the six-stalk/stick versus the five-stalk/stick distinction. Plants from the 12-inch drill spacing were speared six stalks per curing stick; drill spacings of greater than 12 inches were speared at five stalks per stick. The experienced barning crews of the Tobacco Experiment Station were intentionally not given instructions as to what hanging density to use for various spacings, but rather were allowed to use their judgement as to where to space the sticks on the curing rails. Measurements of stick spacing on the rails made after the tobacco was hung in the curing barns indicated that the crews did not hang the larger, wide-spaced plants any differently than the narrower spacings. Therefore, barn space per thousand sticks of production was assumed to be constant. However, barn space on a per acre basis of production would fall proportionally with population as wider plant spacings were employed, excepting, of course, the six- versus five-stalk discontinuity.

Variability in machinery requirements on a per acre basis depended on the practice in question. Land preparation practices were the same across all spacing treatments. Machinery requirements per acre for primary and secondary tillage and seeding of a cover crop were not influenced by the plant spacings. Transplanting machinery requirements varied with row

width and drill spacing. Wider row widths required fewer rows per acre and wider drill spacings permitted faster ground speeds. Both these factors contributed to lower transplanting machinery requirements for wider spacings. Cultivation machinery requirement was not influenced by drill spacing but did vary with the number of rows per acre, a function of row width. Preplant and foliar application of pesticides was provided by ground equipment calibrated on a per acre basis and thus application machinery requirements did not vary across spacing treatments. Machinery requirements for harvest, housing, and market preparation practices varied with population as transport vehicle capacity was assumed constant across treatments. Therefore, wider spacings required fewer loads per acre in the harvest, housing, and market preparation practices.

Plant nutrient and pesticide inputs were held constant across spacing treatments. Current recommendations for fertilizer, lime, and pesticides used in the SPACING experiment are based on land area without regard to per acre populations. No adjustments were made to any of the recommended levels to account for population variation. Previous research (Atkinson, Byers, and Fuqua 1971; Link and Terrill 1985) had not indicated any fertilizer-yield interactions. Furthermore, such adjustments would have introduced another variable into the already large and complex SPACING experiment.

Of the input variables observed or calculated for the SPACING-ECONOMIC treatments, labor was by far the most economically important. Detailed labor data observations from four years of the SPACING experiment (1987-90) allowed estimation of the eight labor-practice models listed in Table IV-15. These eight practices account for 85 percent of the labor requirement and 50 percent of the total cost of a typical burley enterprise. Labor requirements for the balance of the burley practices were obtained from the UTGFP or the PRODUCTION-RUN experiment (see Table III-3) and were assumed to be constant on a land area basis (e.g. tillage practices) or linearly related to plant population (e.g. plant bed production and plant pulling). The machinery and labor requirement component of STEPS (illustrated in Table III-6) incorporated the regression models and the other labor data sources to estimate the total labor requirements for any possible plant spacing within the range of the SPACING experiment. The estimated labor requirements for the twenty nominal treatments are indicated in Table IV-16a, 16b, and 16c.

Predicted total labor hours per acre are shown in Table IV-16a. The positive relationship between population per acre and labor requirement per acre that is indicated in all eight of the labor equations in Table IV-15 is also evident in the predicted total labor requirement results reported in Table IV-16a. Across the range of the SPACING experiment, plant population per

Table IV-15. Multiple regression coefficient estimates for labor parameters observed in SPACING-ECONOMIC experiment. SPACING research project, Greeneville, TN. 1987-90.

Model[b]	Variable[a]							
	Intercept	Y87	Y88	Y89	Y90	MPPA	F-value	R^2
TPL	1.45 (5.69)	-0.35 (-1.67)	-1.07 (-5.09)	-0.39 (-1.86)	1.81 (8.63)	0.843 (29.46)	135.73	0.94
TOP	1.90 (6.32)	NA[c]	0.63 (4.40)	-0.63 (-4.40)	NA[c]	0.224 (6.66)	13.22	0.72
DRP	0.15 (0.77)	0.16 (1.02)	0.43 (2.72)	0.04 (0.26)	-0.64 (-4.00)	0.268 (12.33)	24.41	0.75
CUT	6.13 (6.77)	-2.33 (-3.13)	-0.30 (0.40)	-1.16 (1.56)	3.79 (5.09)	1.954 (19.28)	57.75	0.88
LOD	2.59 (9.61)	-0.74 (-3.36)	0.32 (1.46)	0.88 (3.98)	-0.46 (2.08)	0.715 (23.69)	84.63	0.91
HNG	2.55 (4.46)	-3.96 (-8.45)	1.97 (4.20)	0.47 (1.01)	1.52 (3.24)	1.049 (16.43)	50.00	0.86
TDN	1.72 (2.30)	-1.93 (-3.16)	-0.27 (0.44)	-2.25 (-3.68)	4.45 (7.27)	0.933 (11.18)	26.11	0.77
GRD	8.72 (3.42)	0.85 (0.40)	5.34 (2.55)	-8.34 (-3.98)	2.64 (1.26)	6.279 (22.01)	72.15	0.90

[a] Variables Y87-Y89 are dummy variables for each year of the experiment. MPPA is thousands of plants per acre. T-values are indicated in parentheses.

[b] Models are defined as follows:

TPL is transplanting labor in hours per acre
TOP is topping labor in hours per acre
DRP is stick dropping labor in hours per acre
CUT is cutting and spearing labor in hours per acre
LOD is wagon loading labor in hours per acre
HNG is barn hanging labor in hours per acre
TDN is takedown labor in hours per acre
GRD is stripping/grading labor in hours per acre.

[c] Topping labor was observed for only two years of the experiment.

Table IV-16. Predicted labor requirements for in-row and between-row plant spacings. (a) Hours per acre, (b) hours per 1000 plants, and (c) hours per hundredweight. SPACING research project. Greeneville, TN. 1985-90.

(a) Hours per acre

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			(hr/ac)		
36	326.2	233.1	186.7	158.8	140.1
42	286.0	206.1	166.5	142.5	126.5
48	255.8	185.9	151.2	130.2	116.2
54	232.3	170.2	139.4	120.7	108.3

(b) Hours per 1000 plants

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			(hr/M plt)		
36	22.5	24.1	25.7	25.7	28.9
42	23.0	24.8	26.7	28.6	30.5
48	23.5	25.6	27.8	29.9	32.0
54	24.0	26.4	28.8	31.2	33.6

(c) Hours per hundredweight

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			(hr/cwt)		
36	8.4	6.5	5.6	5.3	5.2
42	8.0	6.3	5.6	5.3	5.3
48	7.6	6.2	5.6	5.4	5.3
54	7.3	6.1	5.6	5.4	5.4

acre was reduced 78 percent and the estimated labor requirement declined slightly less than proportionally, 67 percent.

The same estimated labor requirements are expressed in Table IV-16b in terms of predicted labor requirements per thousand plants. Data shown in Table IV-16b provide an indication of the economic significance of the plant dimension data discussed in the SPACING-AGRONOMIC results. Labor requirements, expressed in hours per thousand plants, increased as plants were spaced wider within or between rows. This result seems reasonable in light of the increased plant size (GRNWT and STDIA) associated with the wider spacings. This result provides some indication as to why labor requirements per acre did not decline proportionally as plant populations were decreased. Larger plants simply require more energy to handle than smaller plants, particularly in the physically demanding harvest and housing practices.

Results presented in Table IV-16c incorporate estimates of plant yield from the YLDPLT model to provide an indication of labor requirement per hundredweight of estimated production of cured tobacco leaf for each of the nominal treatments. Labor hours per hundredweight diminish more rapidly as populations are decreased from the highest populations but remain rather constant across a substantial range of the wider spacings.

The tabular results shown in Tables IV-16 were expanded to include observations at each two-inch increment of drill and row spacing and are

presented in a graphical format in Figures IV-4, IV-5, and IV-6. The continual decrease in labor requirement per acre as populations were decreased is illustrated in Figure IV-4. The labor requirement per thousand plants is expressed graphically in Figure IV-5, but the units are expressed in hours per thousand sticks to capture the discontinuity introduced with the transition from 6-stalk to 5-stalk sticks at all combinations with greater than 18-inch drill spacings. The labor requirement in hours per hundredweight is illustrated in Figure IV-6. The stability of the labor requirement per hundredweight is clearly illustrated at the wider plant spacings. Tabular data from which Figures IV-4 through IV-6 were generated are included in Appendix Tables A-4, A-5, and A-6.

INCORPORATION OF RESULTS INTO STEPS MODEL

The physical and economic results just presented provided the basis for development of the enterprise system model in the STEPS software. The SPACING-AGRONOMIC and SPACING-ECONOMIC results represent the typical results generated in reductionist scientific research. STEPS represents the attempt to incorporate these research results and other physical and economic information regarding the burley tobacco enterprise into an analytical system which accounts for the interactions and interdependencies of the enterprise. Mathematical formulas within the various components of STEPS specify the relationships defined in the

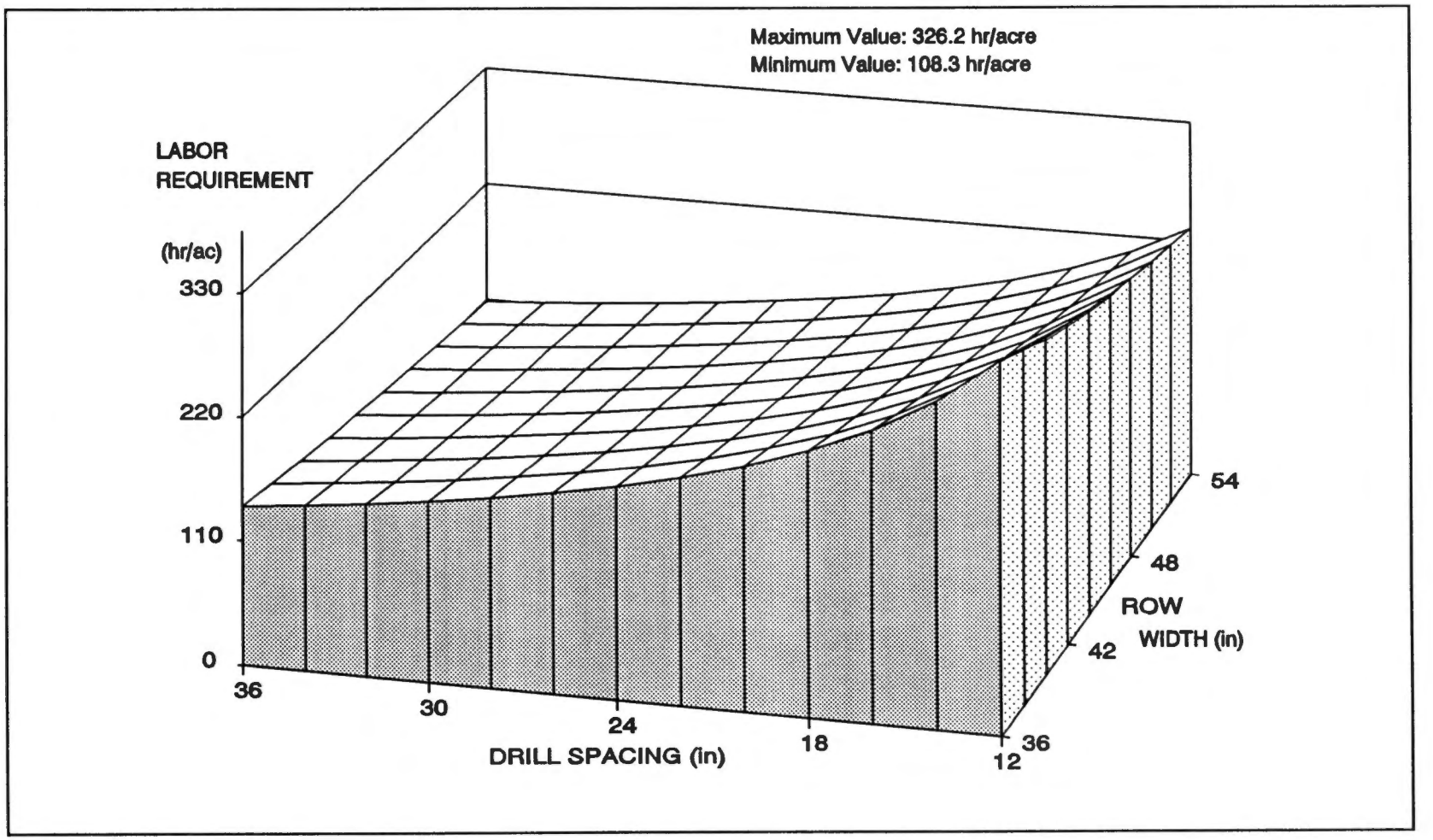


Figure IV-4. Predicted labor requirement in hours per acre for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING research project. Greeneville, TN. 1987-90.

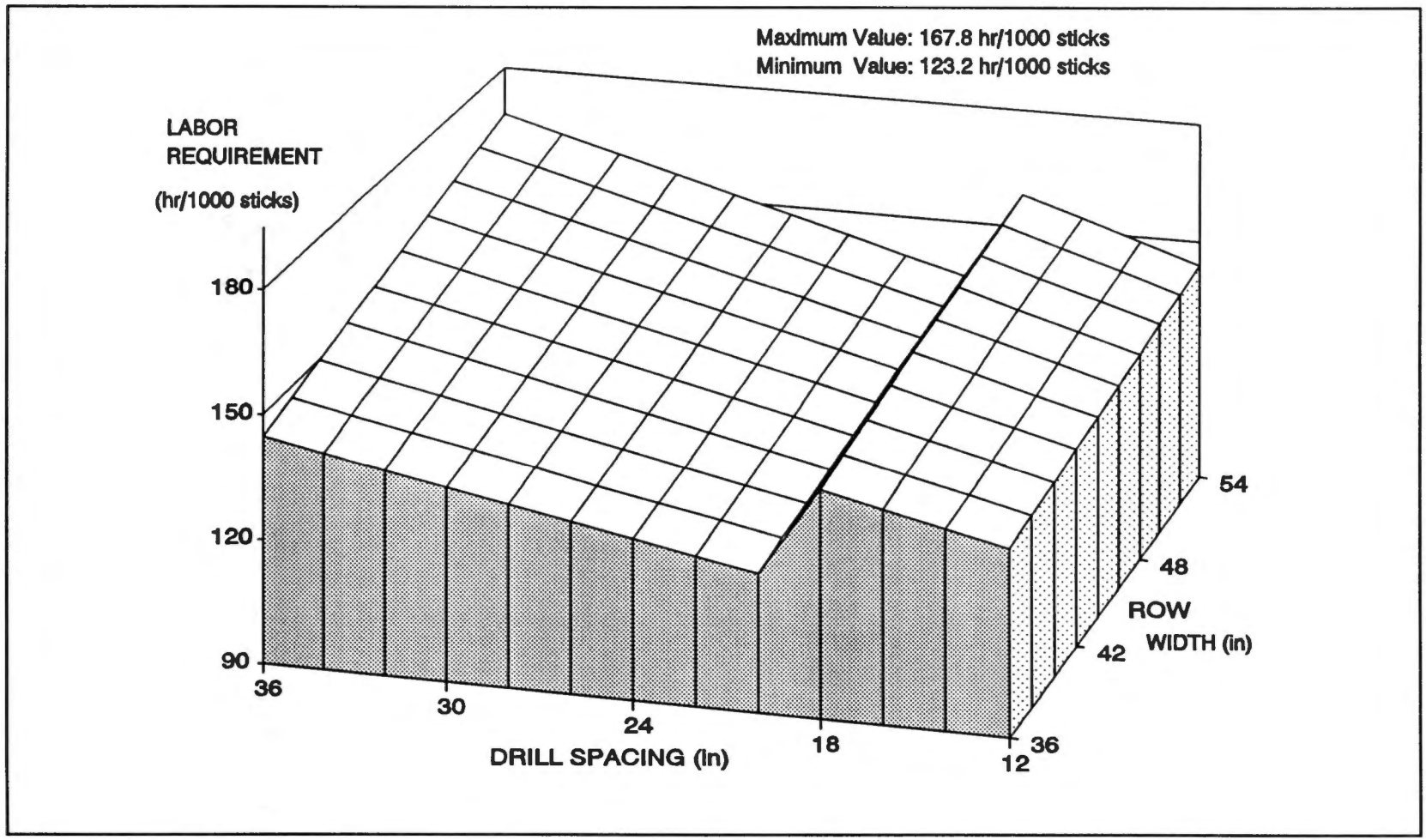


Figure IV-5. Predicted labor requirement in hours per thousand sticks for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING research project. Greeneville, TN. 1987-90.

