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To the Graduate Council:

I am submitting herewith a thesis written by Buford Byrle Bradley, Jr., entitled "Prediction of the Effects of Pattern Selection on Pattern Efficiency and Soil Erosion." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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PREDICTION OF THE EFFECTS OF PATTERN SELECTION ON PATTERN EFFICIENCY AND SOIL EROSION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

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ABSTRACT

The choice of a tillage pattern is an important contributor to the effective and economic utilization of a particular agricultural field machine. One important consideration in the choice of a tillage pattern is the effect of that pattern on soil and water conservation. While a particular pattern might be more efficient, its use might be restricted because of excessive soil loss due to surface runoff. Likewise, the optimal tillage pattern, from the standpoint of soil conservation, might result in a much less efficient operation. The relative efficiency of a particular tillage pattern, the pattern efficiency, takes into account time losses which are directly attributed to the pattern. These losses are the result of such nonproductive work as turning at the end of rows. The overall efficiency of a particular field operation, often called the field efficiency, considers the effect of the pattern efficiency and of losses which are associated with the acreage processed and with the particular operation. Examples of such losses are refueling, repair of machinery, and the filling of seed hoppers.

This particular study involved the development of a computer program which, when given the particular tillage pattern and field configuration, will predict the pattern efficiency and the resulting soil loss. Several patterns, within the constraints of the given land management program, can be proposed and an optimal solution found. This study was undertaken in conjunction with The University of Tennessee Agricultural Experiment Station research project Hatch-379, "Development

of Compatible Erosion-Control Practices and Machinery Systems." This project is administered by The University of Tennessee Agricultural Engineering Department with Professor Curtis Shelton as the project leader. The study is being conducted at watersheds located on the Milan Field Station and the Middle Tennessee Experiment Station. Various land management practices are being applied to the watersheds, and both the efficiency of machine operations and sediment discharge are monitored. The resulting data were used to corroborate the computer results.

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CHAPTER I

INTRODUCTION TO THE STUDY

As our society develops, we become increasingly more aware that human actions constitute a determining factor of the environment. The agriculturalist should be especially aware of the effects of land management practices on present and future land use, and correspondingly on its productivity. In particular, soil erosion and its attendant harmful effects must be recognized and controlled. While erosion control is expensive, erosion is also expensive. Costs of erosion result from reduction of productivity due to loss of soil and nutrients, from the creation of gulleys which make efficient machinery use difficult, and from the pollution of streams and gardual filling of reservoirs (14). To provide an added incentive for improved land use practices, some states have recently passed legislation requiring erosion and sedimentation control. For example, North Carolina has established a monitoring board; and although the present law excludes agricultural erosion, legislation to control it is certain to come (21).

The problem of erosion gained public recognition in the 1930's (5). Deterioration of many of our soils was emphasized then by such individuals as H. H. Bennett, who later was instrumental in organizing federal support for soil erosion control (5). His estimates (1939) indicated that nearly 50 million acres of cropland had been eroded to the point of being ruined, another 50 million acres had been reduced to

a state of marginal productivity, and another 200 million acres were being eroded at a rapid rate (5). As late as 1962, a national survey showed that soil erosion was a prominent problem on about 237 million acres--more than half the total (5).

Upon recognizing that erosion control is beneficial even when not required, the agriculturalist is confronted with a myriad of possible erosion control schemes for a given area. Each field requires a different erosion control method depending on the topography, crops, and management objectives. One must also be aware of the effects of an erosion control practice on other factors. One of these factors is machine efficiency. The erosion control practice is, in fact, one of the most important modifiers of machine efficiency (6). Many current erosion control practices were developed in the era of horsedrawn machinery and have become totally unsuited for modern multi-row cropping practices. Some early erosion control practices such as conventional terraces will control erosion but will frequently result in many point (short) rows. With high machinery expenses, farmers realize that any inefficiency will result in a very real additional cost which must be added to the erosion control expense. Often this additional expense is considered as justification for allowing erosion to occur while using an efficient pattern. An optimal solution would be to select a set of conditions where pattern efficiency would be maximized while holding soil runoff within an allowable limit.

CHAPTER II

OBJECTIVES

The purpose of this investigation was to develop a method to predict the amount of soil erosion from a particular field and the corresponding pattern efficiency for that field. By comparing results for different patterns of operation on a given field, an optimal pattern could be chosen. Specific objectives were:

1. Development of a computer program to predict soil losses based on the Universal Soil Loss Equation;
2. Development of a computer program to predict the efficiency associated with a particular pattern or operation. The results of this program were to be corroborated by actual field data.

This study did not analyze the economic feasibility of the erosion prevention practice or the corresponding contribution to productivity. Economic factors certainly must be considered in the establishment of erosion control practices; however, this information would fall outside the scope of this study.

CHAPTER III

REVIEW OF LITERATURE

I. PURPOSE OF REVIEW

This section presents a general review of available literature concerning the Universal Soil Loss Equation, machine efficiencies, and the relationship between soil conservation and efficiency.

II. EROSION CONTROL VERSUS MACHINE PATTERN EFFICIENCY

In deciding which erosion control measure to adopt, the farmer must consider several relevant cost factors. The costs which can be attributed to the conservation measure are the installation cost, the maintenance cost, the cost (or savings) of machinery use time, and the cost (or savings) of change in production.

A bulletin on this subject by S. W. Atkins (2) of The University of Tennessee Agricultural Experiment Station concludes that:

> If all costs (cash or noncash) are charged and future incomes are discounted at 6% per year, high conservation would not be profitable during the lifetime of present farmers under the assumption of constant technology and constant prices. The sum of all present values of future income from high conservation would be 10% below similar incomes from low conservation for the first 50 years. For inoperate conservation, the comparative income would be only 3% below that for the low conservation level of management. Omission of noncash costs, however, would improve the relative income position of the higher conservation systems.

Current conditions and knowledge would lead one to question the validity of this conclusion. Several factors are assumed to be constant

which presently would not be considered as such. Types of farms, technology, price of farm products, and price of farm inputs were considered to be constant. Furthermore, all data for erosion analysis were based on estimates, and costs of water pollution were not included. Unfortunately, little work has been done to corroborate or refute this study. Renoll of Auburn University (10) and Richardson (13) have conducted studies involving erosion control and machine efficiency associated with conservation practices. In an analysis of the use of parallel and conventional terraces, Renoll found that the effective machine field capacity (acres per hour) was greatest for a nonterraced field, less for parallel terraces, and least for conventional terraces (10). Richardson, in contrasting cultivation for graded furrows with that for contour terracing, reported a 21 percent increase in machine field capacity for the graded furrow pattern (13).

III. SOIL LOSS

For many years agriculturalists were able to predict soil losses from water erosion only in relative terms. In the early 1960's, W. H. Wischmeier (7) and others introduced the so-called "Universal Soil Loss Equation," which could be used to predict the soil loss based on environmental, topographical, and agricultural information. This equation evolved from the work of many researchers reflected in more than 10,000 plot-years of data. Tennessee has the distinction of being the first state to adapt the equation to local conditions (7).

The soil loss equation is usually given as follows:

$$A = RKLSCP. \qquad 3.1$$

In this equation "A" is the average annual soil loss in tons per acre under the specific rainfall pattern, soil, topography, cropping-management plan, and particular conservation practice as defined by the independent factors on the right-hand side of the equation (15). The equation is based upon the erosion of a standard plot of soil in the given location with independent factors as described below. The standard plot has been specified to be in a continuous fallow condition, tilled up and down slope with the slope being 9 percent and the slope length being 72.6 feet (7). Continuous fallow is that condition in which the land has been tilled and kept free of vegetation for at least two years or until crop residue has been decayed (7).

The rainfall erosion index "R" was chosen statistically as the best indicator of the ability of a storm to erode the soil (16). Rainstorm characteristics considered were: (a) rainstorm energy, (b) a product term measuring the interaction of storm energy and maximum prolonged intensity, (c) antecedent moisture conditions, and (d) total antecedent rainfall energy since last tillage operation (16). In analyzing more than 8,000 plot years of data concerning soil loss and hydrological data, it was found that the product of the storm energy and maximum thirty-minute intensity explained a greater percentage of the total soil loss than did any other single variable or combination of variables (16). Values for the rainfall erosion index for selected Tennessee counties have been tabulated in Appendix A.

The soil erodibility factor "K" expresses the amount of soil loss for a given soil when the rainfall erosion index "R" is unity. Different soils react differently to a given storm because of such things as soil

structure, texture, organic matter, infiltration, and permeability (7). Multiplying the soil erodibility factor for a given soil by the rainfall erosion index will give the predicted soil loss for a standard plot of the soil. The values for common Tennessee soils are listed in Appendix A.

The length of slope "L" and slope "S" factors are used to relate the topography of a given field to the standard plot. The relationship of slope to erosion was first investigated comprehensively by Zingg in 1940 (18). As a result of his work and later investigations the following expression was developed:

$$Y = 0.43 + 0.30S + 0.43S^2, \qquad 3.2$$

in which "Y" is soil loss (tons per acre) and "S" is percent slope (16). This expression is used in the soil loss equation by finding the ratio of soil runoff ("Y" above) of a particular field to the runoff of the standard plot (9 percent slope). The ratio is the "S" value in the Universal equation.

Zingg was also instrumental in developing a relationship between slope length and erosion (15). It has been found generally that the following relationship holds true:

$$X = L^a. \qquad 3.3$$

In this equation, "S" is relative soil loss (tons per acre), "L" is length of slope in feet, and "a" is an exponent (15). Many values for the exponent "a" have been advanced; however, a group study of the subject at Purdue University in 1956 concluded that the value of this

exponent should be 0.5 (15). As with the slope factor, the length of slope is used to specify the relationship between soil lost at a specified location to that lost at the standard plot (72.6 feet).

The cropping management factor "C" is the most complex of the soil loss equation factors (7). It relates the land management practices of the area in question to the fallow condition of the standard plot. Ground cover is one of the greatest deterents to soil erosion (15). Besides the apparent value of crop roots holding the soil in place, a major action of vegetative cover is the interception of raindrops to reduce their velocity before contacting the soil (14). To determine the factor "C," information is collected relating crop sequence, crop type, production level, treatment of crop residue, and the length of growing season to soil loss from a field. Using these data, the cropping-management factor is determined by the method described by Wischmeier in which he compares soil losses for the land-management scheme used to those for fallow conditions, based on statistical information (16). The factor "C" has been calculated for the common land-management practices used in Tennessee and values are tabulated in the Tennessee Agricultural Eqperiment Station Bulletin No. 395 (7). Typical values are listed in Appendix A.

Another deterrent to soil losses is the use of erosion-control practices. Their effectiveness compared to the standard plot practice (up-and-down slope cultivation) is reflected in the erosion control practice factor "P." Up-and-down slope cultivation is usually the least effective erosion control method of cultivation and is usually assigned the value of one. Contour cultivation involves placing rows

along equal elevations in a field. This method is usually more effective than up-and-down cultivation (dependent upon the degree of slope) but can result in excessive erosion if row breakage is frequent during storm periods. Strip-cropping is usually more effective than either of the other two methods; it provides a sod barrier to slow and filter water-born sediment and has been shown to be up to 50 percent more effective than contouring alone (7). Terraces are usually considered more effective than strip-cropping as an erosion control method because they divide the slope length and thus reduce the effective length (14). The accepted values for effectiveness of erosion practices are listed in Appendix A.

Another factor, not included in the Universal Soil Loss Equation, but which should be considered is the soil loss tolerance. This tolerance is an estimate of the average annual soil loss which can be tolerated and yet achieve the degree of long-term production which is desired (7). Factors to be considered in this estimate include reduction of crop yield per inch loss of topsoil, the maintenance of an adequate soil depth, and change in soil moisture relationships due to texture, infiltration, percolation or water storage capacity. In general, it has been found that losses from soils of Tennessee should not exceed a maximum loss of five tons per acre per year.

Using the Universal Soil Loss Equation and related information, agriculturalists are better able to determine the average annual soil loss of a particular area; and perhaps more importantly, are able to isolate those factors which can be used to reduce soil loss.

IV. MACHINE FIELD EFFICIENCY

Efficient field performance of machines requires careful management. Modern agriculture has tended to rely on machinery, properly managed, to increase production. A single American farmer can now supply food for 46 other people (6).

The value of a management decision is usually judged by its contribution to profit. Associated with each machine are certain costs which must be charged to the field operations in which the machine participates. Generally these costs are divided into fixed costs and variable costs. Fixed costs are defined as those costs which do not change with the number of hours the machine is used per year. Examples of this type of cost are depreciation, taxes, and insurance which are incurred regardless of the extent of use of the machine. Variable costs are those costs which vary with changes in the hours of machine use. Examples are fuel, lubrication, and repair costs.

Regardless of the nature of a machine expense, the objective of efficient machine utilization is to maximize the contribution of the machine for a given cost. The machine must be operated in a way that minimizes nonproductive work. This investigation should help decrease nonproductive work by determining field tillage patterns which have a minimum of turns, since turns result in lost time.

Using geometrical relationships, the number of turns and their consequence on pattern efficiency can be determined for a particular pattern. Several proposed patterns can be compared to find the most efficient one. Various proposed methods of predicting the efficiency of a pattern are investigated in the following section.

Field Efficiency

Measures of agricultural machine performance are based upon the rate and quality with which field operations are accomplished (6). Quality of machine performance is related to quality of the harvested product and to completeness of harvest. The rate of a field operation is measured by the quantity processed per unit of time such as acres per hour and bushels per hour. For any machine there is an optimal performance capacity, often referred to as theoretical field capacity (6), which is the maximum area it can cover per unit of time. This capacity is never obtained in actual field operation, of course, but is useful for evaluating the measured field capacity (called the effective field capacity). The field efficiency of a machine then is the ratio of effective field capacity (C_e) to the optimal theoretical field capacity (C_t). This can be expressed as:

$$E_f = \frac{C_e}{C_t} \times 100 \text{ percent.} \qquad 3.4$$

Losses which cause discrepancies between effective and theoretical field capacity have been listed by Hunt (6) and are summarized below:

1. Machine preparation time at farmstead (shop work);
2. Travel time to and from field;
3. Machine preparation time in the field both before and after operation;
4. Turning time;
5. Time to load and unload machine;
6. Machine adjustment time;

7. Maintenance time (refueling, lubrication);
8. Repair time (in field);
9. Operator's personal time.

The equation for efficiency might be rearranged as follows (with E_f expressed as a decimal);

$$C_e = E_f \times C_t. \qquad 3.5$$

The effective field capacity then is dependent on the theoretical field capacity and an efficiency constant related to the particular operation. These constants have been tabulated from time and motion studies of different field operations, and a sample is shown below (3).

Most tillage operations	.75 - .90
Drill planting of row crops	.70 - .85
Combining grain	.60 - .75
Mowing, raking or baling hay	.75 - .90

Since the theoretical field capacity of a machine can be expressed as the area processed in a given unit of time, an expression for the theoretical capacity, using acres per hour as an example, can be determined dimensionally as follows:

$$\frac{\text{Acres}}{\text{Hour}} = \frac{\text{Miles}}{\text{Hour}} \times (\text{Feet}) \times 5280 \frac{\text{Feet}}{\text{Mile}} \times \frac{\text{Acre}}{43560\ \text{Feet}^2}. \qquad 3.6$$

$$\text{Dimensional Constant} = \frac{5280}{43560} = \frac{1}{8.25}, \qquad 3.7$$

then

$$C_t = \frac{\text{Speed} \times \text{Width}}{8.25}. \qquad 3.8$$

Substituting into the previous expression relating C_t, C_e, and E_f (3):

$$C_e = \frac{\text{Speed x Width}}{8.25} E_f. \qquad 3.9$$

This equation can be used to predict the amount of time required to cover a given field. The theoretical time would then be expressed as:

$$T_e = \frac{\text{Area of Field}}{C_e} . \qquad 3.10$$

Dimensionally, this would be:

$$(\text{Hours}) = \frac{(\text{Acres})}{(\text{Acres/Hours})} . \qquad 3.11$$

This equation is useful in predicting the theoretical time and in computing an actual field efficiency. By calculating the theoretical time and measuring the actual field time, one can compute the field efficiency as follows:

$$E_f = \frac{\text{Actual Time in Field}}{\text{Theoretical Time}} \times 100\ \% = \frac{T_f}{T_e} \times 100\ \%. \qquad 3.12$$

The measured efficiency should be within the range of the previously listed values. An efficiency below this range would indicate the occurrence of unnecessary time losses.

Another type of efficiency is the pattern efficiency, a measure of the adaptability of a field pattern to mechanization. Pattern efficiency takes into account the losses which result from following a particular geometric pattern in working a field. The principal loss attributed to a particular field pattern is the time lost in turning at the ends of rowe. Different patterns applied to the same field

will require different numbers of turns and consequently have different efficiencies.

Tillage Patterns

As mentioned in the previous discussion, a particular tillage pattern influences the efficiency of an operation. Although there are large numbers of pattern variations, the basic patterns are: headland, continuous and circuitous. These are discussed below.

Headland pattern. The headland pattern divides a field into sections with each section processed separately. This pattern is primarily used in plowing where the design of the moldboard plow is such that the soil is thrown in one direction only. Because of the one-way action, soil is thrown either toward the center of the field (back-furrowed field) or toward the outside of the field (dead-furrowed) (6). Plowing must be started either on the side of a field (dead-furrow) or within the field (back-furrow). In a wide field the headland pattern will result in a large amount of end travel (the average end travel is field width divided by two). A more efficient pattern results when the field is divided into smaller areas or lands. The average travel per turn will then be the land width divided by two. This is not to say that the field should be divided into many lands; for as the number of lands increases, the end travel will approach that of an undivided field (maximum number of lands). Also, each dead-furrow requires an extra trip to process. A diagram of a typical divided headland pattern is shown in Figure 1. In general, for a rectangular shaped field, the back-furrowed and dead-furrowed lands will be the same size; and, as

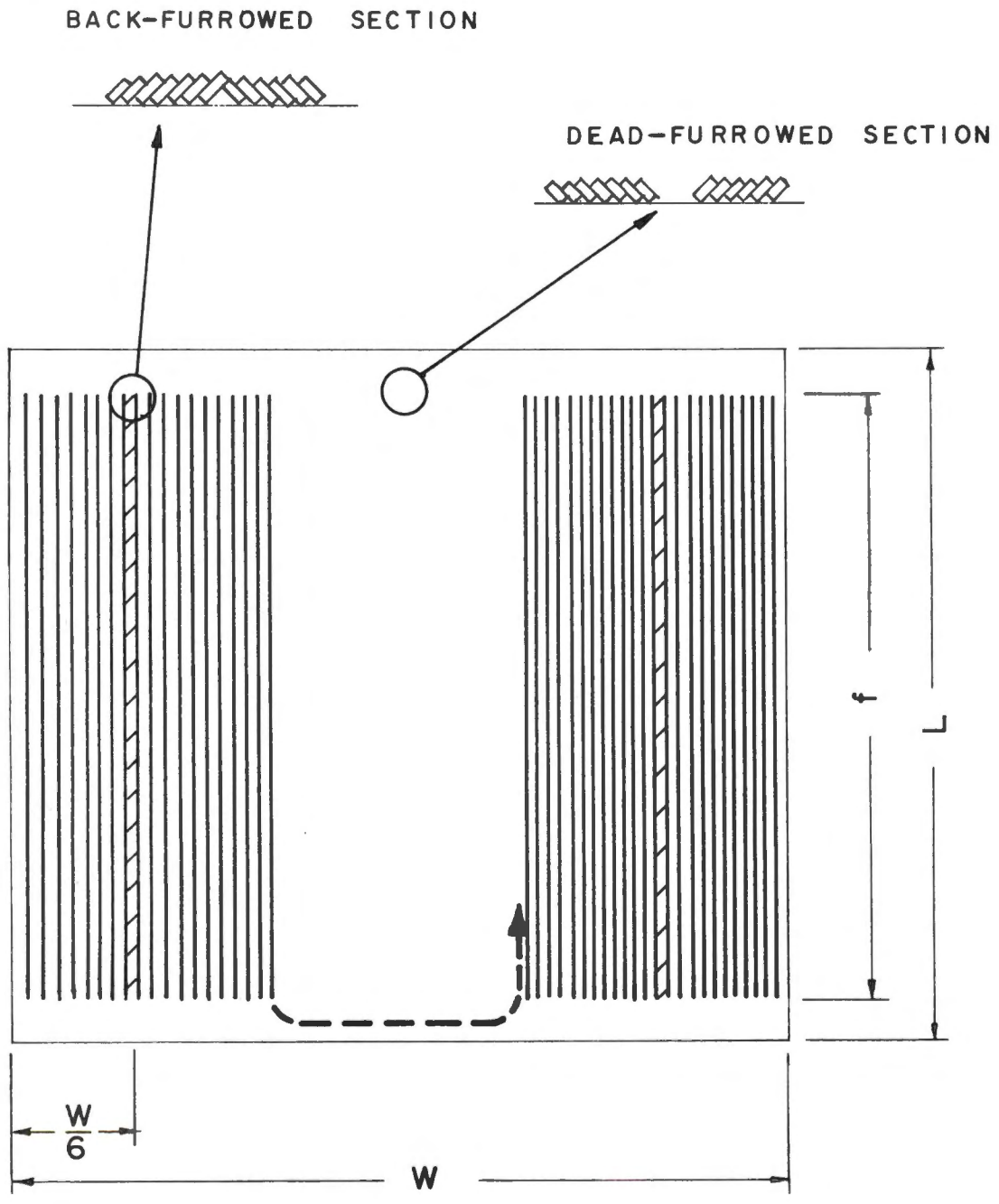

FIGURE 1. Divided headland pattern for three-land field (from Hunt, 1973).

shown in Figure 1, there will always be one more back-furrowed land than dead-furrowed lands (6).

Donnell Hunt (6) states that the prediction of pattern efficiency for the divided headland pattern requires the calculation of time spent for plowing, for idle travel, and for finishing the dead-furrows (6). A summary of his analysis is given below.

If n = number of back-furrow lands and

$n-1$ = number of dead-furrow lands, then

$2n-1$ = total number of lands. 3.13

Time for one trip (also time to finish dead-furrows) would be:

$$T = \frac{\text{Furrow Length}}{\text{Speed of Operation}} \times \text{Dimensional Constant.}$$

So

$$T = \frac{f(\text{feet})}{Sp\ (\text{Miles/Hour})} \times \frac{1}{5280\ \frac{\text{Feet}}{\text{Mile}}} \quad . \qquad 3.14$$

Number of trips would be:

$$N = \frac{\text{Field Width}}{\text{Implement Width}} \quad .$$

or

$$N = \frac{W}{wi} \quad . \qquad 3.15$$

Total time for plowing lands:

T_t = Time Per Trip x (Number of Trips), or substitution from the above developments,

$$T_t = \frac{f}{Sp\ (5280)} \left[\frac{W}{wi}\right] \quad . \qquad 3.16$$

Average distance for turns on one end of a land is half the width of the land.

If Width of Land = $\frac{\text{Field Width}}{\text{Number of Lands}}$, then average distance for turns would be:

$$D = .5 \frac{W}{2N-1} \quad . \tag{3.17}$$

Average turning time for lands would be:

$$T_{avg.} = \frac{\text{Average Distance of Turn}}{\text{Turning Speed}} \times (\text{Dimensional Constant})$$

or

$$T_{avg.} = \left[\frac{W}{2\ (2n-1)}\right] \left[\frac{1}{S_t}\right] \left[\frac{1}{5280\ \text{Feet/Mile}}\right] . \tag{3.18}$$

Total time would then be:

$$T = \left[\frac{W}{2(2n-1)}\right] \left[\frac{1}{S_t \times 5280}\right] \left[\frac{W}{wi}\right] . \tag{3.19}$$

Time for plowing dead-furrow:

$$T_{df} = \text{Time for One Trip} \times \text{Number of Dead-Furrows},$$

or

$$T_{df} = \frac{f}{S_p \times 5280} \ (n-1). \tag{3.20}$$

Then, the pattern efficiency can then be calculated as follows:

$$PE = \frac{\text{Time Spent in Doing Useful Work}}{\text{Time in Useful Work + Time Lost in Turning}}$$

$$\frac{}{\text{+ Time Lost in Working Dead-Furrows.}}$$

Or by substituting

$$PE = \frac{\frac{f}{S_p \times 5280}\left[\frac{W}{wi}\right]}{\frac{f}{S_p \times 5280}\left[\frac{W}{wi}\right] + \frac{W^2}{2(2n-1) \times 5280 \times S_t \times wi} + [N-1]\left[\frac{f}{5280 \times S_p}\right]} . \quad 3.21$$

By substituting known values of W, Wi, f, S_p and S_t into the equation and varying the number of back-furrows, a graph was derived by Hunt as shown in Figure 2. As noted by Hunt, the region of the curve representing an optimal solution is relatively flat. Consequently, there are several "good" solutions in the most efficient range (6).

If the area at the ends of the field where the turns are made (headland) is to be processed, this processing time must also be included. This time is calculated in a manner similar to that for the main part of the field, where

$$\text{Plowing time for headlands} = \frac{W(L-f)}{S_p \times wi \times 5280} . \quad 3.22$$

Then total time spent in turning at headlands

$$= \frac{(L-f)^2}{S_t \times Wi \times 4 \times 5280} . \quad 3.23$$

Another published report on pattern efficiency was by McKibben in 1939 (9). He proposed the following method of analysis based on the pattern shown in Figure 3.