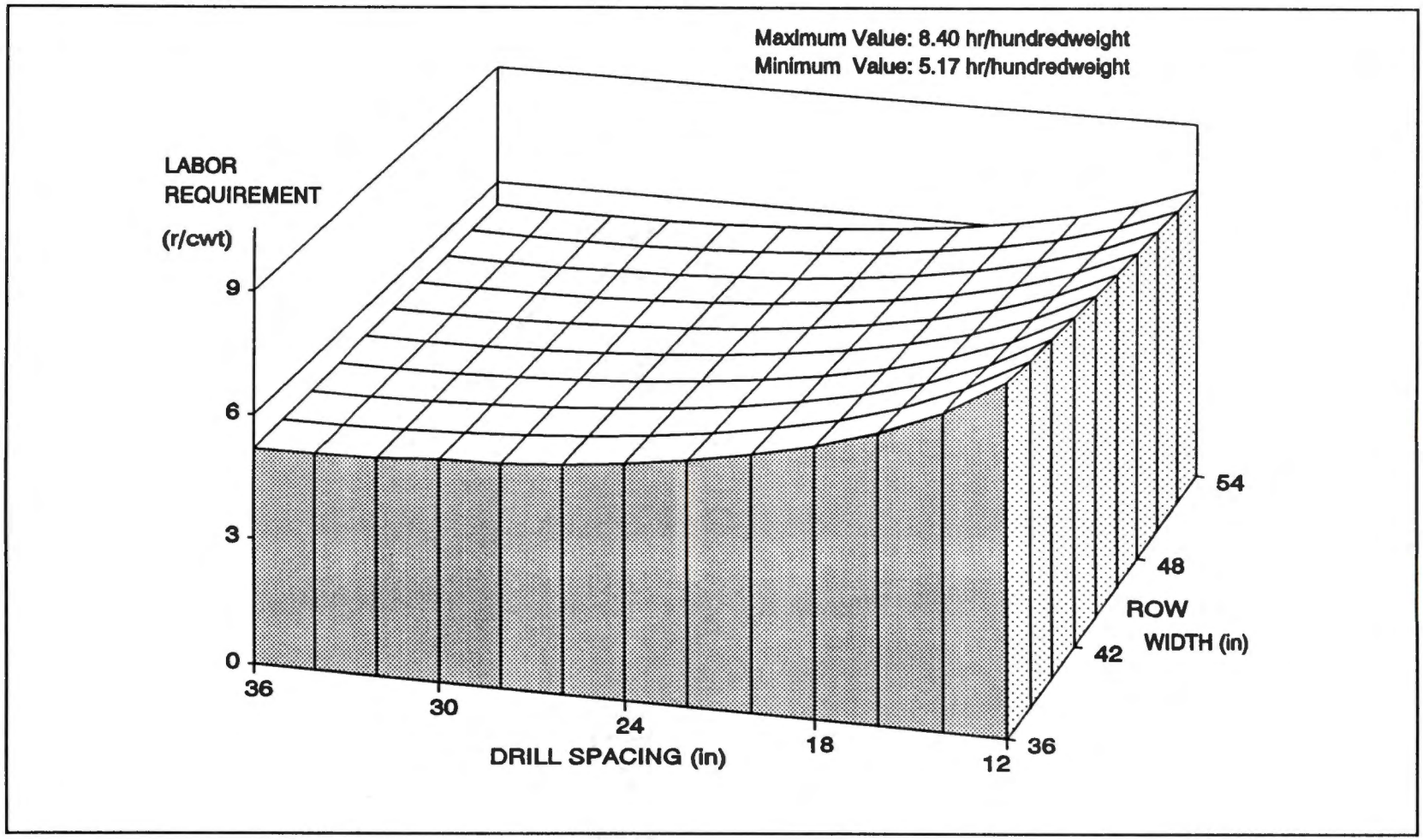


Figure IV-6. Predicted labor requirement in hours per hundredweight for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING research project. Greeneville, TN. 1987-90.

predictive models estimated in the SPACING experiments. Other formulas and component linkages within the STEPS spreadsheet describe how resources are combined and provide information on how factors of production may substitute for one another. A highly detailed description of each cell and component of STEPS would probably serve no useful purpose; however, some examples and descriptions of how research results and technical and economic information were compiled in the STEPS model would be in order.

The STEPS model as constructed in a Lotus 1-2-3® spreadsheet is comprised of five major interrelated components: **DATA** is the UTGFP data source for input and output items and their 1991 prices; **PARAMETERS** is the input screen which permits user interaction with the model; **LABOR** is the component which describes and computes labor, power, and machinery requirements; **MACHINERY** is the summary table of machinery input requirements and costs; and **BUDGET** is the component of the model which incorporates data from all other components into an enterprise budget format. These components have been described and illustrated in Chapter III. Figure III-1 is a schematic diagram of how the components are arranged in the worksheet. This discussion is intended to illustrate how STEPS incorporates information from a plant spacing decision to generate estimated results for total returns, total costs, and net returns for plant spacing combinations. To retain consistency with University of Tennessee crop

budget formats, the unit of analysis in STEPS is one acre of tobacco. Conversions to accommodate other units of analysis were incorporated in computation of net returns.

The PARAMETERS component of the software provides user control and choice of several important parameters and defines some previously established assumptions. Figure III-2 is an illustration of the parameters screen. The user selects any drill spacing between 12 and 36 inches inclusive and any row spacing between 36 and 54 inches inclusive. Formulas imbedded in the PARAMETERS component calculate the per acre population, the number of rows in an acre of given proportions, the number of sticks per acre (a software decision rule determines 5- or 6-stalk sticks), and the number of 900 ft^2 plant beds per acre. The yield per plant is computed from the estimated YLDPLT regression model. The multiplier factor for labor and the transport distance and speed reflect previously stated assumptions but may be varied to accommodate different situations.

The LABOR component of STEPS (illustrated in Table III-6) incorporates the eight predictive labor models to estimate the labor requirement for those eight practices based on the population per acre which corresponds to the specified row and drill spacings. Other land related and population related labor requirements are computed on their respective bases. Machinery use requirements are provided by UTGFP estimates or by the estimated labor requirements for the eight major practices observed. For

multiple worker crews, the machinery requirement is appropriately adjusted to insure that machinery is charged only its elapsed time requirement. Similarly, the machinery requirement is not calculated to include the 1.25 labor multiplier factor because that factor includes operator inefficiency and overhead not generally charged to machinery.

The cost of the machinery complement is determined in the MACHINERY component of STEPS (illustrated in Table III-7). The MACHINERY component incorporates cost data provided in the DATA section of STEPS and the machinery use requirements generated in the LABOR component to calculate variable costs, fixed costs, and interest costs per acre for the specified plant spacing. The TOTAL USAGE column of the MACHINERY component sums the machinery requirement by machine for each of the burley practices in which that machine is involved. The MACHINERY component uses a software "lookup" feature to locate each machine in the DATA table, find its appropriate hourly costs, and multiply that cost by the estimated hours of use to determine variable, fixed, and interest costs per acre. The cost categories are summed across all machines to determine the total machine costs to be included in the BUDGET component of STEPS. The BUDGET component of STEPS incorporates data and computations from all other components to calculate costs and returns per acre for the entire enterprise.

The remainder of this discussion pertains to how STEPS was used to incorporate research results generated in the SPACING and PRODUCTION RUN experiments with prices and other input data from TES field sheets and the UTGFP. Total value product was determined as the product of yield per plant, population per acre, and 1991 anticipated average price. Constant product price was assumed for all spacing combinations because no statistically significant quality differences were associated with plant spacing variability. Quantities of physical inputs or non-labor services such as marketing fees can be varied to reflect a user's own input levels, but for the purposes of this analysis the average of the actual quantities used at the TES or the University of Tennessee recommendations for quantities of inputs were used. Input prices were obtained from the 1991 version of the UTGFP data file which was used as the DATA table for this version of STEPS. Machinery costs were determined in the MACHINERY component and similarly were based on prices in the UTGFP data and quantities estimated in the LABOR component. The manual labor requirements estimated in the LABOR component were imported directly into the BUDGET component of STEPS and were priced from the UTGFP at $5.25 per hour. No explicit charge was assigned to the management resource. Management alone or in combination with other owned resources was the residual income claimant.

Costs of curing barn and stripping/grading facilities were based on UTGFP assumptions of a $9000 structure per 8000-plant acre, depreciated

over 30 years, with a 1.5 percent annual maintenance cost. Costs of facilities to store machinery were included in the machinery fixed cost component. STEPS allocated the facility costs on the basis of the number of plants per acre for specified spacing combinations. Other cost items included interest rates on variable and fixed capital of 11.0 percent per anum. Production quota rights were valued at $0.10 per pound. Because tobacco generally commands the best land resources on a farm, the land resource was valued at an opportunity cost or rental rate of $100 per acre per year.

The physical and economic relationships, interactions, and adjustments designed into the STEPS model were such that every possible plant spacing combination within the limits of SPACING represented a completely new budget. Even the few cost items which were not adjusted on a per acre basis (i.e. fertilizer and chemicals) varied when expressed as a cost per hundredweight or cost per hour of labor. Thus, the STEPS model is more than a partial budgeting calculator. STEPS is an enterprise planning system and decision aid which allows users to see how a plant spacing decision influences not only net returns but the combinations of resources required to produce that net return as well.

NET VALUE PRODUCT RESULTS

The format of the BUDGET component of STEPS was structured to be consistent with other University of Tennessee crop budgets and therefore expresses units of input and output and costs and returns in terms of one acre of tobacco. Thus, the initial net return computation is expressed as the residual return to the land and management resources. That is, all resources were paid their explicit or imputed cost per acre except for land and management. The difference between the total revenue per acre and these costs is the residual return to land and management expressed in terms of the land resource, $/acre. In the terminology of the input approach described in Chapter III (Formula 3.6), the total return is the total value product (TVP) of the land and management inputs. All the explicit and imputed costs represent the total factor cost (TFC) of the land and management resources, and the net return is the net value product (NVP) of land and management expressed in units of the land resource.

Net returns, or more precisely NVP's, were determined for other resources or resource combinations in a similar fashion. All the factors of production except labor and management were paid their assigned costs, and the residual returns were allocated to the labor and management in terms of $/hour of the labor resource used. This procedure continued for the labor, quota, capital, and barn space resources, all in combinations with the management resource. Finally, the management resource alone was

assigned the residual income after all other resources were paid their respective prices. Management returns were expressed in terms of $ per $100 of TVP because expression in terms of any physical unit implies return to that resource. That is, the return to management in $/$100 TVP is the percentage of the gross return that is left after all inputs except management have been paid.

Any of these six resources might be regarded by the farmer as the most limiting resource(s) for various farming situations. The most limiting resource situation will vary from farm to farm or from crop year to crop year on a particular farm; therefore, the optimization goal of maximizing net returns to the most limiting resource will vary as well. For that reason STEPS was constructed to produce residual net return values for each of the six resource situations. The farmers, who are in the best position to determine the most limiting resource for their farming situation, can evaluate the residual return scenario most appropriate for their resource sets and can choose optimal plant spacings accordingly.

To determine the trends in residual returns for the six resource combinations over the range of the SPACING experiment, the STEPS model was run for each two-inch increment of drill and row spacing within the SPACING range. For each of these 130 possible combinations, residual returns to each of the six resource combinations were computed. Thus, 780 residual return points were identified. These results are displayed in Tables

IV-17 and IV-18 for each of the twenty original SPACING treatments. These tables contain NVP results for each of the six resource combinations under discussion.

To display a greater degree of precision and to evaluate trends in TVP and TFC across the SPACING experiment, Figures IV-7 through IV-12 were developed. Each figure contains three-dimensional graphs of TVP, TFC, and NVP for each limiting resource combination. Tabular data for the figures are included in the Appendix, Tables A-7 through A-12.

OPTIMAL PLANT SPACING COMBINATIONS

Examination of results from 130 solutions of the STEPS model indicates that the optimal plant spacing combination, in terms of maximum net value product of a limiting resource, depends on which resource is most limiting. For the physical and economic relationships derived from the SPACING experiment, the optimal plant spacings for all resources except land were considerably different from what is generally used by tobacco farmers.

Sensitivity analyses were conducted to determine how sensitive the optimal spacing solutions were to yield variation. The estimated YLDPLT equation was adjusted to produce plant yields 0.05 and 0.10 lb/plant greater than the standard equation would yield and 0.05 and 0.10 lb/plant less than the standard equation would yield. These adjustments were within the

Table IV-17. Residual returns to resource combinations for in-row and between-row plant spacing combinations. (a) Dollars per acre, (b) dollars per hour, and (c) dollars per hundredweight. SPACING research project. Greeneville, TN. 1985-90.

(a) Net value product of land and management in $/acre

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/ac)		
36	2283	2802	2748	2588	2324
42	2220	2540	2431	2257	2006
48	2172	2343	2194	2009	1767
54	2135	2191	2009	1816	1581

(b) Net value product of labor and management in $/hour

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/hr)		
36	11.92	16.82	19.41	20.90	21.11
42	12.64	17.07	19.24	20.37	20.30
48	13.33	17.30	19.08	19.89	19.58
54	13.99	17.51	18.93	19.45	18.92

(c) Net value product quota and management in $/hundredweight

Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/cwt)		
36	66.02	84.76	89.78	92.46	91.98
42	69.12	84.79	88.54	90.33	89.16
48	71.82	84.83	87.41	88.36	86.52
54	74.19	84.86	86.37	86.53	84.06

Table IV-18. Residual returns to resource combinations for in-row and between-row plant spacing combinations. (a) Dollars per $100 of capital, (b) dollars per 1000 sticks of barn space, and (c) dollars per $100 of total value product. SPACING research project. Greeneville, TN. 1985-90.

(a) Net value product of capital and management in $/$100 of capital

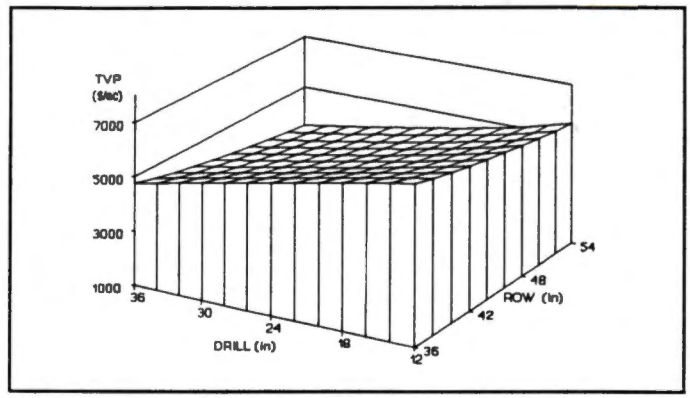
Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/$100)		
36	66.77	96.52	107.26	111.79	109.68
42	71.60	95.90	103.83	106.28	102.77
48	75.08	95.36	100.78	101.43	96.74
54	78.26	94.86	98.05	97.11	91.40

(b) Net value product of barn space and management in $/1000 sticks of capacity.

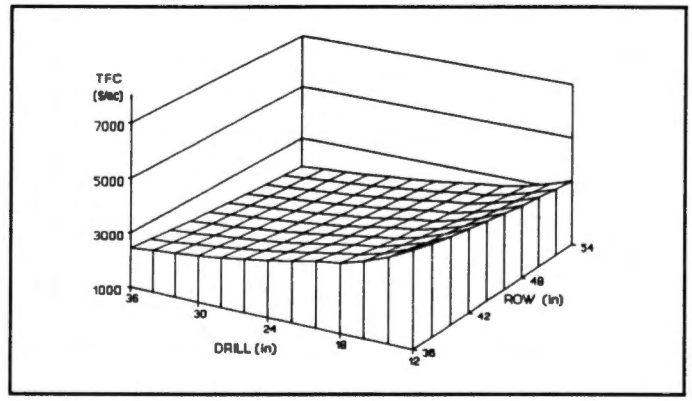
Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/M stks)		
36	1190	1962	2112	2430	2585
42	1309	2052	2161	2454	2585
48	1429	2142	2211	2479	2584
54	1549	2232	2261	2503	2583

(c) Net value of management alone in $/$100 of total value product

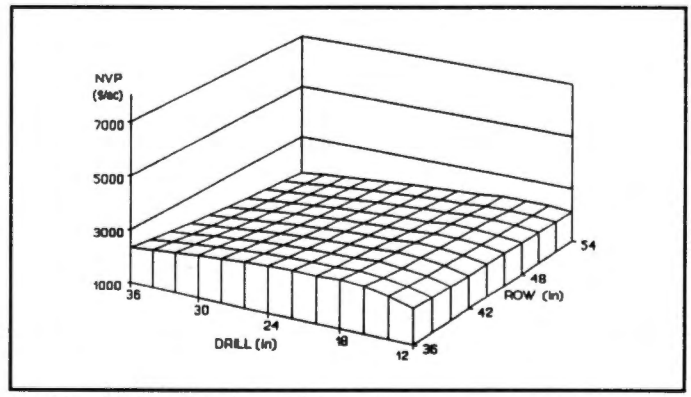
Row Width (in.)	Drill Spacing (in.)				
	12	18	24	30	36
			($/$100)		
36	32.01	42.72	45.59	47.12	46.85
42	33.78	42.74	44.88	45.90	45.23
48	35.32	42.76	44.24	44.78	43.73
54	36.68	42.78	43.64	43.73	42.32



(a) Total Value Product ($/acre)

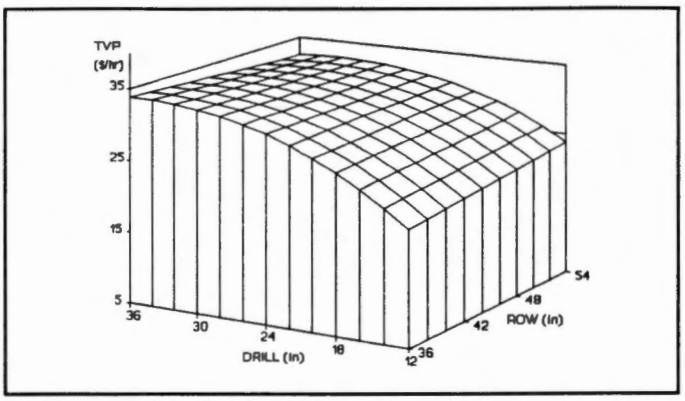


(b) Total Factor Cost ($/acre)

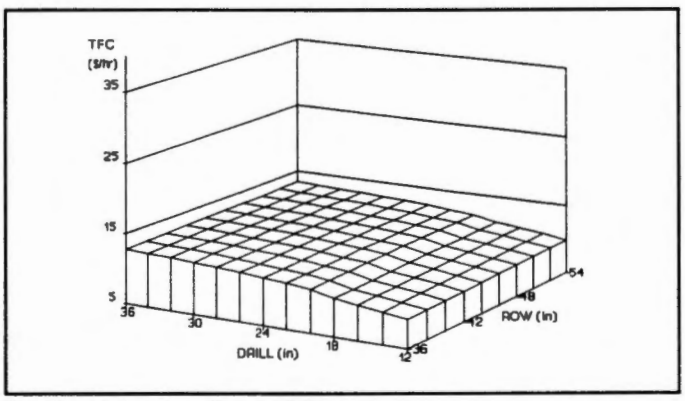


(c) Net Value Product ($/acre)

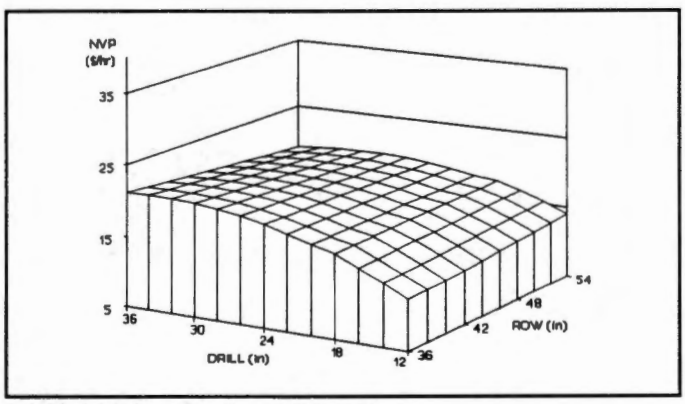
Figure IV-7. Limiting resource combination: land and management. (a) Total value product of land and management, (b) total factor costs of all resources except land and management, and (c) net value product of land and management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.



(a) Total Value Product ($/hour)

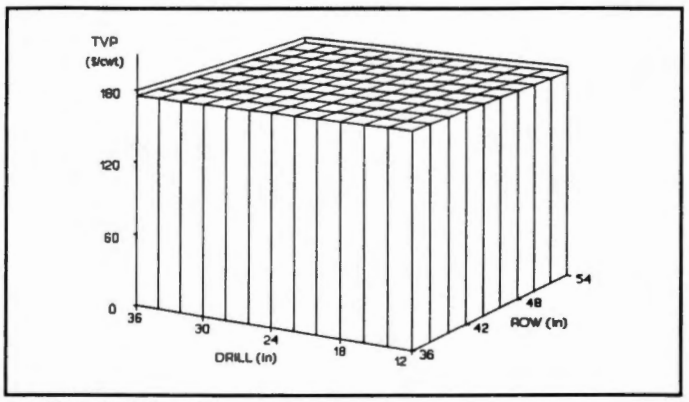


(b) Total Factor Cost ($/hour)

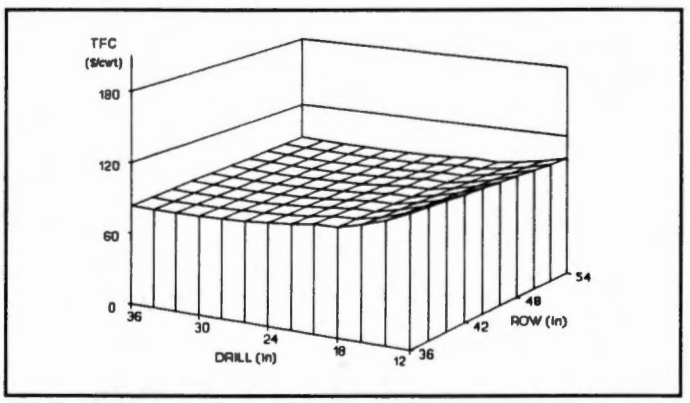


(c) Net Value Product ($/hour)

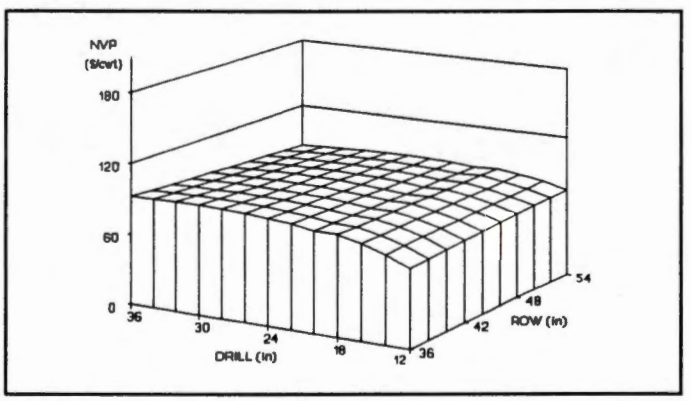
Figure IV-8. Limiting resource combination: labor and management. (a) Total value product of labor and management, (b) total factor costs of all resources except labor and management, and (c) net value product of labor and management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.



(a) Total Value Product ($/cwt)

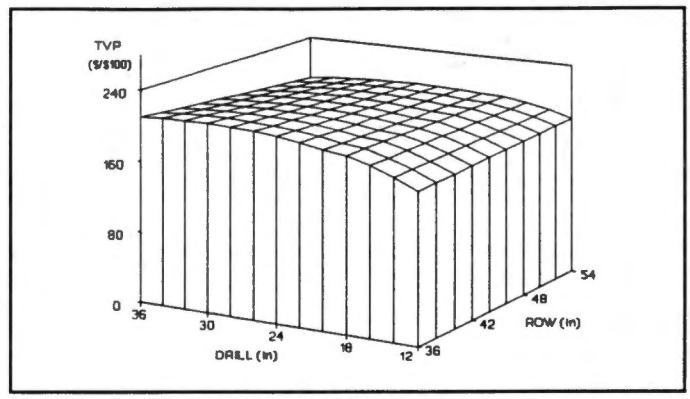


(b) Total Factor Cost ($/cwt)

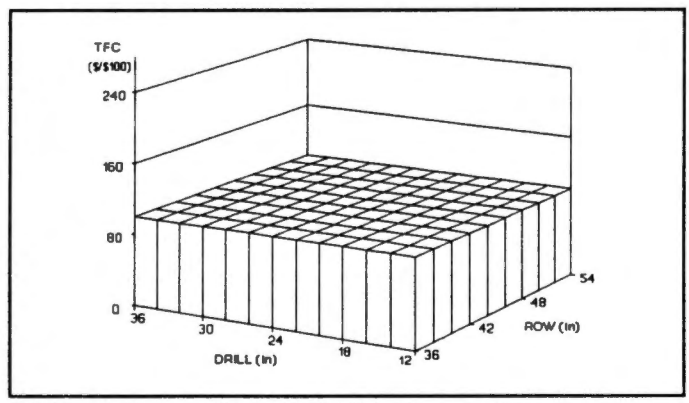


(c) Net Value Product ($/cwt)

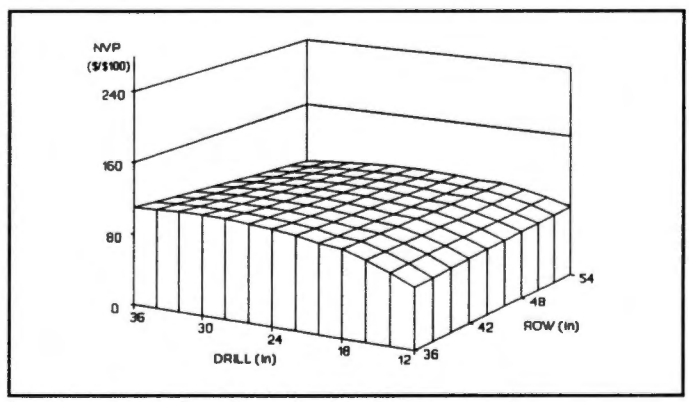
Figure IV-9. Limiting resource combination: quota and management. (a) Total value product of quota and management, (b) total factor costs of all resources except quota and management, and (c) net value product of quota and management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.



(a) Total Value Product ($/$100 of capital)

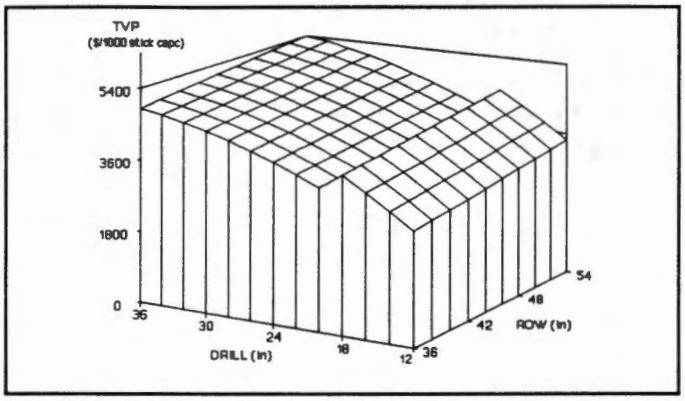


(b) Total Factor Cost ($/$100 of capital)

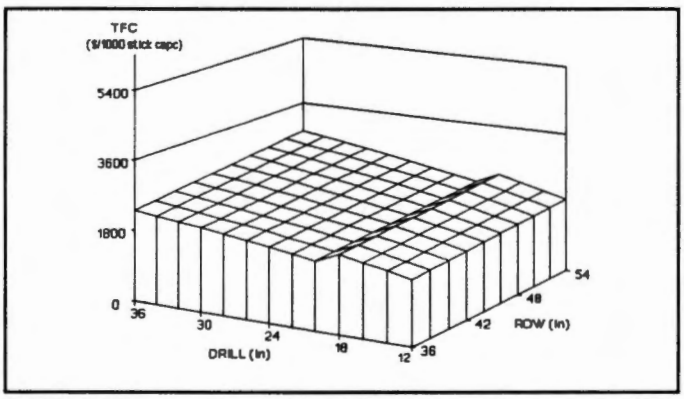


(c) Net Value Product ($/$100 of capital)

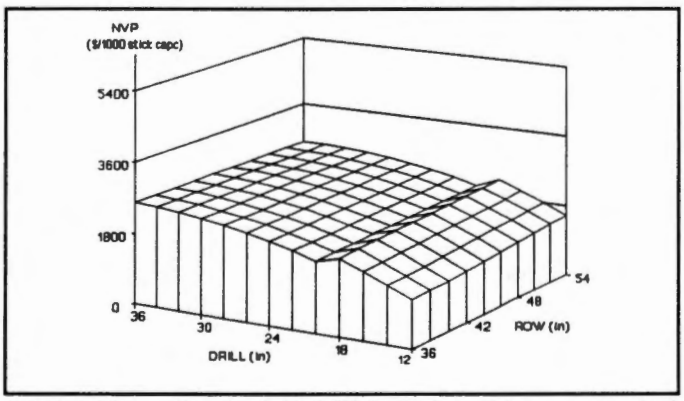
Figure IV-10. Limiting resource combination: capital and management. (a) Total value product of capital and management, (b) total factor costs of all resources except capital and management, and (c) net value product of capital and management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.