Effective Travel = Length x Number of Rows,

or

$$TR_e = L \times \left[\frac{W}{wi}\right] . \quad 3.24$$

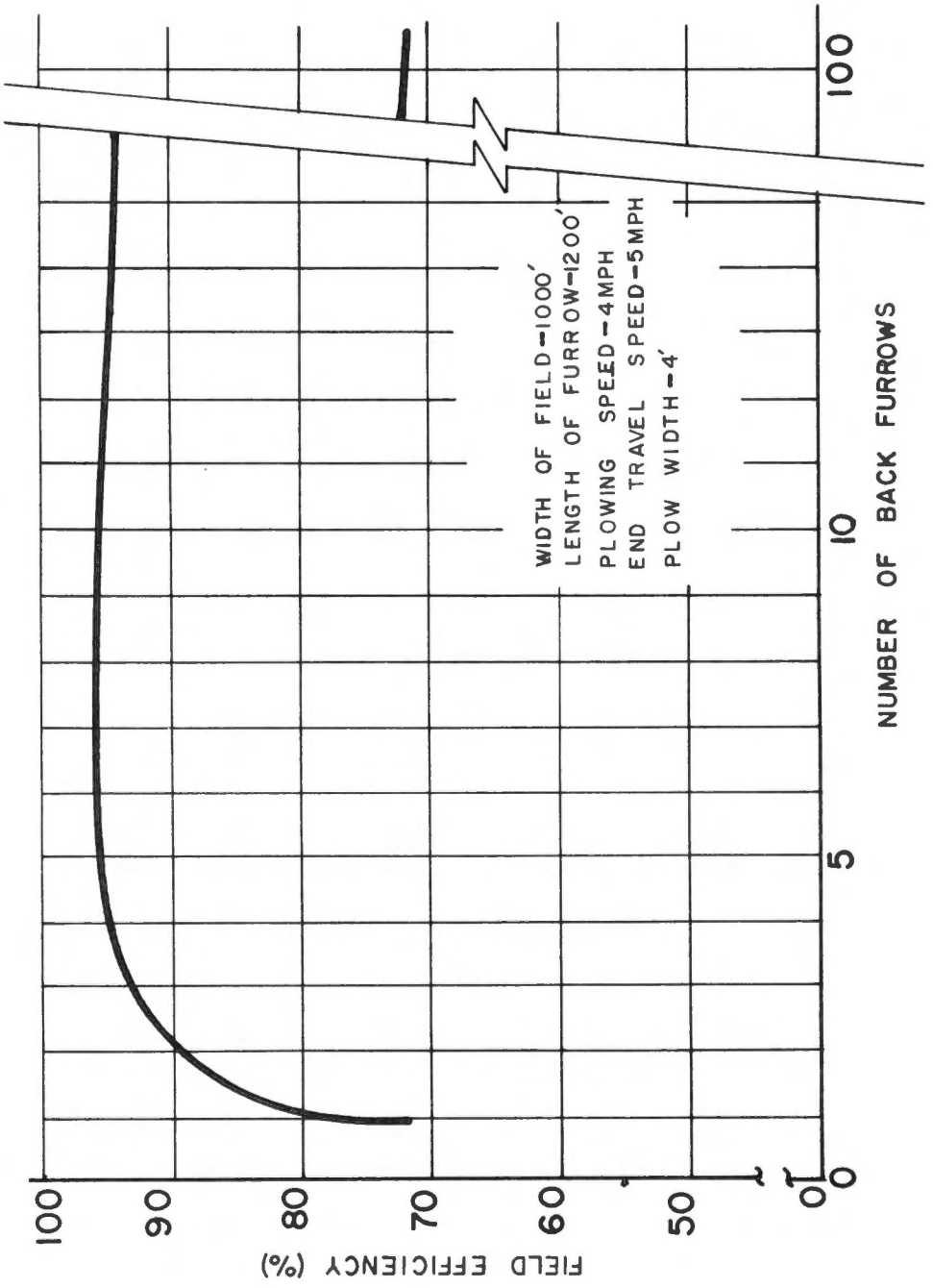

FIGURE 2. Pattern efficiency as a function of lands (from Hunt, 1973).

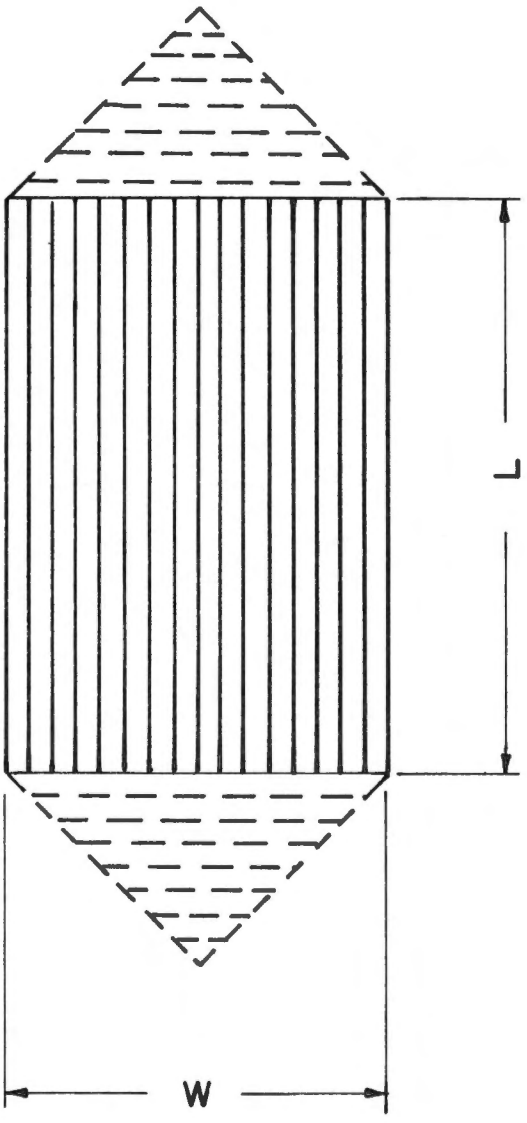

FIGURE 3. Headland pattern (from McKibben, 1960).

As before, average travel time would be half the width, and total travel would be average turning time multiplied by the number of turns as:

$$\text{Turning travel} = \frac{.5\ (\text{Field Width})^2}{\text{Implement Width}} = TR_t. \qquad 3.25$$

Therefore, pattern efficiency is:

$$PE = \frac{TR_e}{TR_t + TR_e} \quad . \qquad 3.26$$

Substituting from above development, pattern efficiency would then be:

$$PE = .5\frac{W}{wi} \times W = .5N \times @. \qquad 3.27$$

As with the Hunt's method, this technique applies only to rectangular fields.

Continuous pattern. The continuous pattern is most commonly used for row crops where the row being worked is adjacent to the preceding row (Figure 4). For this pattern the efficiency depends greatly on the time of turning at the ends (6). Renoll (10) suggests that the turning time can account for up to 20 percent of the total field time. He found that the width of the turning space and the ground surface conditions can greatly influence the turning time. Figure 5 illustrates different types of turns.

In Hunt's analysis of the pattern, an average turning time is used. If this turning time "t" is the same for all turns, the total time of turning is as follows (6):

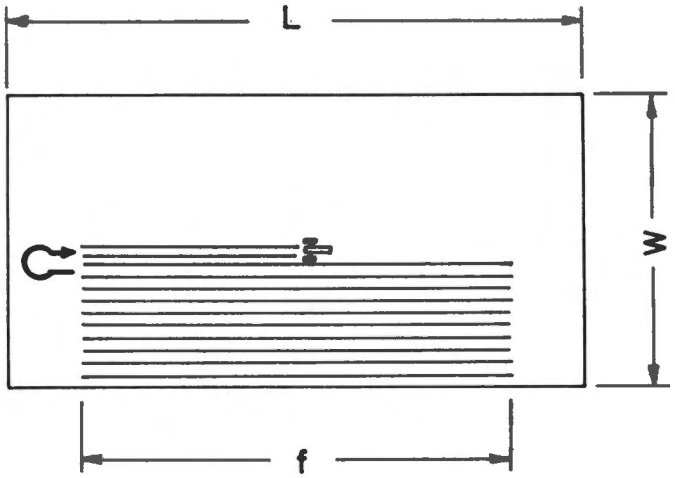

FIGURE 4. Continuous pattern.

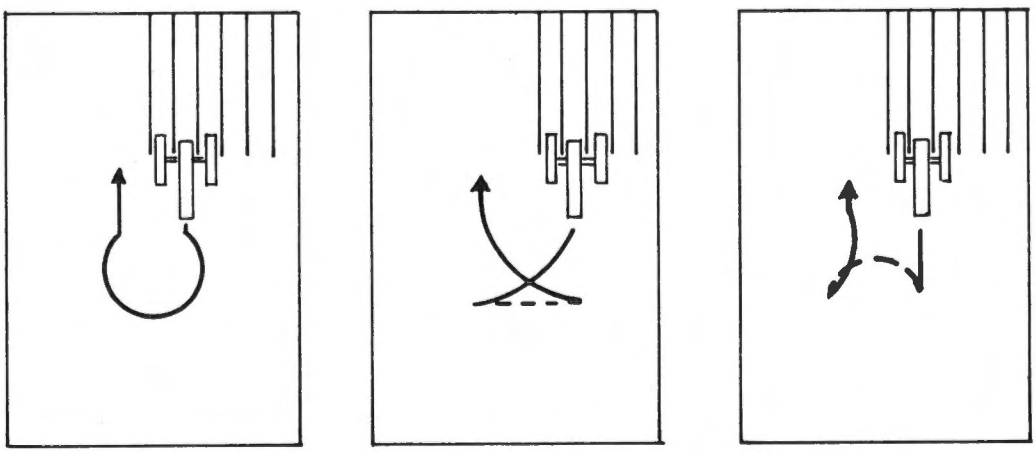

FIGURE 5. Turns used for continuous pattern.

$$T_t = \text{Time for Turn} \times \text{Number of Turns}$$

$$= t \times N = t \times \frac{W}{wi} \quad . \qquad 3.28$$

If the headlands are also tilled by the continuous pattern, the total time lost in turning would be:

$$T_t = \text{Time Per Turn} \times (\text{Total Turns}).$$

Then number of turns for processing ends would be:

$$N = \frac{L-f}{wi} \quad . \qquad 3.29$$

Then by substitution,

$$T_t = t \left[\frac{W}{wi} + \frac{L-f}{wi}\right] . \qquad 3.30$$

Turning time, "t," must be expressed in hours to give T_t in hours. Simplification of this equation goes:

$$T_t = \frac{t}{wi} \ (W + L - f). \qquad 3.31$$

The theoretical operating time is:

$$T_o = \frac{LW}{S_p \times wi \times 5280} . \qquad 3.32$$

The pattern efficiency is as before:

$$PE = \frac{T_o}{T_o + T_t} \quad . \qquad 3.33$$

Substituting the expressions for T_o and T_t into the pattern efficiency equation and simplifying gives:

$$PE = \frac{LW}{LW + 5280 \times t \times S_p \times (W + L - f)} . \qquad 3.34$$

Circuitous pattern. The circuitous pattern is common in grassland type farming and is characterized by Figure 6. This pattern appears to have no lost time for turning, but the turning radius of the implement usually prevents tight cornering of the machine at normal speed and must be considered in calculating the pattern efficiency (6). Notice in Figure 7 that the turning radius of the implement does not coincide with the required corner geometry of the pattern (6). The crescent-shaped areas which are left unprocessed require some extra time to process. Hunt (6) has included an analytical design of the pattern where a loop is used to work these unprocessed areas. For most applications this looping would be impractical and, most frequently, 270 degree turns are used to process these areas as shown by Figure 8.

Using the geometry of the turn, the distance and time can be calculated as below (6).

$$\text{Distance} = 2r_o - wi + 3/4(2)\pi r_o. \qquad 3.35$$

The time per turn would then be:

$$\text{Time} = (2r_o - wi + 3/4(2\pi)r_o)/(S_p \times 5280). \qquad 3.36$$

For a rectangular field with four turns per round and L/2 rounds, the total time spent turning would be:

$$T_t = (2r_o - wi + 3/4(2\pi)r_o) \times 2 \times L / (S_p \times 5280). \qquad 3.37$$

It would appear that the most efficient pattern to use would be a circuitous pattern with 90 degree turns. However, few machines and operators are able to consistently maintain 90 degree turns, and Hunt points out that if these 90 degree turns are not maintained, the

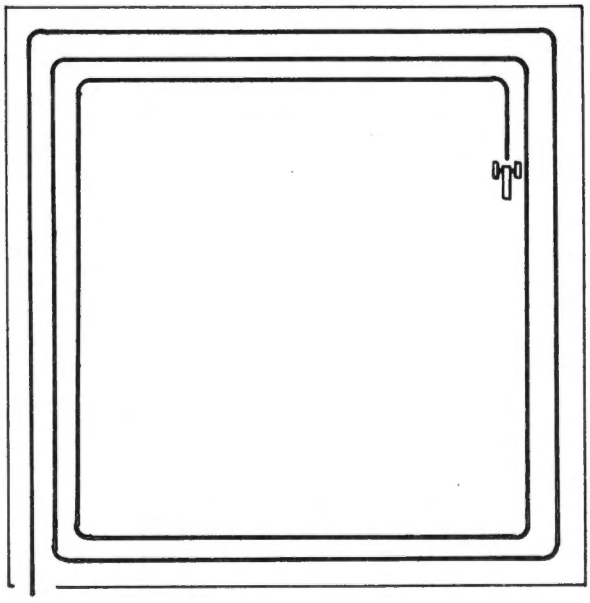

FIGURE 6. Circuitous pattern.

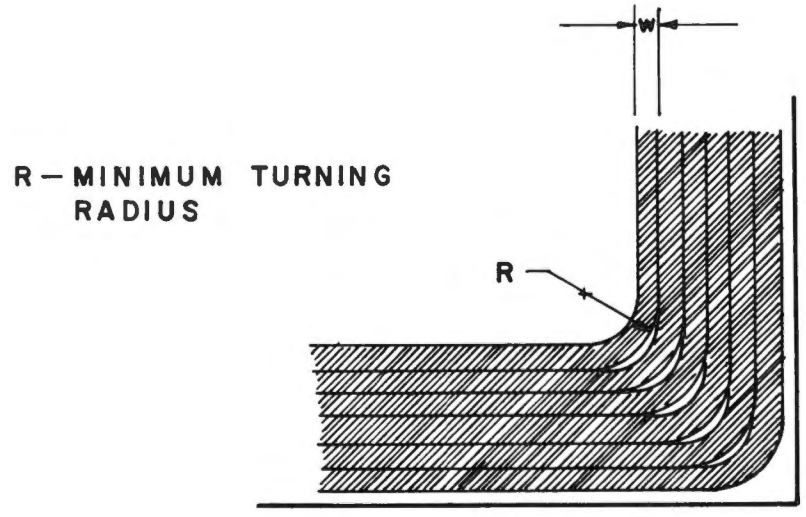

FIGURE 7. Continuous turn of 90 degrees.

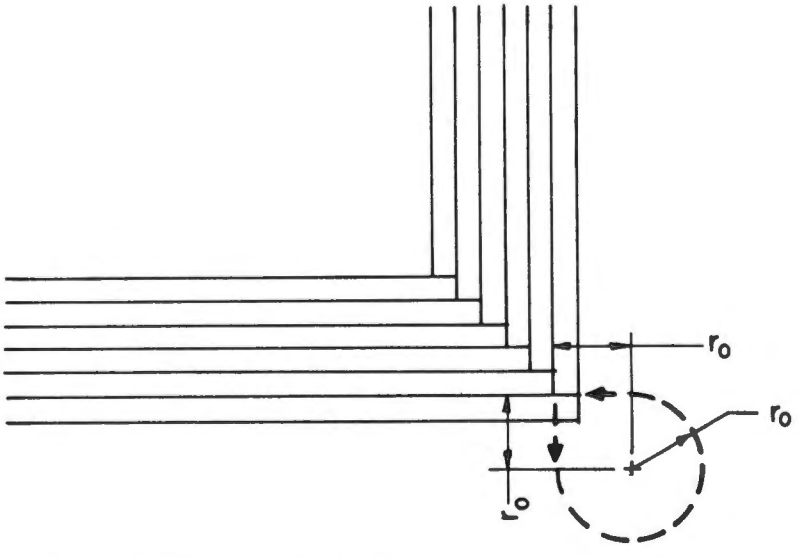

FIGURE 8. Continuous turn of 270 degrees.

efficiency falls to that of 270 degree turns (6). One must remember that Hunt's developments are for rectangular-shaped fields. In odd-shaped fields where corners are greater than 90 degrees, continuous turns will be more practical but will still require an occasional turn strip or pass to work an unprocessed area. This is because the radius of the turn decreases with each turn. To follow exactly the radius of the preceding turn, the effective turning center of the two passes must be the same. This requires a reduction in turning radius by the width of the implement on each succeeding pass. The reduction in turning radius continues until the minimum turning radius is reached; at which point an extra pass becomes necessary to increase the radius of the turn. The number of passes possible before requirement of an extra pass is related to the angle of the corner (6). The smaller the angle of the corner, the more extra passes that will be required. In 1922, Leo Adhart laid out principles for plowing in a circuitous pattern in an odd-shaped field (1).

CHAPTER IV

ANALYSIS OF THE PROBLEM

I. SOIL LOSS PREDICTION

The Universal Soil Loss Equation has become a basic tool for determining effective soil conservation measures. One must remember, however, that this equation is based on statistical studies of runoff plots and subject to the limitations of such a study. In practice it is seldom possible to find a particular area where the measured soil loss agrees with the predicted soil loss. Over a period of years, however, close correspondence between average predicted and measured runoff could be expected. The soil loss prediction equation allows comparison of different sets of land use and management practices. For example, is a cropping system employing rotation of oats, corn and pasture in a three year cycle more likely to cause soil loss than a rotation of soybeans, pasture and corn? The soil loss prediction is of value in selecting one set of practices over another, but may not predict the exact soil loss in tons per acre per year.

The Universal Soil Loss Equation has been proved and made applicable to most land management schemes. Its implementation in this investigation will be documented in the section on computer programs.

II. PATTERN EFFICIENCY

From the review of literature it must be concluded that the best prediction of pattern efficiency will be based on a simple geometric relationship. However, the investigations previously cited have all addressed themselves to the rectangular field layout. While in many locations this is the predominant layout, there is a sufficient number of nonrectangular fields to prevent the previously discussed solution being a general one. It was the intention of this study to investigate general methods of predicting pattern efficiency.

A particular problem in this investigation was to determine the measure of efficiency which best described the efficiency reflected by the operating pattern. As noted previously, there are many contributors to lost time in field operations. For purposes of this study, all losses were disregarded except those attributed to pattern operation. In the same field, it would be likely that refueling stops, personal operating time, and other such losses would be the same regardless of field pattern. The losses that have been attributed most to pattern operation are those associated with time lost in turning. While there can be other time losses associated with pattern operation, turning losses were treated as the primary loss in this investigation.

The theoretical time to actually work a given area must be the same for any pattern orientation. This theoretical time considers only the area processed, the implement width, and speed. Regardless of the pattern of operation, a given field has only a certain area to be processed.

Previous studies related primarily to rectangular fields and consider the average row length and total processed area to find the number of turns. In an irregularly-shaped field, the average row length may not be representative of the number of turns. For this investigation the two important geometric properties of a field were the area and the maximum field width. The area is important for calculating the theoretical operating times as follows:

$$\text{Theoretical Time} = \frac{\text{Area x Dimensional Constant}}{\text{Operating Speed x Implement Width}} \quad 4.1$$

If the operating speed is expressed in miles per hour and the implement width is in feet, then:

$$\text{dimensional constant} = \frac{\text{43560 square feet per acre}}{\text{5280 feet/mile}} \quad 4.2$$

The area is usually known to farm operators or can be determined from land surveys or soil maps.

The maximum field width can be used to determine the number of turns. Regardless of the pattern, there must be one turn for each operating pass:

$$\text{Number of Turns} = \frac{\text{Maximum Field Width}}{\text{Implement Width}} \quad 4.3$$

There are cases where additional turns must be made (as to avoid obstructions) and provision must be made for this in computer analyses.

Using the parameters field area and maximum field width, the theoretical operating time of any field can be calculated. The particular application relative to operating pattern is discussed below.

Headland Pattern

Time losses in the headland pattern include those attributed to turning at the end of rows, to plowing back-furrows, and, if turn strips are also tilled, the time losses in making these turns. The number of turns required is defined by Equation 4.3. The time involved in each turn can be calculated in a manner described by Hunt (6). The average time of each turn is the average distance traveled in the turn strip divided by the turning speed.

$$\text{Average Turning Time} = \frac{\text{Average Distance} \times \text{Dimensional Constant}}{\text{Speed of Turn}} . \qquad 4.4$$

As mentioned previously, the average distance of the turn is determined by the field width and the number of lands in the field width (refer to Figure 1, page 15). The average distance is:

$$1/2 \times \frac{\text{Field Width}}{(2 \times n - 1)} \qquad 4.5$$

where n = number of back-furrowed lands.

It might be noted that this distance is only the straight line distance between turns and does not allow extra time to orientate the machine toward the next row. Although this will undoubtedly introduce some degree of error, the percent of time spent in orientation would not greatly affect the time spent turning.

Additional time is lost in processing dead furrows. These dead-furrow strips are unprocessed areas resulting when soil is thrown away from the center of the land. The extra pass required is lost time

which must be attributed to the pattern. The time lost is calculated by finding the average row length and using the operating speed as below:

If number dead furrows = n - 1

where n = number of lands, then

$$\text{Average Row Length} = \frac{\text{Area}}{\text{Maximum Field Width}} \quad . \qquad 4.6$$

$$\text{Then, time lost} = \frac{(n-1)\ (\text{Area/field width})}{\text{Operating Speed}} \quad . \qquad 4.7$$

If turn strips are cultivated, the time lost in turns at the ends is calculated in a similar manner.

Considering the losses mentioned above the pattern efficiency can be calculated as below:

$$\text{Pattern Efficiency} = \frac{\text{Sum of all Turning Time Losses}}{\text{Operating Time + Turning Time Losses}} \times 100 \text{ percent.} \qquad 4.8$$

Continuous Pattern

The continuous pattern is probably the simplest and most common practice in use, but its analysis presents many problems. The difficulty lies in calculating the turning time. In this investigation it was assumed that the turning time was the only major time loss for this particular pattern. Referring to Figure 5 (page 22), many types of turns are possible, each requiring a different analysis. Field observations indicated that 180 degree turns were most common; consequently, this turn was used in predicting pattern efficiency.

Referring to Figure 5 (page 22), the travel for each turn was established as follows:

$$\text{Arc Travel} = 360° - 2 \times \text{Arc Sin} = \left[\frac{\text{Implement Width}}{\text{Turn Diameter}/2}\right]. \qquad 4.9$$

Time of travel would then be:

$$\text{Travel Time} = \frac{\pi \times \text{Turn Diameter} \times \text{Arc Travel}/360}{\text{Turning Speed}} \times \text{Dimensional Constant}. \qquad 4.10$$

While this procedure is surely more cumbersome than a simple estimation based on field data, it does have specific advantages. As will be seen in Chapter VI, field conditions are generally not sufficiently consistent to determine a theoretical turning time. This equation provides a time independent from operator influence and field conditions.

The turning diameter used in equation 4.9 was the turning diameter of the outside driven wheel. This was done so that the speed (noted by the operator) of the rear wheels could be used as the turning speed.

Circuitous Pattern

In the analysis of the circuitous pattern, Hunt's assumptions and analysis were followed. As suggested by Hunt, 270-degree turns were used in the analysis because 90-degree turns could not be consistently maintained.

CHAPTER V

COMPUTER PROGRAMS

I. COMPUTER USAGE

A computer program was written to evaluate alternate cropping patterns with respect to suitable soil conservation measures and associated pattern efficiency. The computer program permits several alternatives to be presented from which the "best" solution may be selected. This computer program was written for an interactive computer system. In this type of system the computer operator communicates with the computer by use of a terminal such as a teletype; and enters data, receives results, and institutes program control while the program is being executed. This type of system is opposed to a batch-type system where all control, program, and data are entered at some time separate from execution time. The programs for this project were written using the Fortran IV language implemented through the IBM Call-360 system at The University of Tennessee computer facility. As can be noted in the program print-out, there are several differences of the Call Fortran language and Standard Fortran IV. These special commands and symbols are described in the IBM publication (19).

II. PROGRAM FOR SOIL LOSS CALCULATIONS

The manual computation of soil loss requires searching previously compiled tables and introducing these data into the general formula as

described in Equation 3.1. Similarly, the computer program contains search and retrieval procedures for existing tables to find data for solution of soil runoff. Three tables, or files, must be established; one table contains storm data indexed by counties, another lists expected erosion for particular soil types, and another lists effects of conservation practices indexed by type of practice and slope. To simplify the program, the cropping-management factor must be located in available tables listed in Predicting Soil Losses Under Different Management Systems (7). The tecnniques for determining the cropping-management factor have been described in the above publication but their calculation requires much data entry and computer correspondence which was avoided by use of established values in table form. The program was designed to be simple in design and can be rerun by restarting. A copy of this program as it appears as a computer listing is located in Appendix B with a corresponding logic flow diagram. The numbers at the left of the program listing refer to program line numbers and are not related to program statements.

III. PROGRAM FOR PATTERN EFFICIENCY CALCULATION

This program calculates pattern efficiency using either the continuous, circuitous, or headland pattern. The efficiencies were calculated using the method of analysis previously presented. The operator has the option of selecting the particular pattern to be used and also to sum the efficiencies of several different fields into a combined efficiency. Occasions may arise where additional turns may be necessary, such as to avoid obstacles. These can be added to the total

turns at the appropriate time in the program execution. Appendix C contains a program listing and the logic flow diagram for this program.