(a) Total Value Product ($/1000 sticks of barn capacity)

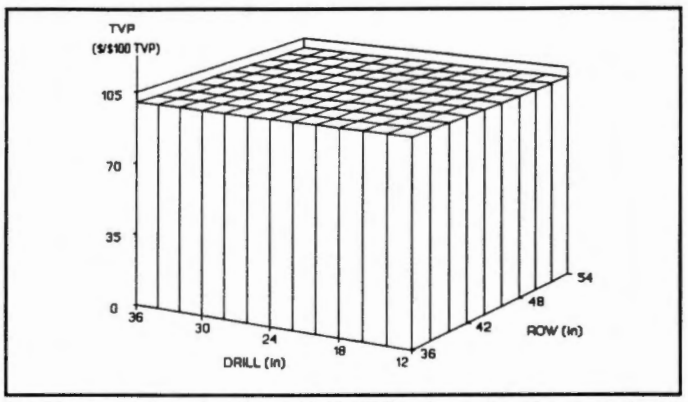


(b) Total Factor Cost ($/1000 sticks of barn capacity)

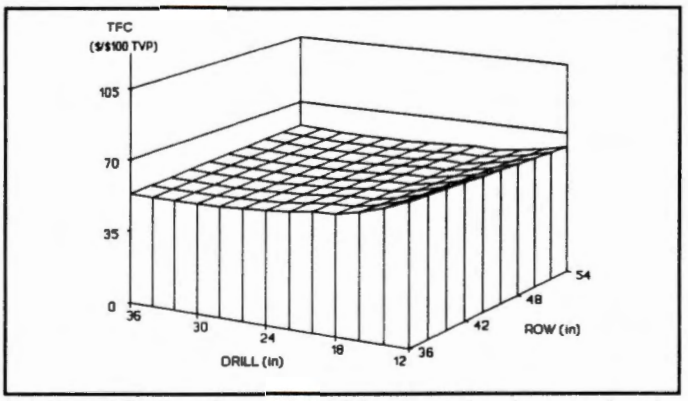


(c) Net Value Product ($/1000 sticks of barn capacity)

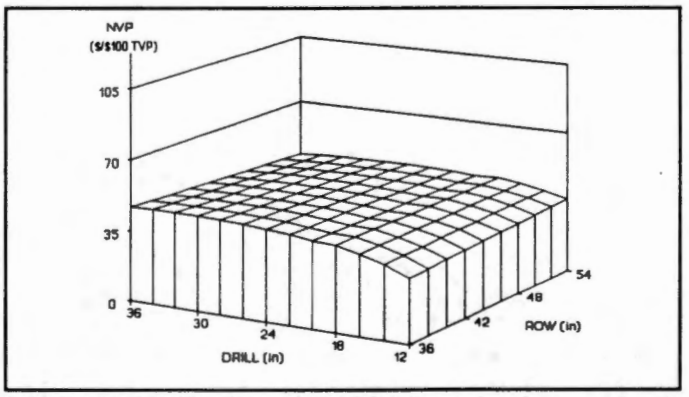
Figure IV-11. Limiting resource combination: barn space and management. (a) Total value product of barn space and management, (b) total factor costs of all resources except barn space and management, and (c) net value product of barn space and management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.



(a) Total Value Product ($/$100 of total value product)



(b) Total Factor Cost ($/$100 of total value product)



(c) Net Value Product ($/$100 of total value product)

Figure IV-12. Limiting resource: management. (a) Total value product of management, (b) total factor costs of all resources except management, and (c) net value product of management. Burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. SPACING research project. Greeneville, TN. 1985-90.

range of yields experienced over the six years of the SPACING experiment. Relative yield differences among spacings were not changed because of the relative stability of spacing coefficients across years.

All optimal spacings occurred in the 36-inch row spacing. The 36-inch row spacing is narrower than is commonly used, although 38-40 inch rows are not uncommon in much of Kentucky. The assumptions of holding a number of land related expenses constant on a land-unit basis, coupled with the relatively small yield changes observed across row widths, may account for the fact that the narrowest row spacings yielded the highest NVP's across most drill spacings.

The highest NVP for the land and management resource occurred at the 18"x36" drill-row combination. This spacing produces a population per acre of 9680 plants. Prior to 1971, when acreage quota set a limit on the amount of land in tobacco production, populations in the 9000-10000 PPA range were not uncommon, and these results from STEPS suggest those high populations were not irrational for growers facing an institutionally fixed land constraint.

Results from the yield sensitivity analysis indicated that choice of optimal plant spacing, when land is the most limiting resource, was sensitive to changes in per plant yield. If YLDPLT decreased 0.05 lb/plant, the optimal drill spacing shifted from 18" to 26" in the 36" row, and a 0.10 lb. decline in YLDPLT resulted in a 28"x36" drill-row combination being the

optimal spacing. These spacings produce 6702 and 6223 PPA respectively. On the other hand, higher plant yields tended to shift the optimal plant spacing toward narrower drill spacings and higher per acre populations.

The optimal plant spacings for the other limiting resource sets occurred at substantially wider drill spacings than the land and management resource. The optimal spacing for capital and management was a 30"x36" drill-row combination producing 5808 PPA. A 32"x36" drill-row spacing with 5445 PPA was the optimal spacing for quota and management and for management alone. When labor and management were most limiting the 34"x36" drill-row spacing, 5125 PPA, was the optimal spacing. The widest spacing tested in the 36" rows, a 36"x36" spacing, was optimal when barn space was most limiting. The yield sensitivity analyses suggested that except for the land resource the optimal plant spacing combinations were not highly sensitive to yield variation. The labor and management and the quota and management resources were evaluated at the same higher and lower YLDPLT levels as the land resource. Like the pattern observed for the land resource, lower per plant yields suggested wider spacings and higher plant yields suggested narrower plant spacings would be optimal. However, for both these resource sets the optimal plant spacing pattern did not shift more than two inches in either direction.

The shapes of the NVP surfaces for labor and management, quota and management, capital and management, barn space and management, and

management alone also suggests that spacings near the optimal position yielded nearly as favorable results. That is, the NVP surfaces tended to be relatively flat in the vicinity of the optimal positions. The practical implications of this observation are substantial. For growers facing limiting resource situations other than land, the financial risk of missing the exact optimal spacing are rather small. Furthermore, the yield sensitivity analysis suggests that the cost of missing the optimal spacing is not high for yield levels which are either higher or lower than the yields observed in the SPACING experiment.

Another observation of practical significance is that while NVP levels varied across row spacings with the narrower spacings usually being associated with the higher values, the percentage change in NVP from high to low across row spacings was less than 10 percent for all resource combinations except for land and management and for capital and management which were 21 percent and 12 percent, respectively. This result is important because the cost of adapting machinery to accommodate different row widths may be negligible for some farmers but may be rather high for others if their transplanting, cultivating, and/or spraying equipment must be modified or replaced to fit new row widths.

The relatively flat portion of the NVP surface also has significance for change agents who might use this information to encourage tobacco farmers to use wider plant spacings than are currently being used. Tobacco growers

tend to change some production practices quite reluctantly as suggested by the high plant populations and high per acre input levels still in use 20 years after the lifting of acreage controls. Changing plant spacings may be no exception. However, growers who might not shift from 18" to 32" drill spacings might make smaller shifts toward wider spacings and still capture much of the higher NVP benefits. For the non-land resource sets considered, rapid improvements in NVP were noted as drill spacings were increased up to approximately 24 inches, with positive but less rapid improvements noted above that level.

CHAPTER V

SUMMARY, LIMITATIONS, AND IMPLICATIONS

SUMMARY

Previous plant spacing research in burley tobacco has often failed to account for the economic implications of changing plant spacing patterns and populations. The previous research that included economic factors did not include an evaluation of a sufficiently wide range of plant spacings to determine an economically optimal drill-row spacing combination. The SPACING study was conducted for six years at the Tobacco Experiment Station at Greeneville, Tennessee, and incorporated a substantially wider range of spacings and populations than had been previously evaluated. In-row spacings from 12 to 36 inches and between-row spacings from 36 to 54 inches provided per acre plant populations from 3227 to 14520. The SPACING-AGRONOMIC component of the SPACING experiment was used to establish some of the physical, chemical, and agronomic variability associated with plant spacing variability. Another component of the research, SPACING-ECONOMIC, evaluated the economic input variability associated with varying plant spacing. Particular emphasis was placed on the labor, machinery, and facilities inputs as these resources account for a large majority of the economic costs associated with burley tobacco production. Briefly, the specific objectives of the SPACING study were:

1) to estimate technical factor-product and substitutionary factor-factor relationships associated with burley plant spacings; 2) to incorporate these relationships into a microcomputer-based software program to model the burley tobacco enterprise; and 3) to use the model to determine the optimal burley plant spacing for various limiting resource situations.

Plant spacing influences many economic and agronomic variables throughout the burley production process. The widespread effects of the plant spacing decision suggested that a systems approach to evaluate the plant spacing question was in order. As opposed to a typical reductionist approach, the systems approach allowed evaluation of the effects of various plant spacings on a wide range of technical (factor-product) and substitutionary (factor-factor) relationships within the burley enterprise.

The burley tobacco enterprise was identified as a subsystem of the larger whole-farm system. This burley subsystem was evaluated at its own enterprise level as a system comprised of 27 subsystem practices, each of which might be further subdivided into specific tasks. A Lotus 1-2-3® based software system which will run on most IBM-compatible personal computers was developed to evaluate the burley enterprise system. This software was given the acronym, STEPS, for Software for Tobacco Enterprise Planning System. STEPS is comprised of five separate but interdependent components within a single Lotus worksheet. The PARAMETERS component allows interaction with the model to permit the user to choose

plant spacings and make changes in several other user-determined production variables. The DATA table in STEPS provides price levels for inputs and outputs. The LABOR component describes and computes labor, power, and machinery requirements, and the MACHINERY section summarizes machinery requirements and costs. The BUDGET component incorporates data from the four other components of STEPS to generate an integrated enterprise budget format.

Statistical relationships from the agronomic and economic components of the SPACING research were estimated, and results were presented in tabular, mathematical, and/or graphical formats for 22 physical and economic variables observed in SPACING. These results were incorporated into the STEPS model along with physical and economic data from the *University of Tennessee Guide to Farm Planning* and the PRODUCTION RUN large plot tobacco experiment. The STEPS model was calculated for each of 130 row-drill combinations within the range of the SPACING experiment.

Residual returns were calculated for each of six resource combinations: land and management, labor and management, quota and management, capital and management, barn space and management, and management alone. Each of these resource combinations represents potentially limiting resources for the burley tobacco farmer. If one of the goals of the farmer is to maximize the net value product of the most limiting

resource, then information is needed as to what plant spacing produces the highest residual return to whatever resource or resource combination the farmers deems most limiting. STEPS was constructed to provide information on residual returns for these six resource combinations for any plant spacing within the range of SPACING.

Except for the land and management resource, the plant spacings which yielded the highest net value product (NVP) were identified at considerably wider drill spacings than farmers generally use. Conducting the analysis for several limiting resource situations revealed that the choice of an economically optimal plant spacing depends on the resource or resources deemed most limiting by the farmer. No single plant spacing was found to be optimal for all limiting resource situations tested.

Table V-1. Plant spacings and populations with the greatest net value product for each of six limiting resource situations. SPACING research project. Greeneville, TN. 1985-90.

Limiting resource(s)	Plant Spacing[1]	Population[2]
Land and Management	18"x36"	9680
Labor and Management	34"x36"	5125
Quota and Management	32"x36"	5445
Capital and Management	30"x36"	5808
Barn Space and Management	36"x36"	4840
Management only	32"x36"	5445

[1] Drill spacing x row width in inches.
[2] Population in plants per acre

A yield sensitivity analysis suggested that, with the exception of the land and management resource, these results are fairly stable at both lower and higher yield per plant. That is, variation of per plant yields of ± 25 percent of the SPACING mean yield did not result in changes of optimal drill spacing of more than 2 inches for any limiting resource situations except land and management. When land and management were the most limiting resources, the optimal NVP spacing increased to 28"x36" as per plant yields were decreased, and as plant yields increased the optimal plant spacing decreased to 12"x36."

LIMITATIONS AND IMPLICATIONS

The SPACING experiment and the STEPS software incorporate a substantial amount of multi-year agronomic and economic data. However, the data and the subsequent evaluation are not without some limitations. Furthermore, many of these limitations suggest potential for further research in this or related areas. This project also suggests some important implications for tobacco growers, researchers, and change agents.

Previous research efforts in the tobacco plant spacing area were somewhat ambiguous concerning fertility and plant population interactions. The size and complexity of the SPACING experiment would have made including a fertility factor in the experimental design excessively expensive in terms of available experiment station resources and administrative support.

Another fertility/plant spacing factor to consider is the placement of fertilizer relative to the position of the plant. Previous fertilizer placement studies to evaluate various broadcast and banding patterns of fertilizer application were conducted with typical plant spacings and populations. Relationships established with typical spacings may or may not hold for wider spacings. Future research might be designed to evaluate the fertility/population interaction and fertilizer placement question.

Another factor of concern to farm managers which was not observed directly in the SPACING experiment was the variation in weed control costs which may exist across plant spacings. Plant density and canopy formation are considered weed control measures in tobacco and other field crops. Casual observation indicated few, if any, weed control problems associated with the wider spacings in the normal or relatively dry years of the experiment when weed pressure was moderate and opportunities to cultivate were ample. However, the relatively wet 1990 growing season did present excessive weed pressure and prevented timely cultivation in all the SPACING plots, and a major salvage operation was required to rescue the experiment. Data are incomplete and largely anecdotal on the levels and effects of weed pressure in various plant spacing combinations. Further research might quantitatively identify weed competitiveness, potential yield effects, and weed control costs associated with various spatial arrangement patterns of burley tobacco plants.

A third factor held constant across the SPACING treatments which might be varied in a farm setting is the hanging density in the curing barns. Except for the 5- or 6-stalk per stick variation, all plants were given the same volume of curing space in the barn regardless of plant size. Farmers might vary hanging densities to allow more space for larger plants and less for smaller plants. If this were the case, another important source of variability in facility costs would need to be considered.

A fourth factor held constant across the SPACING treatments was a labor multiplier factor of 1.25. This factor was applied to all labor practices to capture labor inefficiencies and overhead not observed directly in SPACING-ECONOMIC or PRODUCTION RUN. The likelihood of a single multiplier accurately capturing the labor inefficiencies of all 27 labor practices is low. Peralta, Harrison, and Benson (1991) used different multiplier factors for different practices in their farm enterprise planning program. For example, their multiplier for fertilizer spreading was 1.33 as compared to a multiplier of 1.02 for disking because fertilizer application requires more stops for refill activities. They also suggested that it might be legitimate to use lower multipliers for cash grain enterprises where auxiliary tasks are small compared to the time spent in the field because of the larger scale of cash grain enterprises. For tobacco, the time spent in a particular practice may be low relative to the preparation time for the practice. The most extreme example may be field spraying of a small scale burley

operation. A 20' boom sprayer operating at 5 MPH and 50 percent field efficiency covers an acre in fewer than ten minutes. However, three to four times that amount of time may have been required to hook up the hitch, calibrate the sprayer, mix the chemicals, and fill the tank. Labor efficiencies measures exist for a wide range of practices and tasks yet insufficient data existed to objectively assign different multipliers to the various burley practices. The time line method of collecting labor data offered the potential to capture some of these efficiency measures; however, the time line usually captured activities only at the plot site in the SPACING experiment.

The current version of the STEPS software uses data from three sources: the SPACING experiment, the PRODUCTION RUN experiment, and the *UT Guide to Farm Planning*. STEPS is structured to allow additional technical and/or economic information from other sources to be readily incorporated into the software. Information on fertility, weed control, hanging density, overhead allowances for inefficiencies and unaccounted activities need to be considered in future versions of STEPS if data were to become available. Another important and timely topic which might also be incorporated into STEPS is a user-determined option for alternative plant production technologies such as float and greenhouse systems which have proliferated since the late 1980's. Different types and sizes of curing structures have different annual costs associated with them, and STEPS might also be modified to allow user-determination of the type, size, and

cost of barns available to cure the crop. Finally, STEPS may offer the potential for tobacco researchers to evaluate the economic impact of developing technologies if they can identify and assess the enterprise systems interactions of such developments.

The construction of the STEPS software permits the user to examine how plant population changes will affect output levels, the factor mix, and the net return levels associated with any plant spacing combination within the range of the SPACING experiment. The practices and tasks of the burley enterprise system are integrated in the software in such a manner that the effects of any user-defined changes are reflected appropriately in all 27 practices in the enterprise. For example, multiple iterations of STEPS can reveal how resource mixes of land, labor, quota, capital, and facilities may change as plant spacings are changed.

Some managerial implications which may or may not have been adequately captured in the SPACING research are worthy of note. The SPACING-ECONOMIC experimental plot sizes were eight to ten times as large as the SPACING-AGRONOMIC plots to allow adequate size for workers to establish normal working rhythms and thereby improve the quality of the labor data. The labor requirement per thousand plants indicates that the larger, heavier plants require more labor (particularly in the harvest and housing practices) on a per plant basis than do smaller plants. However, some question remains as to how workers might respond to handling larger

than average plants over a protracted harvest and housing season that may extend several weeks on some burley farms. Some worker complaints pertaining to large plants were heard from the experiment station field crew during the SPACING-ECONOMIC harvest and housing practices which might indicate that workers may be reluctant to handle larger plants over a long harvest season.

Another harvest labor factor which may be only partially accounted for in the estimated labor requirement relates to the physical distance plants must be moved in the cutting and spearing tasks. Currently used plant spacings often allow a one-worker crew to "plant" a pivot foot and rotate on that fixed point to cut and spear enough plants to fill a stick. Wider spacings might lead to the worker having to take one or more steps with each of the five or six stalks needed to fill the curing stick. Again, some of this activity was captured in the SPACING-ECONOMIC labor observations but the repeated drudgery of a physically demanding task over a whole season may not have been captured with the plot sizes used in the SPACING-ECONOMIC experiment.

A consideration directly related to harvest and housing but with implications for some other burley practices is the establishment of custom labor rates. Harvest and housing labor is occasionally contracted on a per acre basis. Growers who use plant spacings which differ from a community or custom labor standard would need to consider changes in plants per acre

and changes in plant size when establishing new custom rates if the rates were expressed in per acre units. Per stick custom rates might similarly need to be adjusted to account for shifts in plant size or spatial arrangement as these factors influence labor productivity.

Except for the land and management resource combination, all the optimal plant spacings were located at drill spacings considerably wider than are commonly found in the burley belt. Considering that land is seldom the most limiting resource for burley farmers, the potential may exist for an educational effort to demonstrate to farmers the income enhancing potential of wider spacings and lower populations. Although the highest NVP results for each resource combination were found in the 36-inch row widths, low variability across the range of widths suggested that choice of drill spacing is considerably more important than choice of row width. This result has significant implications for farmer acceptance of recommendations that might be generated from these results. Drill spacing changes may be made with relatively simple adjustments to the mechanized field transplanter, whereas row adjustments may require more substantial changes in transplanting, cultivating, and spraying equipment. Therefore, growers may be more likely to change drill spacing than row spacing.

The results of the SPACING experiment have some direct income enhancing implications for farmers. Educational efforts will be required to extend this information to the burley producing audience. A less obvious,

but perhaps more important, implication of the SPACING study is generation of information to demonstrate how the choice or perception of most limiting resource situation affects decision making. As previously discussed, land is not often the most limiting resource on a burley tobacco farm. However, among farmers, researchers, and change agents, yield per acre and NVP per acre persist as the criteria for determining optimal input/output levels. The results presented in Chapter IV in terms of returns to various limiting resource combinations demonstrate the importance of correctly identifying the most limiting resource and using residual returns to that resource as the decision criterion. For instance, a grower for whom quota is the most limiting resource who mistakenly uses returns measured in terms of $/acre of the land resource (i.e. NVP of land and management) instead of $/hundredweight of the quota resource would forego $385 of net return on a 5000 lb quota given the parameters of the SPACING experiment. This situation results because choosing a plant spacing which offers the highest NVP per acre of land does not offer the highest NVP per hundredweight of quota.

Thus, the educational effort becomes one of not only demonstrating to farmers that wider spacings offer improved net returns potential, but also that typically used units of analysis may lead to less than optimal decisions. Although tobacco is a suitable enterprise to demonstrate the importance of this "choice of limiting resource" problem, much of the same economic

reasoning is applicable to other enterprises. Maximization of yield per acre or net returns per acre are deeply entrenched standards of performance in agriculture (and may be appropriate for many land intensive enterprises). However, the importance of teaching farmers to evaluate economic performance in terms of alternative units of analysis can not be understated.

The analytical methodology of the evaluation of the SPACING research and the construction methodology of the STEPS software are not exclusive to the burley tobacco enterprise. Burley tobacco production is a labor and facility intensive enterprise which is well suited to an application of systems research methodology at the farm enterprise level. However, this enterprise systems methodology may also be applied to other farm enterprises of a more or less complex nature. Moving further up the farming systems hierarchy, the incorporation of multi-enterprise systems analysis into a whole-farm planning system is conceivable, although the complexity demonstrated in generating adequate data and constructing the analytical tools suggests that the scope of such efforts could be rather large.

The scope of this study demonstrates the difficulty of collecting large-scale time-and-motion data on agricultural enterprises and the reason for the scarcity of research determined labor data. The SPACING-ECONOMIC labor data are in no respect the final word on burley tobacco labor. Rather, the methodologies and techniques developed in SPACING-ECONOMIC have provided the impetus and tools to spur research in the on-going

PRODUCTION RUN experiment and a whole-farm management study just underway at the Tobacco Experiment Station. Indeed, the continuation of the PRODUCTION RUN experiment will provide the opportunity to validate the findings of this study. Also, PRODUCTION RUN, with its farm size plots, might allow further examination of a previously discussed implication, namely the drudgery element associated with the larger plant sizes which accompany wider spacings.

In closing, this study suggests the potential for many burley tobacco producers to improve their net income by transplanting their tobacco at wider spacings and lower plant populations than are currently used. This improvement in net value product results because total factor cost decreases more than total value product as plant spacings are increased. The decrease in cost is largely due to decreases in the labor required to handle fewer plants. Total value product does not decrease proportionally as much as cost because wider spaced plants yield more marketable product per plant than do narrower spaced plants. Thus, area yields decrease less than proportionally with population as spacings are increased. For example, with a 25 percent decrease in population from 8000 PPA to 6000 PPA, area yields decreased only 8.7 percent.

A larger proportion of the economic and agronomic differences associated with wider spacings is due to changes in in-row spacings than between-row spacings. This implies that farmers may capture most of the

advantages of lower plant populations with relatively simple changes in drill spacings rather than with potentially complex and costly changes associated with changing row widths. The STEPS software decision aid illustrates the enterprise systems aspects of burley tobacco production and demonstrates how product-factor mixes and the associated costs and returns vary with changes in plant spacing. This information is useful for the decision maker in planning the burley tobacco enterprise to satisfy farm management goals.

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APPENDIX

Table A-1. Plant populations per acre for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	14520	12446	10890	9680	8712	7920	7260	6702	6223	5808	5445	5125	4840
38	13756	11791	10317	9171	8253	7503	6878	6349	5895	5502	5158	4855	4585
40	13068	11201	9801	8712	7841	7128	6534	6031	5601	5227	4901	4612	4356
42	12446	10668	9334	8297	7467	6789	6223	5744	5334	4978	4667	4393	4149
44	11880	10183	8910	7920	7128	6480	5940	5483	5091	4752	4455	4193	3960
46	11363	9740	8523	7576	6818	6198	5682	5245	4870	4545	4261	4011	3788
48	10890	9334	8168	7260	6534	5940	5445	5026	4667	4356	4084	3844	3630
50	10454	8961	7841	6970	6273	5702	5227	4825	4480	4182	3920	3690	3485
52	10052	8616	7539	6702	6031	5483	5026	4640	4308	4021	3770	3548	3351
54	9680	8297	7260	6453	5808	5280	4840	4468	4149	3872	3630	3416	3227

Table A-2. Predicted yield in pounds per plant for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	0.27	0.30	0.34	0.37	0.40	0.43	0.46	0.48	0.50	0.52	0.53	0.55	0.56
38	0.27	0.31	0.35	0.38	0.41	0.44	0.46	0.49	0.51	0.53	0.54	0.56	0.57
40	0.28	0.32	0.35	0.39	0.42	0.44	0.47	0.49	0.51	0.53	0.55	0.56	0.57
42	0.29	0.32	0.36	0.39	0.42	0.45	0.48	0.50	0.52	0.54	0.55	0.57	0.58
44	0.29	0.33	0.37	0.40	0.43	0.46	0.48	0.51	0.53	0.55	0.56	0.57	0.59
46	0.30	0.34	0.37	0.41	0.44	0.46	0.49	0.51	0.53	0.55	0.57	0.58	0.59
48	0.31	0.34	0.38	0.41	0.44	0.47	0.50	0.52	0.54	0.56	0.57	0.59	0.60
50	0.31	0.35	0.39	0.42	0.45	0.48	0.50	0.53	0.55	0.57	0.58	0.59	0.61
52	0.32	0.36	0.39	0.43	0.46	0.48	0.51	0.53	0.55	0.57	0.59	0.60	0.61
54	0.33	0.36	0.40	0.43	0.46	0.49	0.52	0.54	0.56	0.58	0.59	0.61	0.62

Table A-3. Predicted yield in pounds per acre for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	3883	3795	3703	3608	3511	3413	3315	3215	3115	3014	2913	2811	2710
38	3769	3673	3576	3478	3381	3283	3185	3088	2990	2892	2793	2695	2597
40	3667	3563	3462	3362	3264	3166	3069	2973	2877	2781	2686	2591	2496
42	3575	3464	3358	3257	3157	3060	2964	2869	2775	2682	2589	2497	2405
44	3490	3373	3265	3161	3061	2964	2869	2775	2683	2591	2501	2411	2321
46	3414	3291	3179	3073	2973	2876	2781	2689	2598	2509	2420	2332	2245
48	3343	3216	3100	2993	2892	2795	2701	2610	2521	2433	2346	2261	2176
50	3278	3146	3028	2920	2818	2721	2628	2538	2449	2363	2278	2195	2112
52	3219	3082	2961	2851	2749	2653	2560	2471	2384	2299	2215	2134	2053
54	3163	3022	2899	2788	2686	2589	2497	2409	2323	2239	2157	2077	1998

Table A-4. Predicted labor requirement in hours per acre for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	326.2	286.3	256.3	233.1	214.7	199.5	186.7	176.0	166.8	158.8	151.8	145.6	140.1
38	311.4	273.6	245.2	223.1	205.8	191.3	179.3	169.1	160.3	152.7	146.1	140.3	135.1
40	298.0	262.1	235.1	214.2	197.7	184.0	172.5	162.8	154.5	147.3	141.0	135.5	130.5
42	286.0	251.8	226.1	206.1	190.5	177.4	166.5	157.2	149.3	142.5	136.5	131.2	126.5
44	275.0	242.3	217.8	198.8	183.8	171.3	160.9	152.1	144.5	138.0	132.2	127.2	122.7
46	265.0	233.7	210.3	192.1	177.8	165.8	155.8	147.4	140.2	133.9	128.5	123.6	119.3
48	255.8	225.9	203.4	185.9	172.2	160.8	151.2	143.1	136.2	130.2	125.0	120.3	116.2
50	247.4	218.6	197.1	180.3	167.1	156.1	147.0	139.2	132.6	126.8	121.8	117.3	113.4
52	239.6	211.9	191.2	175.1	162.4	151.8	143.0	135.6	129.2	123.6	118.8	114.5	110.7
54	232.3	205.7	185.8	170.2	158.0	147.9	139.4	132.2	126.0	120.7	116.0	111.9	108.3

Table A-5. Predicted labor requirement in hours per 1000 sticks for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	134.8	138.0	141.2	144.5	123.2	125.9	128.6	131.3	134.0	136.7	139.3	142.0	144.7
38	135.8	139.2	142.6	146.0	124.7	127.5	130.3	133.1	136.0	138.8	141.6	144.4	147.3
40	136.8	140.4	144.0	147.5	126.1	129.0	132.0	135.0	137.9	140.9	143.9	146.8	149.8
42	137.9	141.6	145.3	149.1	127.5	130.6	133.7	136.9	140.0	143.1	146.2	149.3	152.4
44	138.9	142.8	146.7	150.6	128.9	132.2	135.4	138.7	141.9	145.2	148.4	151.7	154.9
46	139.9	144.0	148.1	152.1	130.4	133.8	137.1	140.5	143.9	147.3	150.7	154.1	157.5
48	140.9	145.2	149.4	153.7	131.8	135.3	138.9	142.4	145.9	149.5	153.0	156.5	160.1
50	142.0	146.4	150.8	155.2	133.2	136.9	140.6	144.3	147.9	151.6	155.3	159.0	162.7
52	143.0	147.6	152.2	156.8	134.6	138.5	142.3	146.1	149.9	153.7	157.6	161.4	165.2
54	144.0	148.8	153.5	158.3	136.1	140.0	144.0	147.9	151.9	155.9	159.8	163.8	167.8

Table A-6. Predicted labor requirement in hours per hundredweight for burley tobacco planted in 12- to 36-inch drill spacings in 36- to 54-inch row widths. Predictive model generated from data observed in SPACING-AGRONOMIC research project. Greeneville, TN. 1985-90.