CHAPTER VI

DISCUSSION OF ANALYSIS AND EXAMPLE PROBLEM

Firld trials were conducted at the Milan Field Station to evaluate the relationship between predicted values and measured values of pattern efficiency. Those trials consist of both soil loss studies and field efficiency studies. Because of the long-term nature of the problem and because the Universal Soil Loss Equation is widely accepted, no evaluation was made of predicted and absolute soil losses.

During the 1975 growing season, various field operations were timed to compare actual field data with that predicted by the previously discussed model. All measurements were made on row crop plots; therefore, the tillage pattern analyzed was the continuous pattern. Very little repetitive testing was possible during this growing season because of work scheduling and inclement weather during the growing season. The test plots varied from large wide fields with many turns as Field "A" (Table 1), to narrow small fields with few turns as in Field "E" (Table 1). In general, all fields had been orientated so as to facilitate machine operations with little regard to soil losses. Row orientation varied among plots and varied within plots, so as not to make row orientation important in preventing soil loss. The predicted values compiled in Table 1 have been based on information gathered during these field trials. For a summation of field conditions and measurements, refer to Appendix D.

TABLE 1. Summation of field data.

Location	Predicted Times (Hours)				Observed Time (Hours)			
	Average Turning Time (mins.)	Operating Time	Total Turning Time	Pattern Efficiency[a] (%)	Average Turning Time (mins.)	Operating Time	Total Turning Time	Pattern Efficiency (%)
Field A-1st Operation	0.14	1.35	0.13	89.7	0.31	1.69 (24.9)[b]	0.30 (120.1)	81.9
Field B-1st Operation	0.14	0.77	0.08	89.7	0.36	0.92 (25.4)	0.18 (128.8)	80.2
Field A-2nd Operation	0.10	1.20	0.10	91.8	0.17	1.56 (29.7)	0.17 (73.3)	88.8
Field B-2d Operation	0.08	0.57	0.04	91.7	0.16	0.71 (25.1)	0.08 (78.72)	88.2
Field C	0.16	0.65	0.06	89.8	0.23	0.87 (33.3)	0.089 (33.6)	89.75
Field D	0.08	1.03	0.08	91.5	0.13	1.17 (13.3)	0.141 (62.9)	87.9
Field E	0.08	0.85	0.03	96.4	0.11	1.11 (30.3)	0.039 (27.74)	96.4

[a]Efficiency was calculated from: Eff = Operating Time/(Operating Time + Turning Time).

[b]Numbers in parenthesis refer to percent error of predicted values: Error = (Observed - Predicted)/Predicted.

It is apparent from Table 1 that field observations do not agree with predicted values for turning time and operating time. This error obviously has resulted from failure to effectively isolate the measured efficiency from factors other than pattern efficiency. This can be illustrated by referring to the turning times for Field A and Field B (Table 1). Note that the predicted total turning time for the first operation on both fields was at least 120 percent below the observed values. The second operation was predicted at 75 percent below the observed values. This difference was the result of having two different drivers. The first driver was an older, more cautious driver and the second was a younger driver who made turns at rapid speed which, at times, damaged more plants.

Pattern efficiency as a geometric relationship cannot be readily isolated from actual field data. Its usefulness lies in comparing two or more operating conditions in the same field or area on the basis of efficient field operations. An example of how this analysis might be used to compare operation patterns is listed below.

Problem Variables

- Field orientation as given in Figure 9
- Implement width 10 feet
- Field contains 20 acres
- Turn diameter 20 feet
- Operating speed 4 miles/hour
- Turning speed 2 miles/hour
- Slope is 4 percent within the direction

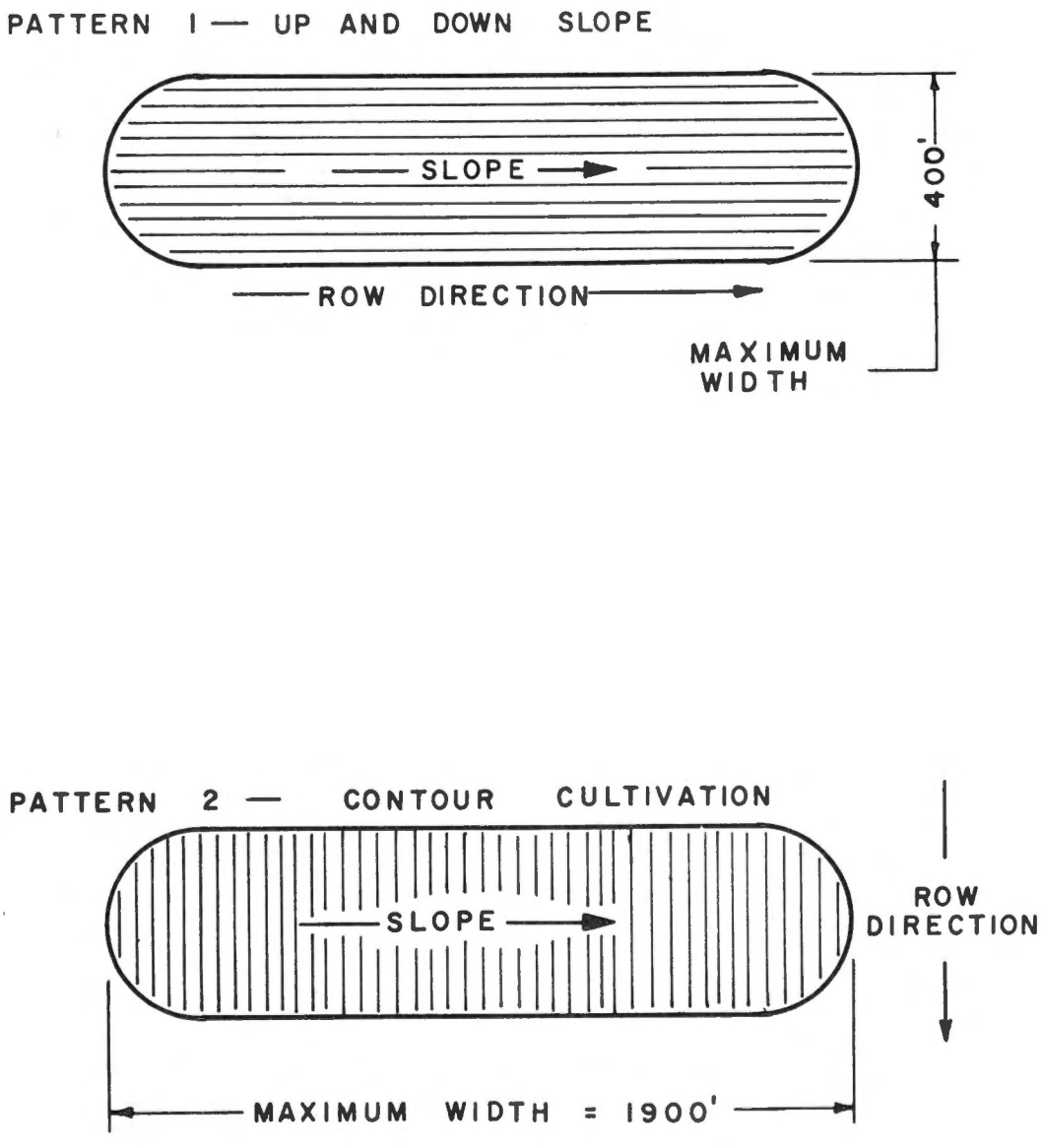

FIGURE 9. Example problem alternatives.

- Soil type is Memphis
- County is Gibson
- Field is planted in continuous soybeans with late-seeded winter cover

FIND:

Soil losses and pattern efficiency resulting from processing according to pattern 1 and pattern 2 (Figure 9).

SOLUTION:

Soil Loss--from Table 4 (Appendix A), the cropping-management factor for continuous Soybeans in West Tennessee is 0.316.

The information is entered in the computer program as indicated in the sample program output. Lines preceded by a question mark (Figure 10) were entered by the operator; other lines were printed by the computer. As can be seen in the output the average annual soil loss under the conditions of pattern 1 would be 46.36 tons per acre. Using the program under conditions of pattern 2 resulted in a runoff of 10.63 tons per acre per year.

Similarly, calculations were performed by the computer to find pattern efficiency. In the program output included in Figure 11, it can be seen that under the conditions of pattern 1 the efficiency is very high at 97.2 percent. The efficiency for pattern 2 was 87.9 percent.

Combining this information, pattern 1 will have a predicted soil loss of 46.36 tons per year and a pattern efficiency of 97.2 percent. Pattern 2, however, should have a soil loss of 10.63 tons per

```
?RUN

ENTER COUNTY
?GIBSON

ENTER TYPE OF SOIL
?MEMPHIS

ENTER SLOPE AND LENGTH OF SLOPE
?4,1900

ENTER CROPPING MANAGEMENT FACTOR
?.316

ENTER CONSERVATION PRACTICE
    UP AND DOWN SLOPE CULTIVATION -- ENTER 1
    CONTOUR CULTIVATION -- ENTER 2
    STRIPCROPPING -- ENTER 3
    TERRACING -- ENTER 4


?1

PREDICTED SOIL LOSS IS 46.36 TONS/ACRE/YEAR

TOLERANCE FOR MAMPHIS SOIL IS BETWEEN
    5.0 TONS/ACRE/YEAR FOR CLASS 1 AND 2 SOILS

    AND 4.0 TONS/ACRE/YEAR FOR CLASS 3 SOIL


STOP
```

FIGURE 10. Typical printout of Soil Loss Program.

```
?RUN

ENTER AREA OF FIELD IN ACRES
?20

ENTER MAXIMUM WIDTH OF FIELD IN FEET
?400

ENTER EFFECTIVE WIDTH OF IMPLEMENT
?10

ENTER OPERATING SPEED IN MILES PER HOUR
?4

ENTER TURNING SPEED IN MILES PER HOUR
?2

ENTER TYPE OF OPERATING PATTERN
    1 FOR CONTINUOUS PATTERN
    2 FOR HEADLAND PATTERN
    3 FOR CIRCUITOUS PATTERN

?1

IF TURN STRIPS ARE CULTIVATED ENTER THE STRIP WIDTH
    IF NOT CULTIVATED ENTER 0.

?0

ENTER APPROXIMATE TURN DIAMETER IN FEET
?20

ENTER NUMBER OF EXTRA TURNS IF REQUIRED
    0.0 OTHERWISE

?0

OPERATING TIME IS 4.125 HOURS
    TURNING TIME IS 0.11896 HOURS
THE EFFICIENCY ASSOCIATED WITH THIS FIELD IS 97.2 PERCENT
IF OTHER FIELDS ARE TO BE CONSIDERED ENTER A1.0, OTHERWISE ENTER 2.0
?1
STOP
```

FIGURE 11. Typical computer printout of Pattern Efficiency Program.

year and an efficiency of 87.9 percent. This information can serve as the basis for evaluating manpower/energy savings, alternate land use or justification for additional soil conservation measures.

CHAPTER VII

CONCLUSION

This study was initiated to write a computer program to implement the "Universal Soil Loss Equation" and to determine methods of predicting pattern efficiency. A workable computer program for soil loss prediction and pattern efficiency calculations was developed and evaluated. The value of these programs will depend on their use in field pattern analysis by the average farmer. The methods developed for predicting pattern efficiency can be used to evaluate alternate operating patterns in an effort to minimize field time; or conversely, these methods can be used to help justify alternate soil conservation methods in light of improved operating efficiency. As agriculture, like industry, becomes more dependent on capital for its productivity, the farmer must make his land and machinery perform at maximum justifiable efficiency to remain a viable economic unit.

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BIBLIOGRAPHY

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APPENDICES

APPENDIX A

UNIVERSAL SOIL LOSS FACTORS

TABLE 2. Rainfall-erosion index factor "R" values of selected Tennessee counties.

County	"R"	County	"R"
Anderson	190	Jefferson	180
Cocke	170	Knox	190
Gibson	250	Loudon	210
Greene	150	Sevier	180
Hamblen	170	Unicoi	150
Hamilton	260	Washington	150

TABLE 3. Soil-erodibility factor (K) values and soil loss tolerance (T) values by soil type ("T" value is allowable loss in tons/acre/year).

Soil Type	"K"	"T"
Decatur	0.32	3
Dickson	0.43	3
Dunmore	0.43	3
Fullerton	0.32	3
Hartsells	0.24	3
Holston Sil.	0.32	4
Memphis	0.37	5
Sequatchie	0.28	4
Talbott	0.43	2

TABLE 4. Typical cropping management factors (C).

Values	Yield	Avg. Annual "C" Value
EAST TENNESSEE		
Meadow, well-established grass--Legume	1-2 tons	0.006
Small grain followed by 2 years in meadow	1-2 ton meadow + 15 + bu. grain	0.047
Tobacco, followed by small grain then meadow	1-2 ton meadow 70+ bu. grain	0.063
Corn, followed by small grain, then meadow	1-2 ton meadow 40 bu. corn	0.105
Soybeans followed by soybean, then meadow	2-3 ton meadow 70 bu. soybean	0.56
Continuous soybean with winter cover	2-3 ton + 75 bu.	0.378
Tobacco continuous without winter cover		0.665
WEST TENNESSEE		
Small grain followed by 2 years in meadow	1-2 tons 15+ bu. grain	0.049
Continuous soybean with winter cover		0.361
Continuous Fallow 1 or more years		1.000

TABLE 5. Conservation practices factor (P) value for Tennessee.