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	8.4	7.5	6.9	6.5	6.1	5.8	5.6	5.5	5.4	5.3	5.2	5.2	5.2
38	8.3	7.4	6.9	6.4	6.1	5.8	5.6	5.5	5.4	5.3	5.2	5.2	5.2
40	8.1	7.4	6.8	6.4	6.1	5.8	5.6	5.5	5.4	5.3	5.2	5.2	5.2
42	8.0	7.3	6.7	6.3	6.0	5.8	5.6	5.5	5.4	5.3	5.3	5.3	5.3
44	7.9	7.2	6.7	6.3	6.0	5.8	5.6	5.5	5.4	5.3	5.3	5.3	5.3
46	7.8	7.1	6.6	6.2	6.0	5.8	5.6	5.5	5.4	5.3	5.3	5.3	5.3
48	7.7	7.0	6.6	6.2	6.0	5.8	5.6	5.5	5.4	5.4	5.3	5.3	5.3
50	7.5	6.9	6.5	6.2	5.9	5.7	5.6	5.5	5.4	5.4	5.3	5.3	5.4
52	7.4	6.9	6.5	6.1	5.9	5.7	5.6	5.5	5.4	5.4	5.4	5.4	5.4
54	7.3	6.8	6.4	6.1	5.9	5.7	5.6	5.5	5.4	5.4	5.4	5.4	5.4

Table A-7. Limiting resource combination: land and management. (a) Total value product of land and management, (b) total factor costs of all resources except land and management, and (c) net value product of land and management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/acre)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	6795	6641	6480	6314	6145	5973	5800	5626	5451	5274	5097	4920	4742
38	6596	6427	6258	6087	5917	5746	5575	5403	5232	5060	4889	4717	4545
40	6417	6235	6058	5884	5711	5541	5371	5203	5035	4868	4701	4534	4368
42	6255	6062	5877	5699	5526	5355	5187	5021	4857	4693	4531	4369	4208
44	6108	5904	5713	5532	5357	5187	5020	4856	4695	4535	4376	4219	4062
46	5974	5759	5563	5378	5203	5033	4867	4706	4547	4390	4235	4082	3930
48	5851	5627	5425	5238	5061	4892	4727	4568	4411	4257	4106	3956	3808
50	5737	5506	5299	5109	4931	4762	4599	4441	4286	4135	3987	3840	3696
52	5633	5393	5182	4990	4811	4642	4480	4323	4171	4023	3877	3734	3592
54	5536	5289	5074	4880	4700	4531	4370	4215	4065	3918	3775	3635	3496

(b) Total Factor Cost ($/acre)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	4512	4090	3768	3512	3395	3210	3052	2915	2794	2686	2589	2500	2418
38	4337	3934	3626	3382	3269	3094	2943	2812	2697	2594	2501	2416	2338
40	4178	3793	3498	3265	3157	2988	2845	2720	2609	2511	2422	2341	2267
42	4036	3666	3383	3159	3055	2894	2756	2636	2531	2436	2351	2274	2202
44	3906	3550	3278	3063	2962	2807	2675	2560	2458	2368	2286	2212	2143
46	3787	3444	3183	2975	2878	2728	2601	2490	2393	2306	2227	2156	2090
48	3678	3348	3095	2895	2800	2656	2533	2427	2333	2249	2173	2104	2041
50	3578	3259	3014	2821	2729	2590	2471	2368	2277	2196	2123	2057	1996
52	3486	3176	2940	2752	2663	2529	2414	2314	2226	2148	2077	2013	1954
54	3400	3100	2871	2689	2602	2472	2360	2264	2179	2103	2035	1972	1915

(a) Net Value Product ($/acre)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	2283	2550	2712	2802	2750	2763	2748	2711	2656	2588	2509	2420	2324
38	2260	2493	2631	2706	2647	2652	2631	2591	2535	2466	2388	2301	2207
40	2239	2442	2559	2619	2555	2552	2527	2483	2425	2357	2279	2193	2101
42	2220	2396	2494	2540	2471	2461	2431	2385	2326	2257	2180	2095	2006
44	2203	2354	2435	2469	2395	2380	2345	2297	2236	2167	2090	2007	1919
46	2187	2315	2380	2404	2325	2304	2266	2215	2154	2084	2008	1926	1840
48	2172	2280	2330	2344	2261	2235	2194	2141	2079	2009	1933	1852	1767
50	2159	2247	2285	2289	2202	2172	2127	2073	2009	1939	1864	1784	1700
52	2147	2217	2242	2238	2148	2113	2066	2009	1945	1875	1800	1721	1638
54	2135	2189	2203	2191	2098	2059	2009	1951	1886	1816	1741	1663	1581

Maximum value for each row spacing

Maximum value for all row/drill combinations

Table A-8. Limiting resource combination: labor and management. (a) Total value product of labor and management, (b) total factor costs of all resources except labor and management, and (c) net value product of labor and management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/hour)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	20.83	23.20	25.28	27.09	28.61	29.95	31.06	31.97	32.69	33.22	33.59	33.80	33.85
38	21.18	23.50	25.52	27.28	28.75	30.03	31.10	31.96	32.63	33.13	33.46	33.63	33.65
40	21.53	23.79	25.76	27.47	28.89	30.12	31.14	31.95	32.58	33.04	33.33	33.47	33.47
42	21.87	24.08	25.99	27.65	29.01	30.19	31.16	31.94	32.53	32.95	33.20	33.31	33.28
44	22.21	24.36	26.23	27.83	29.15	30.28	31.20	31.93	32.48	32.87	33.09	33.17	33.11
46	22.54	24.64	26.45	28.00	29.27	30.35	31.23	31.92	32.43	32.78	32.97	33.02	32.93
48	22.87	24.91	26.67	28.17	29.39	30.43	31.26	31.91	32.38	32.69	32.85	32.87	32.76
50	23.19	25.18	26.89	28.34	29.51	30.50	31.29	31.90	32.34	32.61	32.74	32.74	32.60
52	23.51	25.45	27.10	28.50	29.62	30.57	31.32	31.89	32.29	32.54	32.64	32.60	32.44
54	23.83	25.71	27.31	28.66	29.74	30.64	31.35	31.88	32.25	32.46	32.53	32.48	32.29

(b) Total Factor Cost ($/hour)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	8.91	9.41	9.86	10.27	11.04	11.36	11.65	11.90	12.13	12.32	12.49	12.63	12.74
38	9.02	9.52	9.97	10.37	11.14	11.46	11.75	12.00	12.22	12.41	12.57	12.71	12.82
40	9.13	9.63	10.07	10.48	11.24	11.56	11.84	12.09	12.30	12.49	12.65	12.79	12.90
42	9.23	9.73	10.18	10.58	11.34	11.65	11.93	12.17	12.39	12.57	12.73	12.86	12.97
44	9.34	9.83	10.28	10.68	11.43	11.74	12.02	12.26	12.47	12.65	12.81	12.94	13.05
46	9.44	9.94	10.38	10.78	11.52	11.83	12.10	12.34	12.55	12.73	12.88	13.01	13.12
48	9.54	10.04	10.48	10.87	11.61	11.91	12.18	12.42	12.63	12.80	12.96	13.08	13.19
50	9.64	10.13	10.57	10.97	11.70	12.00	12.26	12.50	12.70	12.88	13.03	13.15	13.25
52	9.74	10.23	10.67	11.06	11.78	12.08	12.34	12.57	12.77	12.95	13.09	13.22	13.32
54	9.84	10.33	10.76	11.15	11.87	12.16	12.42	12.65	12.85	13.02	13.16	13.28	13.38

(c) Net Value Product ($/hour)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	11.92	13.79	15.42	16.82	17.57	18.58	19.41	20.07	20.56	20.90	21.10	21.17	21.11
38	12.16	13.98	15.55	16.91	17.61	18.57	19.35	19.96	20.42	20.72	20.89	20.92	20.83
40	12.40	14.16	15.69	16.99	17.65	18.56	19.30	19.87	20.28	20.55	20.68	20.68	20.57
42	12.64	14.35	15.82	17.07	17.68	18.54	19.24	19.76	20.14	20.37	20.47	20.45	20.30
44	12.87	14.53	15.95	17.15	17.72	18.54	19.19	19.68	20.01	20.21	20.28	20.23	20.06
46	13.10	14.70	16.07	17.22	17.75	18.52	19.13	19.58	19.88	20.05	20.09	20.01	19.81
48	13.33	14.88	16.19	17.30	17.78	18.51	19.08	19.49	19.76	19.89	19.90	19.79	19.58
50	13.55	15.05	16.31	17.37	17.81	18.50	19.03	19.40	19.63	19.74	19.72	19.59	19.35
52	13.77	15.22	16.43	17.44	17.84	18.49	18.98	19.32	19.52	19.59	19.54	19.39	19.13
54	13.99	15.38	16.55	17.51	17.87	18.48	18.93	19.23	19.40	19.45	19.37	19.19	18.92

Maximum value for each row spacing

Maximum value for all row/drill combinations

Table A-9. Limiting resource combination: quota and management. (a) Total value product of quota and management, (b) total factor costs of all resources except quota and management, and (c) net value product of quota and management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/cwt)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
38	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
40	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
42	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
44	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
46	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
48	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
50	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
52	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00
54	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00	175.00

(b) Total Factor Cost ($/cwt)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	108.98	100.60	94.62	90.24	89.65	87.10	85.22	83.90	83.03	82.54	82.40	82.56	83.02
38	107.89	100.00	94.35	90.23	89.79	87.38	85.64	84.43	83.66	83.27	83.21	83.45	83.98
40	106.86	99.42	94.10	90.21	89.91	87.66	86.05	84.95	84.27	83.97	83.99	84.31	84.91
42	105.88	98.89	93.87	90.21	90.04	87.95	86.46	85.47	84.89	84.67	84.77	85.17	85.84
44	104.93	98.35	93.62	90.18	90.15	88.20	86.83	85.94	85.46	85.33	85.51	85.98	86.72
46	104.04	97.85	93.41	90.18	90.28	88.46	87.22	86.43	86.04	85.99	86.25	86.79	87.61
48	103.18	97.37	93.19	90.17	90.39	88.72	87.59	86.91	86.60	86.64	86.97	87.59	88.48
50	102.36	96.90	92.99	90.16	90.51	88.97	87.95	87.36	87.15	87.26	87.67	88.36	89.32
52	101.57	96.45	92.79	90.15	90.61	89.20	88.30	87.81	87.68	87.88	88.36	89.12	90.14
54	100.81	96.02	92.59	90.14	90.72	89.43	88.63	88.24	88.20	88.47	89.03	89.85	90.94

(c) Net Value Product ($/cwt)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	66.02	74.40	80.38	84.76	85.35	87.90	89.78	91.10	91.97	92.46	92.60	92.44	91.98
38	67.11	75.00	80.65	84.77	85.21	87.62	89.36	90.57	91.34	91.73	91.79	91.55	91.02
40	68.14	75.58	80.90	84.79	85.09	87.34	88.95	90.05	90.73	91.03	91.01	90.69	90.09
42	69.12	76.11	81.13	84.79	84.96	87.05	88.54	89.53	90.11	90.33	90.23	89.83	89.16
44	70.07	76.65	81.38	84.82	84.85	86.80	88.17	89.06	89.54	89.67	89.49	89.02	88.28
46	70.96	77.15	81.59	84.82	84.72	86.54	87.78	88.57	88.96	89.01	88.75	88.21	87.39
48	71.82	77.63	81.81	84.83	84.61	86.28	87.41	88.09	88.40	88.36	88.03	87.41	86.52
50	72.64	78.10	82.01	84.84	84.49	86.03	87.05	87.64	87.85	87.74	87.33	86.64	85.68
52	73.43	78.55	82.21	84.85	84.39	85.80	86.70	87.19	87.32	87.12	86.64	85.88	84.86
54	74.19	78.98	82.41	84.86	84.28	85.57	86.37	86.76	86.80	86.53	85.97	85.15	84.06

Maximum value for each row spacing

Maximum value for all row/drill combinations

Table A-10. Limiting resource combination: capital and management. (a) Total value product of capital and management, (b) total factor costs of all resources except capital and management, and (c) net value product of capital and management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/$100 of capital)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	167.77	179.58	189.02	196.52	199.28	203.85	207.26	209.64	211.11	211.79	211.73	211.01	209.68
38	169.09	180.32	189.25	196.31	198.74	202.98	206.07	208.18	209.42	209.88	209.64	208.75	207.28
40	170.38	181.04	189.49	196.12	198.24	202.14	204.95	206.80	207.81	208.07	207.64	206.61	205.00
42	171.60	181.72	189.69	195.90	197.72	201.30	203.83	205.43	206.22	206.28	205.69	204.51	202.77
44	172.81	182.41	189.92	195.74	197.26	200.54	202.80	204.17	204.75	204.63	203.88	202.56	200.71
46	173.96	183.05	190.12	195.54	196.79	199.77	201.77	202.91	203.29	203.00	202.10	200.64	198.68
48	175.08	183.67	190.31	195.36	196.33	199.03	200.78	201.70	201.89	201.43	200.39	198.81	196.74
50	176.17	184.28	190.50	195.18	195.89	198.32	199.83	200.54	200.55	199.93	198.75	197.05	194.88
52	177.23	184.87	190.68	195.02	195.48	197.64	198.92	199.43	199.26	198.49	197.18	195.37	193.11
54	178.26	185.44	190.87	194.86	195.07	196.99	198.05	198.36	198.03	197.11	195.67	193.75	191.40

(b) Total Factor Cost ($/$100 of capital)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
38	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
42	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
44	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
46	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
48	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
54	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

(c) Net Value Product ($/$100 of capital)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	67.77	79.58	89.02	96.52	99.28	103.85	107.26	109.64	111.11	111.79	111.73	111.01	109.68
38	69.09	80.32	89.25	96.31	98.74	102.98	106.07	108.18	109.42	109.88	109.64	108.75	107.28
40	70.38	81.04	89.49	96.12	98.24	102.14	104.95	106.80	107.81	108.07	107.64	106.61	105.00
42	71.60	81.72	89.69	95.90	97.72	101.30	103.83	105.43	106.22	106.28	105.69	104.51	102.77
44	72.81	82.41	89.92	95.74	97.26	100.54	102.80	104.17	104.75	104.63	103.88	102.56	100.71
46	73.96	83.05	90.12	95.54	96.79	99.77	101.77	102.91	103.29	103.00	102.10	100.64	98.68
48	75.08	83.67	90.31	95.36	96.33	99.03	100.78	101.70	101.89	101.43	100.39	98.81	96.74
50	76.17	84.28	90.50	95.18	95.89	98.32	99.83	100.54	100.55	99.93	98.75	97.05	94.88
52	77.23	84.87	90.68	95.02	95.48	97.64	98.92	99.43	99.26	98.49	97.18	95.37	93.11
54	78.26	85.44	90.87	94.86	95.07	96.99	98.05	98.36	98.03	97.11	95.67	93.75	91.40

Maximum value for each row spacing

Maximum value for all row/drill combinations

Table A-11. Limiting resource combination: barn space and management. (a) Total value product of barn space and management, (b) total factor costs of all resources except barn space and management, and (c) net value product of barn space and management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/1000 sticks of barn capacity)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	2808	3201	3570	3913	3527	3771	3995	4198	4379	4541	4681	4800	4898
38	2877	3271	3639	3983	3584	3829	4052	4255	4437	4598	4738	4858	4956
40	2946	3340	3709	4052	3642	3887	4110	4313	4495	4656	4796	4915	5014
42	3016	3409	3778	4121	3700	3944	4168	4371	4553	4714	4854	4973	5072
44	3085	3479	3847	4191	3758	4002	4226	4428	4610	4771	4912	5031	5129
46	3154	3548	3916	4260	3815	4060	4283	4486	4668	4829	4969	5089	5187
48	3224	3617	3986	4329	3873	4117	4341	4544	4726	4887	5027	5146	5245
50	3293	3686	4055	4398	3931	4175	4399	4602	4784	4945	5085	5204	5303
52	3362	3756	4124	4468	3988	4233	4457	4659	4841	5002	5143	5262	5360
54	3431	3825	4193	4537	4046	4291	4514	4717	4899	5060	5200	5320	5418

(b) Total Factor Cost ($/1000 sticks of barn capacity)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	1618	1733	1844	1951	1718	1802	1883	1962	2037	2111	2181	2248	2313
38	1648	1765	1879	1990	1753	1840	1924	2006	2084	2160	2233	2303	2371
40	1677	1798	1915	2030	1789	1878	1965	2049	2131	2209	2285	2358	2429
42	1706	1831	1952	2069	1824	1917	2007	2094	2178	2259	2338	2414	2487
44	1735	1863	1987	2108	1860	1955	2048	2137	2224	2308	2390	2469	2544
46	1765	1896	2024	2148	1896	1994	2089	2181	2271	2358	2442	2524	2603
48	1794	1929	2060	2187	1931	2032	2130	2226	2318	2408	2495	2579	2661
50	1824	1961	2096	2227	1967	2071	2171	2270	2365	2458	2547	2634	2719
52	1853	1994	2132	2266	2002	2109	2213	2314	2412	2507	2600	2690	2777
54	1882	2027	2168	2305	2038	2147	2254	2357	2458	2557	2652	2745	2835

(c) Net Value Product ($/1000 sticks of barn capacity)

ROW	DRILL (in)												
(in)	12	14	16	18	20	22	24	26	28	30	32	34	36
36	1190	1469	1726	1962	1809	1969	2112	2236	2342	2430	2500	2552	2585
38	1230	1505	1760	1992	1831	1989	2128	2250	2353	2438	2505	2554	2585
40	1270	1542	1793	2022	1853	2008	2145	2264	2364	2447	2511	2557	2585
42	1309	1579	1826	2052	1875	2027	2161	2277	2375	2454	2516	2559	2585
44	1350	1615	1860	2082	1898	2047	2178	2291	2386	2463	2522	2562	2585
46	1389	1652	1893	2112	1920	2066	2194	2305	2397	2471	2527	2565	2584
48	1429	1689	1926	2142	1942	2085	2211	2318	2408	2479	2532	2567	2584
50	1469	1725	1959	2172	1964	2105	2227	2332	2419	2487	2537	2570	2584
52	1509	1762	1992	2202	1986	2124	2244	2346	2430	2495	2543	2572	2584
54	1549	1798	2026	2232	2008	2143	2261	2360	2441	2503	2548	2575	2583

Maximum value for each row spacing

Maximum value for all row/drill combinations

Table A-12. Limiting resource: management. (a) Total value product of management, (b) total factor costs of all resources except management, and (c) net value product of management. Burley tobacco planted in 12 to 36 inch drill spacings in 36 to 54 inch row widths. SPACING research project. Greeneville, TN. 1985-90.

(a) Total Value Product ($/100 of TVP)

ROW (in)	DRILL (in) 12	14	16	18	20	22	24	26	28	30	32	34	36
36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
38	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
42	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
44	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
46	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
48	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
54	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

(b) Total Factor Cost ($/100 of TVP)

ROW (in)	DRILL (in) 12	14	16	18	20	22	24	26	28	30	32	34	36
36	67.99	63.20	59.78	57.28	56.95	55.48	54.41	53.66	53.16	52.88	52.80	52.89	53.15
38	67.37	62.86	59.63	57.27	57.02	55.65	54.65	53.96	53.52	53.30	53.26	53.40	53.70
40	66.78	62.53	59.48	57.26	57.09	55.81	54.88	54.26	53.87	53.69	53.71	53.89	54.23
42	66.22	62.22	59.35	57.26	57.17	55.97	55.12	54.55	54.22	54.10	54.15	54.38	54.77
44	65.68	61.91	59.21	57.25	57.23	56.11	55.33	54.83	54.55	54.47	54.58	54.84	55.27
46	65.17	61.63	59.09	57.24	57.30	56.27	55.55	55.10	54.88	54.85	55.00	55.31	55.78
48	64.68	61.35	58.97	57.24	57.37	56.41	55.76	55.37	55.20	55.22	55.41	55.76	56.27
50	64.21	61.09	58.85	57.23	57.43	56.55	55.97	55.64	55.51	55.58	55.81	56.21	56.75
52	63.76	60.83	58.73	57.23	57.49	56.69	56.17	55.89	55.82	55.93	56.21	56.64	57.22
54	63.32	60.58	58.62	57.22	57.55	56.82	56.36	56.14	56.11	56.27	56.59	57.06	57.68

(c) Net Value Product ($/100 of TVP)

ROW (in)	DRILL (in) 12	14	16	18	20	22	24	26	28	30	32	34	36
36	32.01	36.80	40.22	42.72	43.05	44.52	45.59	46.34	46.84	47.12	47.20	47.11	46.85
38	32.63	37.14	40.37	42.73	42.98	44.35	45.35	46.04	46.48	46.70	46.74	46.60	46.30
40	33.22	37.47	40.52	42.74	42.91	44.19	45.12	45.74	46.13	46.31	46.29	46.11	45.77
42	33.78	37.78	40.65	42.74	42.83	44.03	44.88	45.45	45.78	45.90	45.85	45.62	45.23
44	34.32	38.09	40.79	42.75	42.77	43.89	44.67	45.17	45.45	45.53	45.42	45.16	44.73
46	34.83	38.37	40.91	42.76	42.70	43.73	44.45	44.90	45.12	45.15	45.00	44.69	44.22
48	35.32	38.65	41.03	42.76	42.63	43.59	44.24	44.63	44.80	44.78	44.59	44.24	43.73
50	35.79	38.91	41.15	42.77	42.57	43.45	44.03	44.36	44.49	44.42	44.19	43.79	43.25
52	36.24	39.17	41.27	42.77	42.51	43.31	43.83	44.11	44.18	44.07	43.79	43.36	42.78
54	36.68	39.42	41.38	42.78	42.45	43.18	43.64	43.86	43.89	43.73	43.41	42.94	42.32

Maximum value for each row spacing

Maximum value for all row/drill combinations

Figure A-1. Seasonal rainfall, quantity and distribution.
Tobacco Experiment Station, Greeneville, TN June - August, 1985

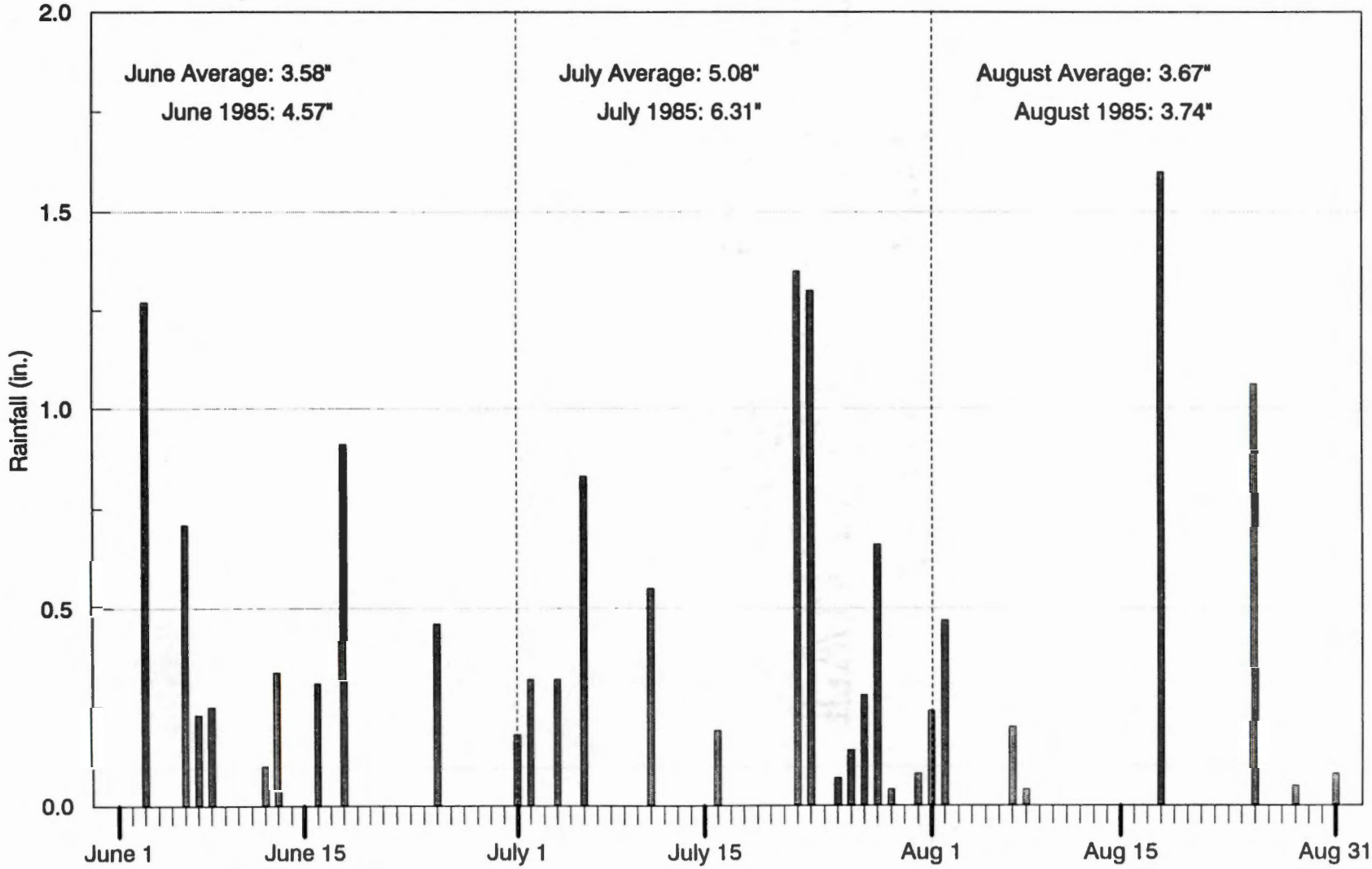


Figure A-2. Seasonal rainfall, quantity and distribution.

Tobacco Experiment Station, Greeneville, TN June - August, 1986

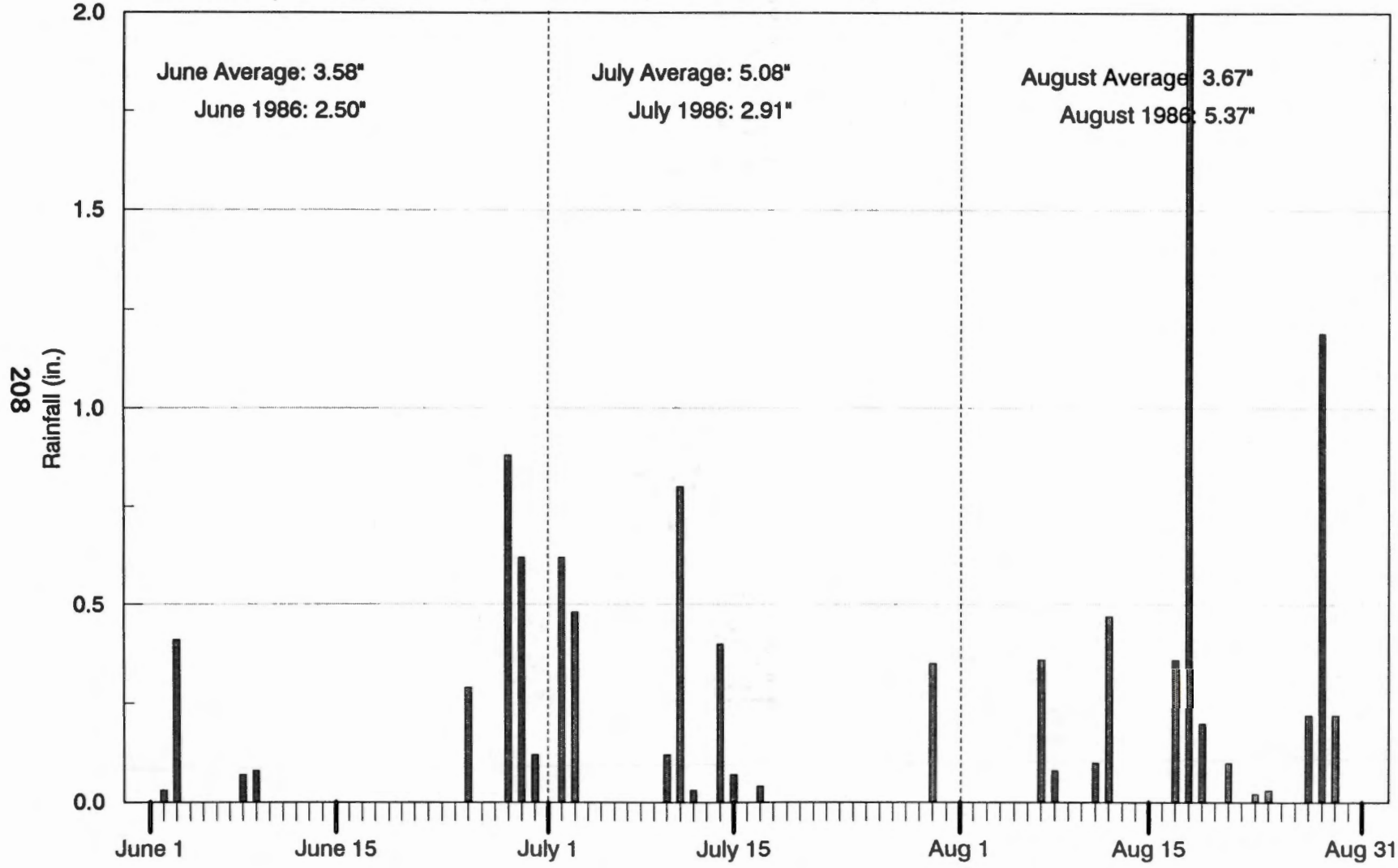


Figure A-3. Seasonal rainfall, quantity and distribution.