Slope Percent	Contour Farming or Terracing	Contour Stripcropping	Field Stripcropping
1.1 - 2.0	0.60	0.30	0.45
2.1 - 7.0	0.50	0.25	0.375
7.1 - 12.0	0.60	0.30	0.45
12.1 - 18.0	0.80	0.40	0.60
18.1 - 24.0	0.90	0.45	0.675

NOTE: Values shown in Appendix A are a summary of information given in Reference 7 in the Bibliography.

APPENDIX B

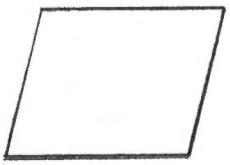
COMPUTER PROGRAM TO CALCULATE SOIL LOSS

Explanation of Logic Flow Chart Symbols

START OR END OF PROGRAM



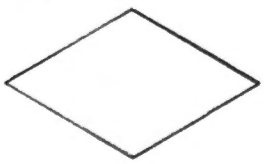
INPUT OR OUTPUT OPERATION



ANY PROCESSING OPERATION



A DECISION



CONNECTION BETWEEN PARTS OF PROGRAM
(LETTERS USED TO CONNECT BETWEEN PAGES,
NUMBERS USED OTHERWISE)



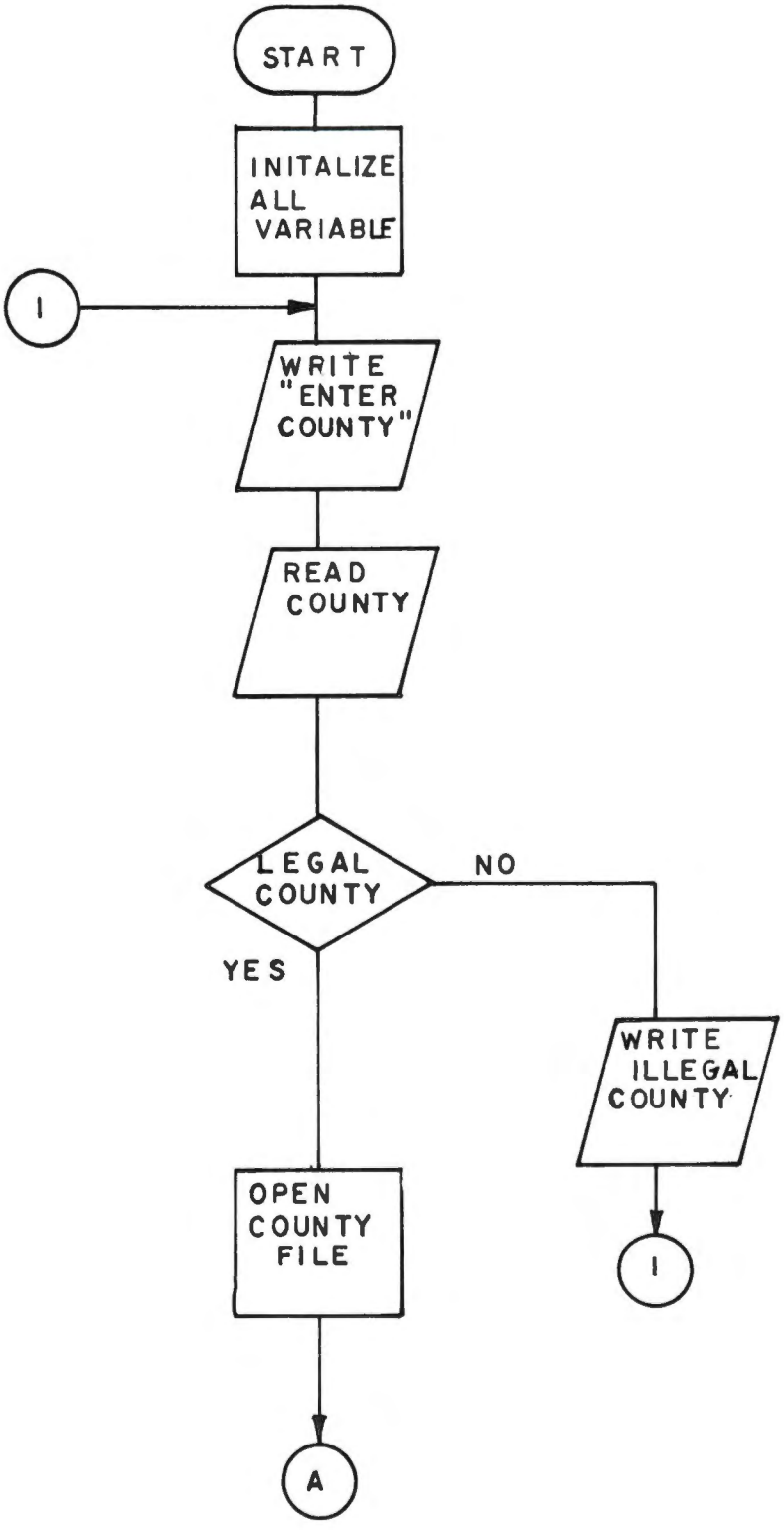


FIGURE 12. Logic flow diagram for soil loss program.

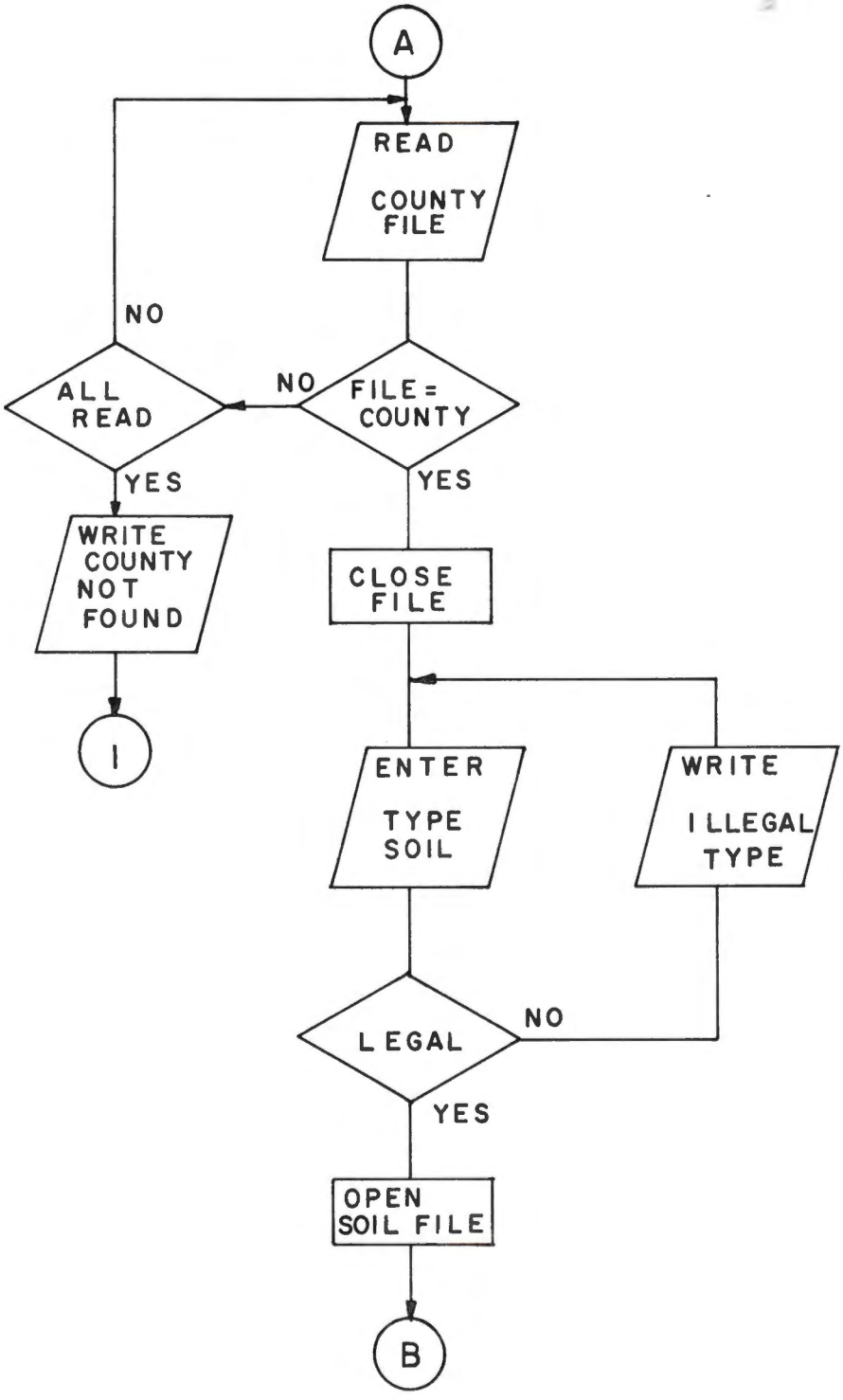


FIGURE 12. Continued.

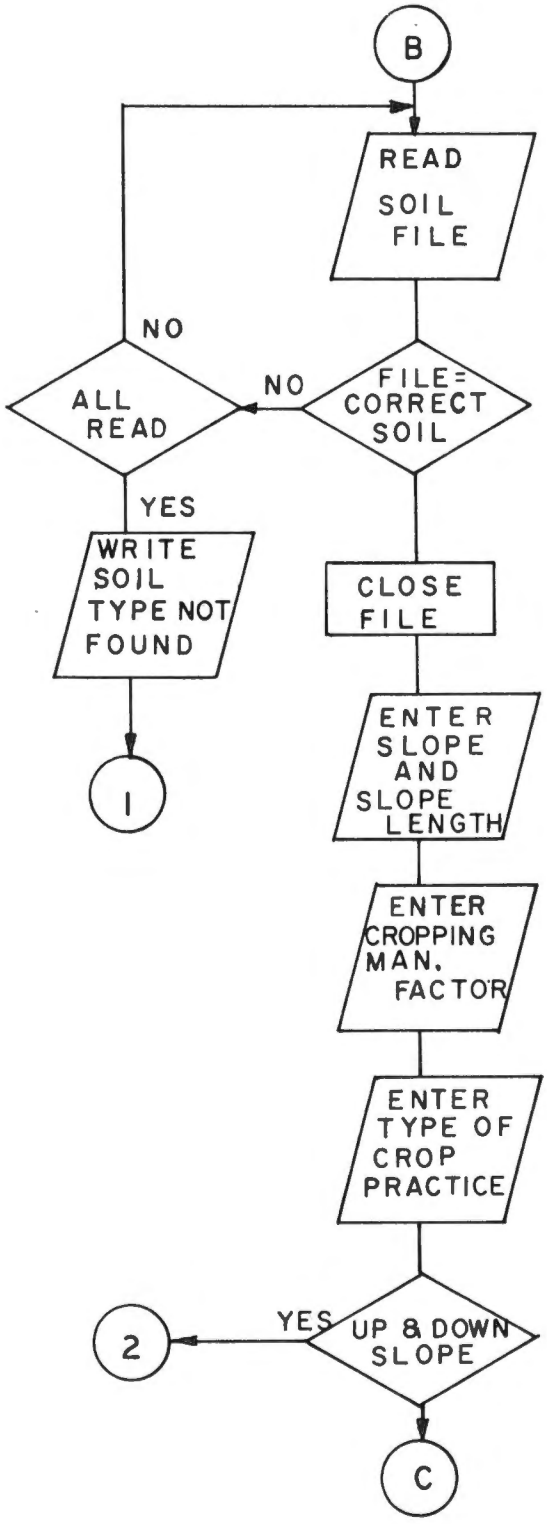


FIGURE 12. Continued.

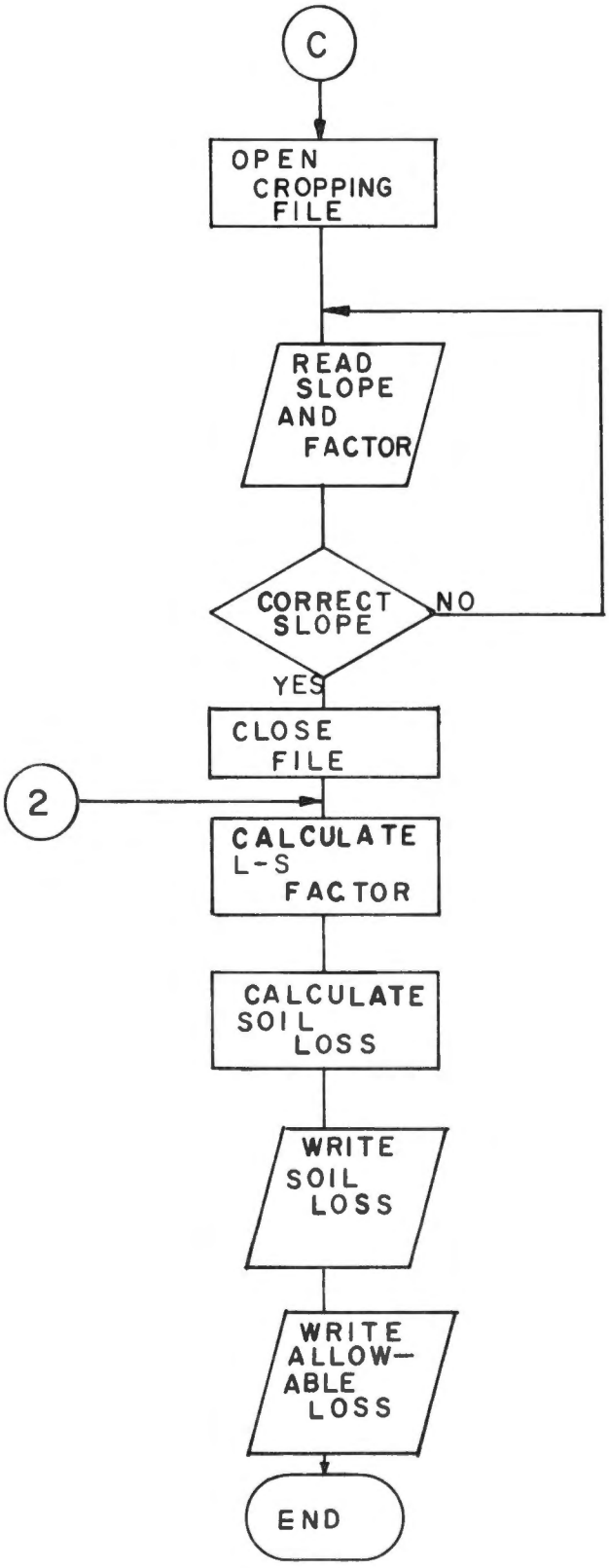


FIGURE 12. Continued.

```
      DIMENSION COUNTY(3), PSOIL(4), TSOIL(3), FAC(3)
      REAL L,LOSS, LENGTH,K
"FIND COUNTY AND RAINFALL FACTOR
      WRITE(6,301)
 301  FORMAT(' ENTER COUNTY')
     1 READ(5,100,ERR=2) COUNTY
 100  FORMAT(A4)
      GO TO 3
     2 WRITE(6,300)
 300  FORMAT(' ILLEGAL COUNTY NAME-RETYPE')
      REWIND 4
      GO TO 1
   3  CALL OPEN(4,'RAIN','INPUT')
   4  READ(4,110,END=5) CONTY, RFAC
 110  FORMAT(3A4,F3.0)
      GO TO 6
   5  WRITE(6,310)
 310  FORMAT('OCOUNTY NOT FOUND-RETYPE')
      REWIND 4
      GO TO 1
   6  IF(COUNTY.NE.CONTY(1)) GO TO 4
      CALL CLOSE(4)
"FIND SOIL-ERODIBILITY FACTOR AND LOSS TOLERANCE
      WRITE(6,311)
 311  FORMAT('ENTER TYPE OF SOIL-MUST TAKE UP AT LEAST 12 SPACES')
   7  READ(5,115,ERR-8) TSOIL
 115  FORMAT(4A4)
      GO TO 9
   8  WRITE(6,320)
 320  FORMAT('ILLEGAL NAME-RETYPE')
      REWIND 4
      GO TO 7
   9  CALL OPEN (4,"SOIL','INPUT')
  10  READ(4,120,END=11) PSOIL,QUALIF,K,T1,T2
 120  FORMAT(4A4,A4,F4.2,IX,F1.0,1X,F1.0)
      GO TO 12
  11  WRITE(6,330)
 330  FORMAT ('SOIL NOT FOUND-RETYPE')
      REWIND 4
      GO TO 7
  12  IF(PSOIL(1).NE.TSOIL(1)) GO TO 10
      IF(PSOIL(2).NE.TSOIL(2)) GO TO 10
      IF(PSOIL(3).NE.TSOIL(3)) GO TO 10
      IF(PSOIL(4).NE.TSOIL(4)) GO TO 10
  13  CALL CLOSE (4)
      WRITE(6,350)
 350  FORMAT('CENTER SLOPE AND LENGTH OF SLOPE')
```

```
 1000  READ(5,*,ERR=14) SLOPE,LENGTH
       GO TO 15
       14 WRITE(6,360)
  360  FORMAT('0ERROR IN TYPING-RETYPE')
       GO TO 1000
   15  WRITE(6,370)
  370  FORMAT('ENTER CROPPING MANAGEMENT FACTOR')
 1010  READ(5,*,ERR=16)CPFAC
       GO TO 17
   16  WRITE(6,360)
       GO TO 1010
   17  WRITE(6,375)
  375  FORMAT('0ENTER CONSERVATION PRACTICE FACTOR'/'  UP AND -
      DOWN SLOPE CULTIVATION--ENTER 1'/1  CONTOUR CULRIVATION -
      ENTER 2'/'  STRIPCROPPING -- ENTER 3'/'  TERRACING -
      ENTER 4'/
   18  READ(5,155,ERR=18)
  155  FORMAT(I1)
       GO TO 20
   19  WRITE(6,360)
       GO TO 18
   20  IF(I.GT.1)  GO TO 1020
       CFAC=1
       GO TO 1030
 1020  CALL OPEN(4,'CONPRA','INPUT')
   21  READ(4,160,ERR=22)SLO,FAC
  160  FORMAT(F3.1,3(1X,F5,3))
       GO TO 23
   22  WRITE(6,360)
       GO TO 21
   23  IF(SLOPE.GT.SLO) GO TO 21
       CALL CLOSE(4)
       I=I-1
       CFAC=FAC(I)
       "FIND LS
 1030  L=SORT(LENGTH/72.6)
       S=(0.43 + 0.30*SLOPE + 0.043*SLOPE**2)/6.613
       "FIND SOIL LOSS
       LOSS=FRAC*K*L*S*CFAC*CPFAC
       "WRITE OUT DATA
       WRITE(6,380) LOSS
  380  FORMAT('OPREDICTED SOIL LOSS IS ',F5,2,'TONS/ACRE/YEAR')
       WRITE(6,390) PSOIL,T1,T2
  390  FORMAT('OTOLERANCE FOR ',4A4,'SOIL IS BETWEEN'/5X,F4.1,'-
      TONS/ACRE/YEAR FOR CLASS 1 AND 2 SOIL'/10X,'AND',F4.1,'TONS/-
      ACRE/YEAR FOR CLASS 3 SOIL')
       END
```

APPENDIX C

COMPUTER PROGRAM TO CALCULATE PATTERN EFFICIENCY

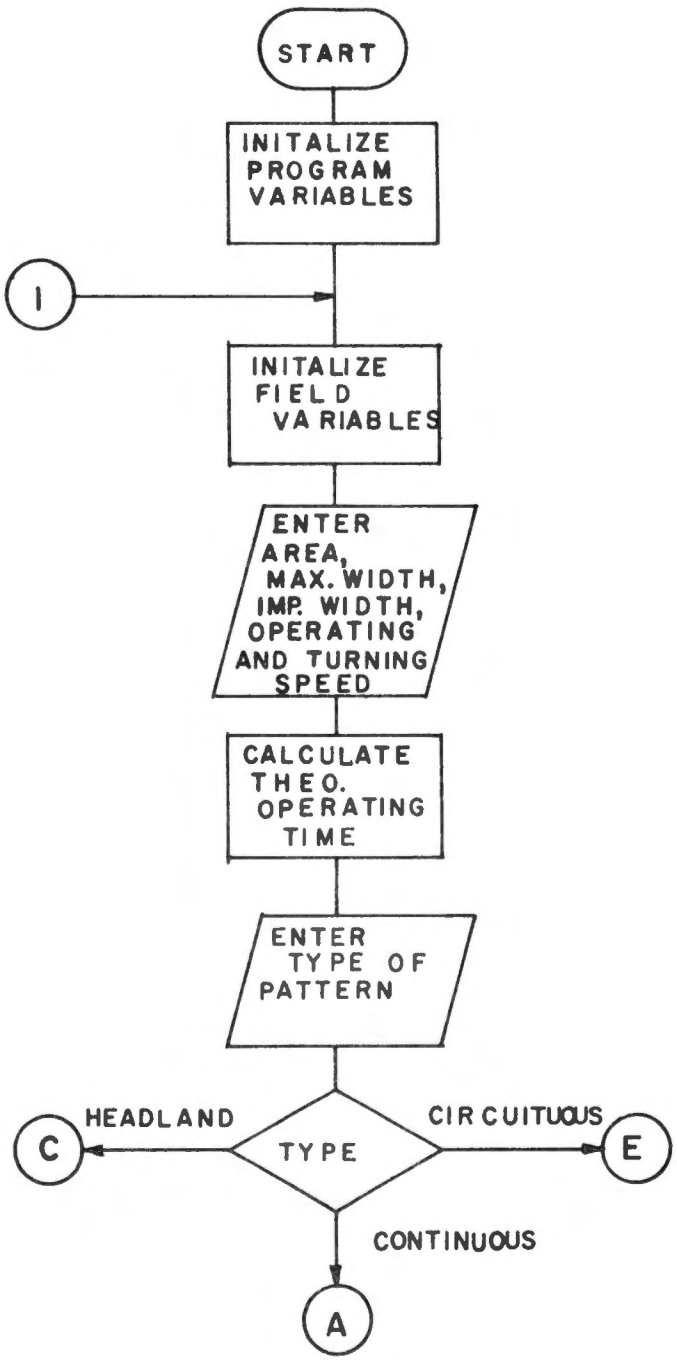


FIGURE 13. Logic flow chart of pattern efficiency program.

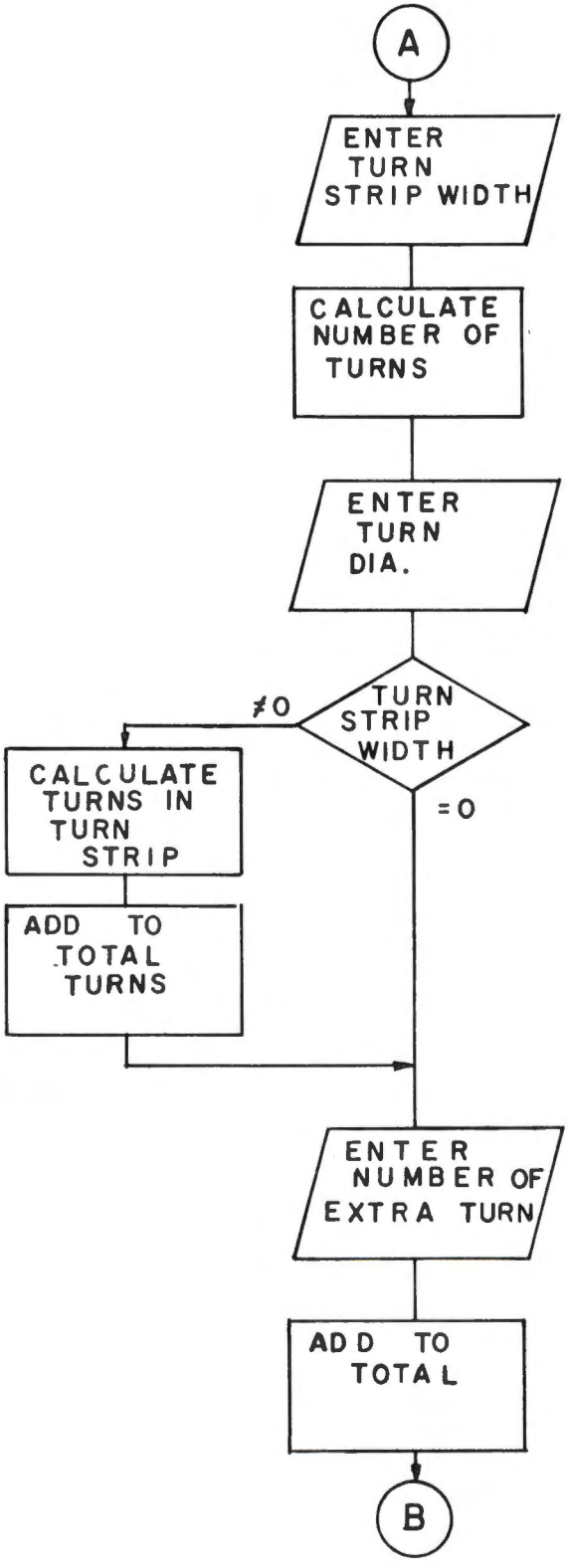


FIGURE 13. Continued.