Tobacco Experiment Station, Greeneville, TN June - August, 1987

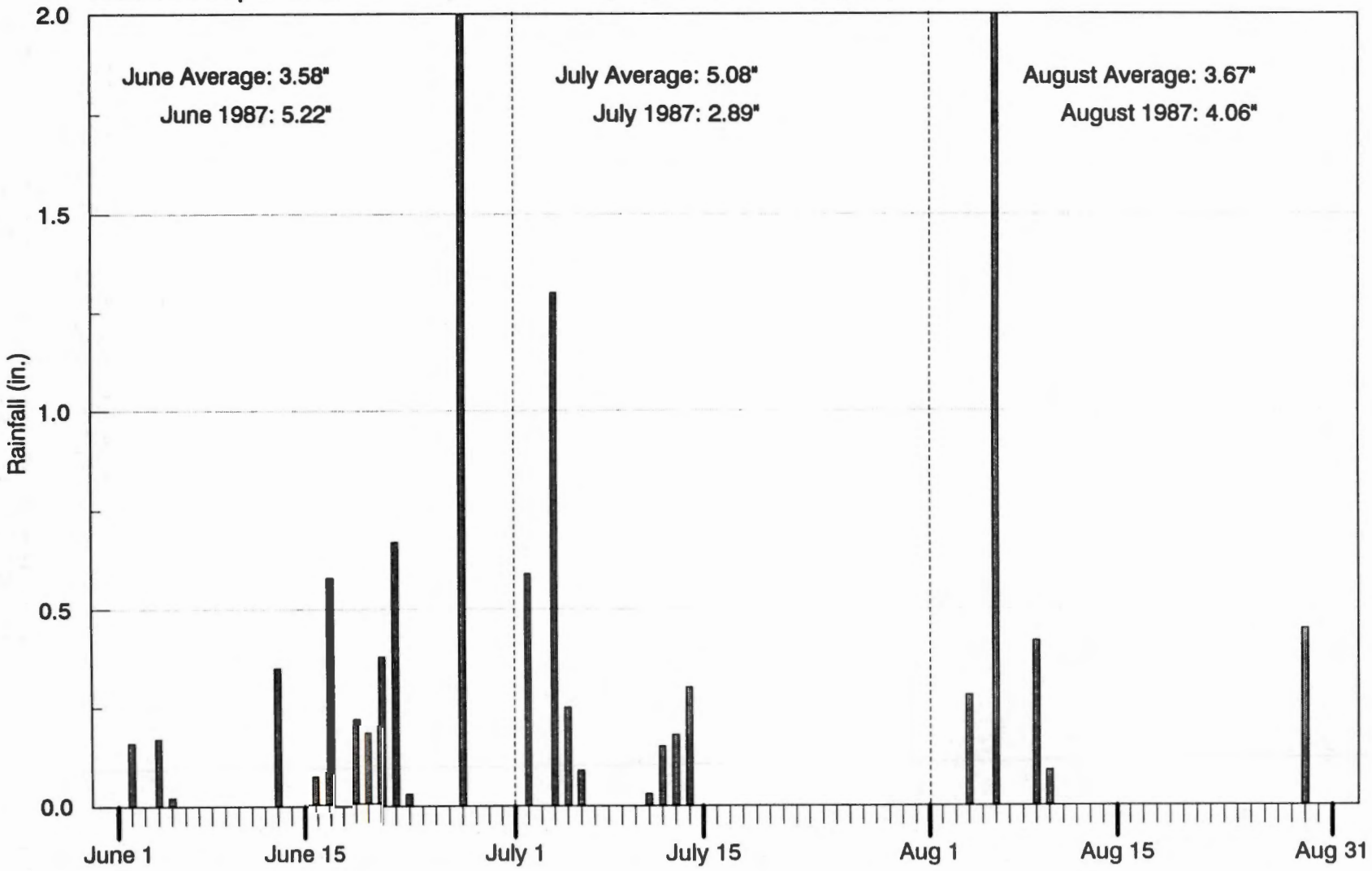


Figure A-4. Seasonal rainfall, quantity and distribution.

Tobacco Experiment Station, Greeneville, TN June - August, 1988

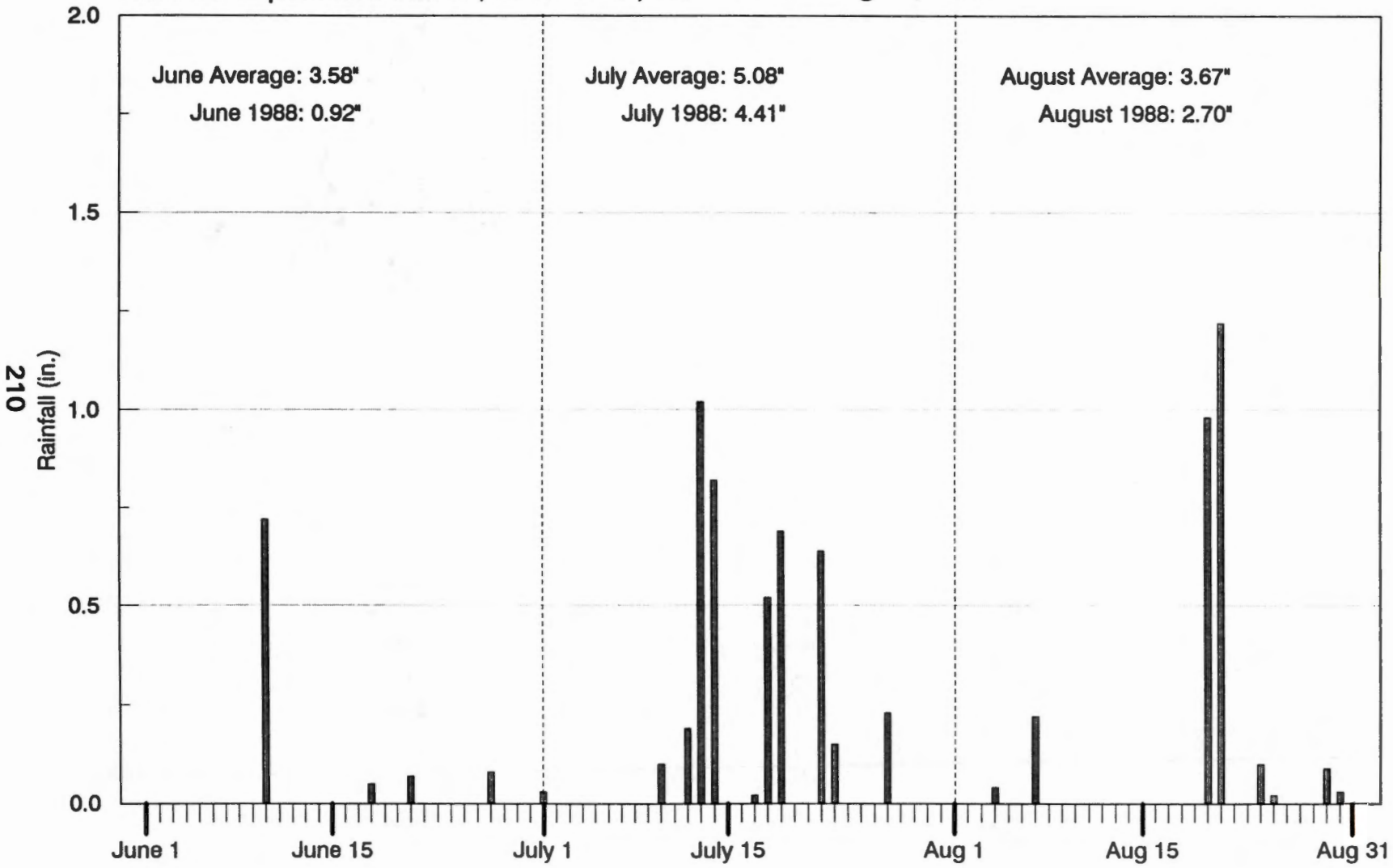


Figure A-5. Seasonal rainfall, quantity and distribution.
Tobacco Experiment Station, Greeneville, TN June - August, 1989

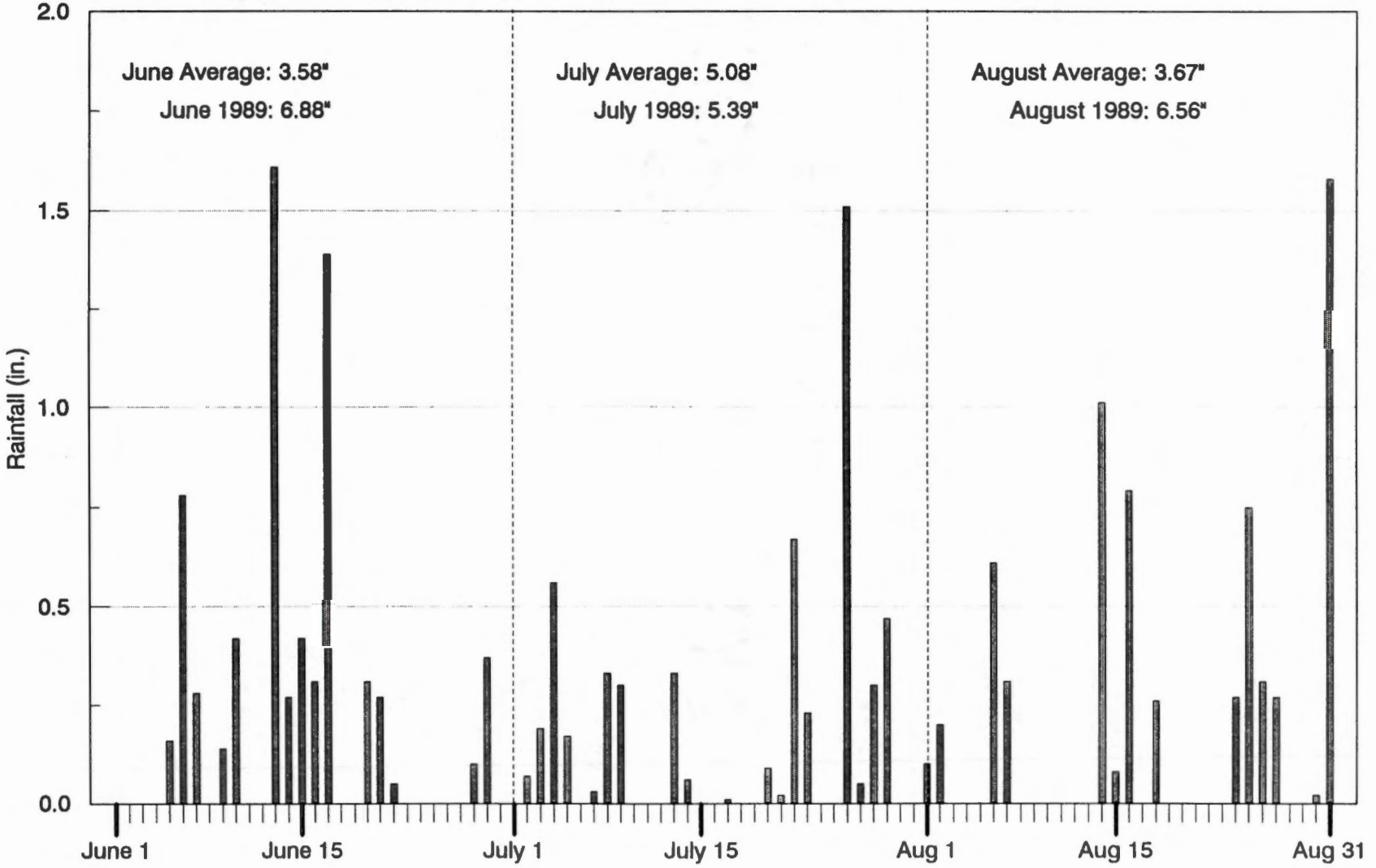
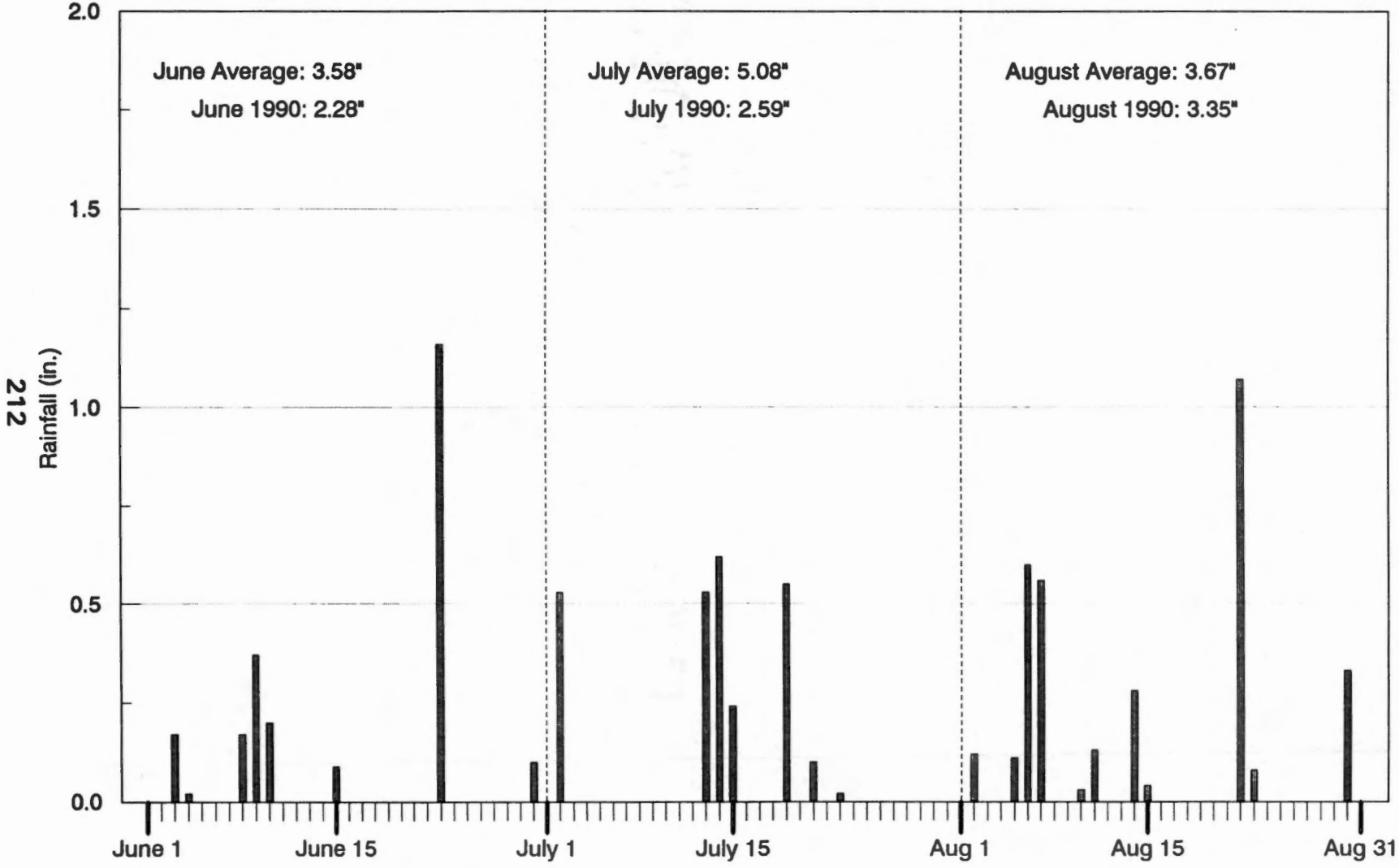


Figure A-6. Seasonal rainfall, quantity and distribution.

Tobacco Experiment Station, Greeneville, TN June - August, 1990



VITA

Steven Grady Isaacs was born October 17, 1954, the first child of Carter and Florence Isaacs. He grew up on a tobacco and beef farm in Johnson County, the easternmost county in Tennessee. Primary and secondary education was at Dry Run Elementary and Johnson County High School with graduation in 1972. Undergraduate education was at East Tennessee State University (1972-73) and The University of Tennessee (1973-76). A Bachelor's of Science in Agriculture was awarded in 1976.

From 1976 to 1985 he was employed as General Manager of Maymead Stock Farm, Inc., Mountain City, Tennessee. In 1980, Steve, his wife Geri, and his parents established a farm partnership, Isaacs Farm. In 1985 he was employed as a research associate in the Department of Agricultural Economics and Rural Sociology at The University of Tennessee. From 1985 to 1992, he also completed the requirements for a Doctorate of Philosophy in Agricultural Economics. He joined the faculty of the Agricultural Economics Department at The University of Kentucky as an Extension Farm Management Specialist in March of 1992.