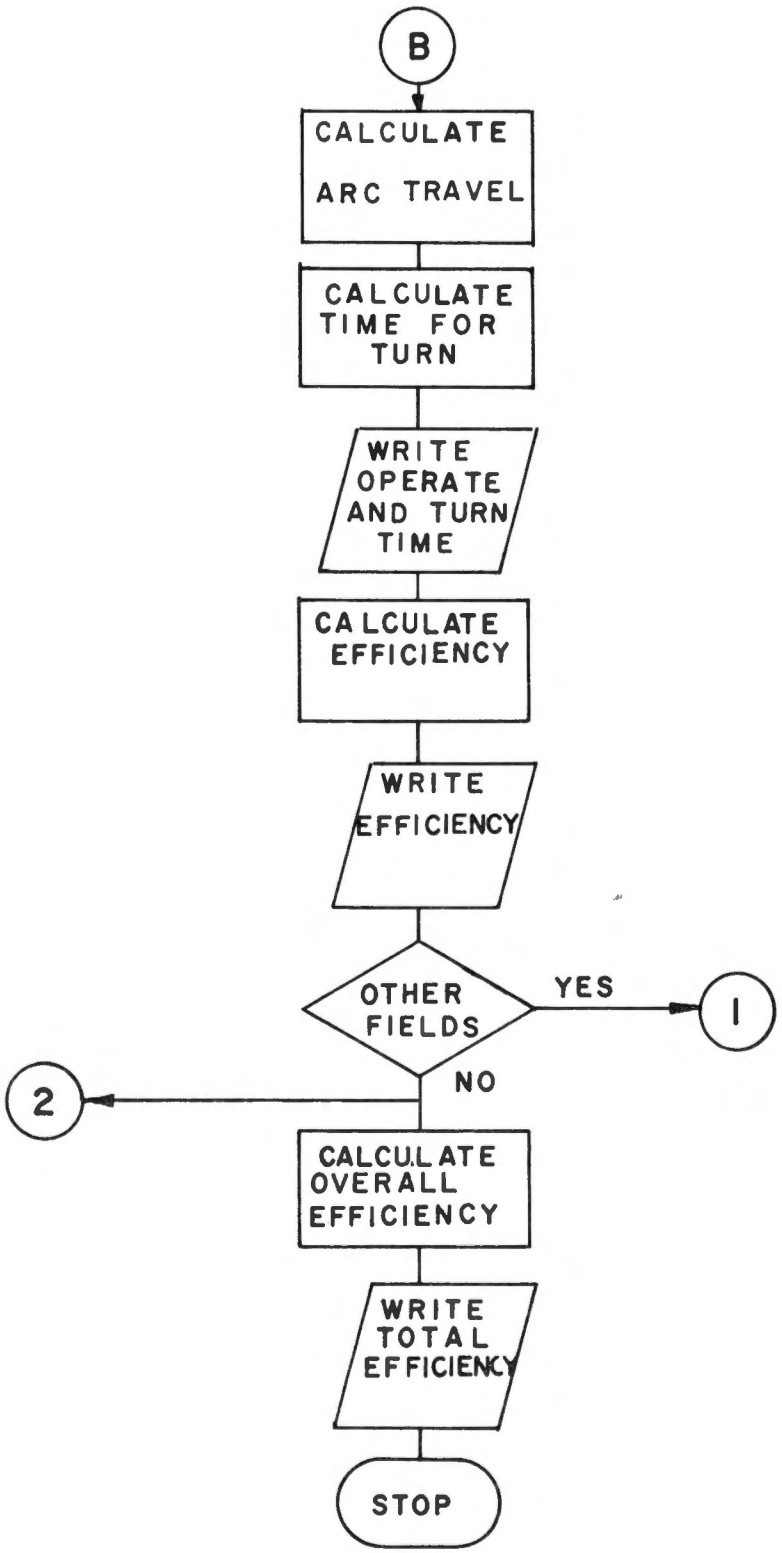


FIGURE 13. Continued.

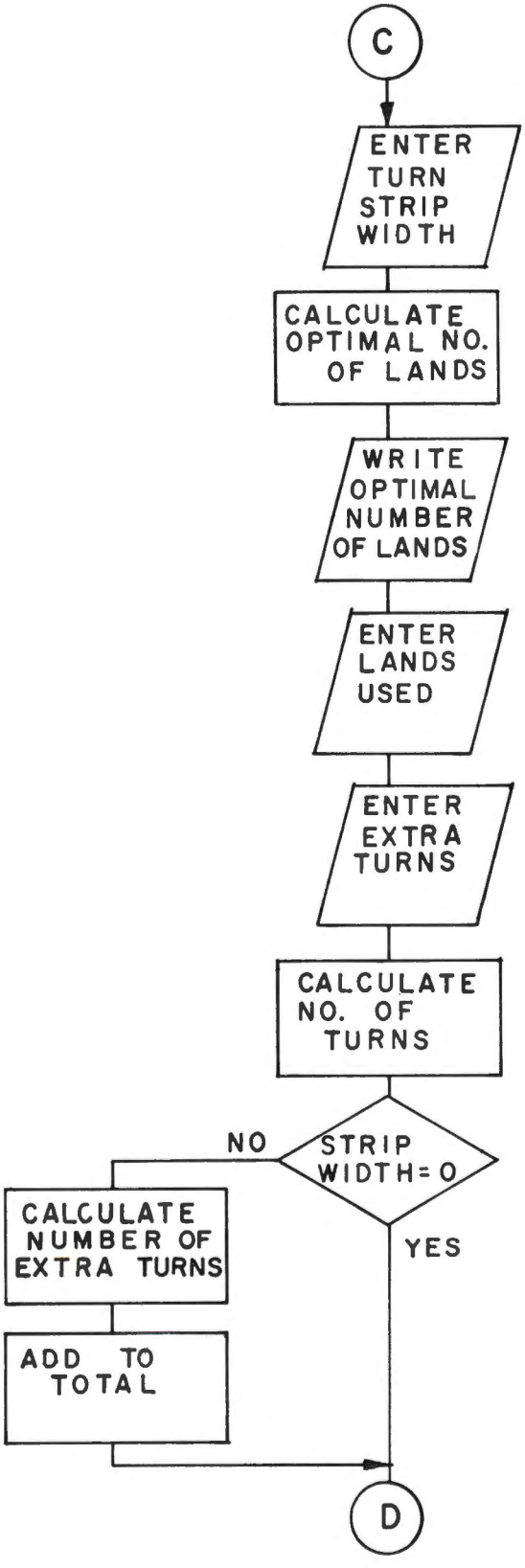


FIGURE 13. Continued.

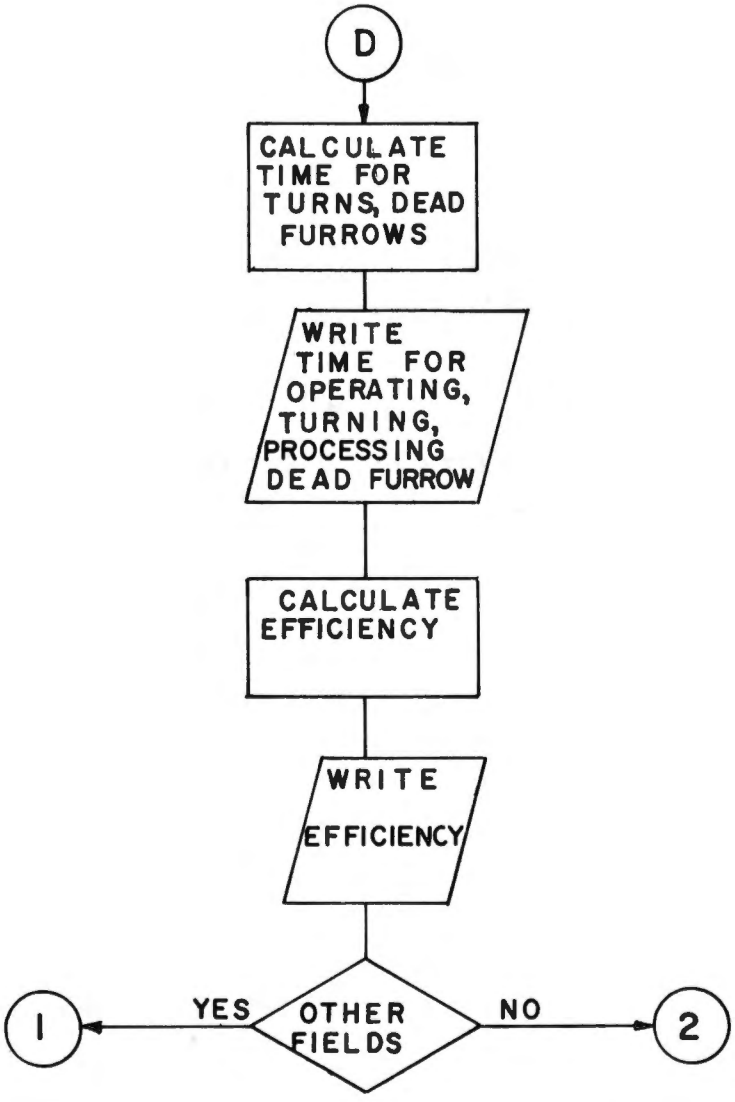


FIGURE 13. Continued.

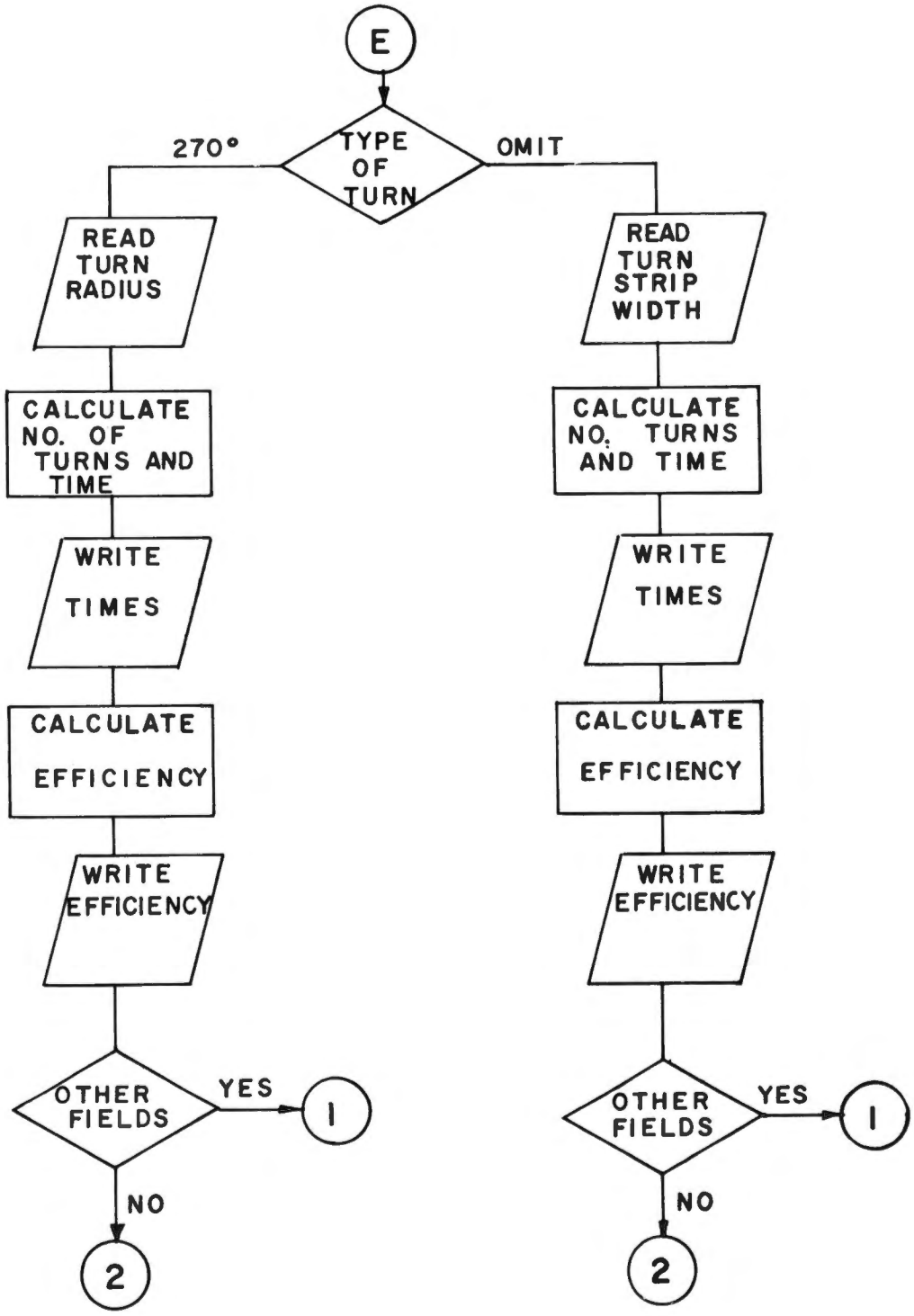


FIGURE 13. Continued.

```
1          REAL MAXWID,IMPWID,LANDS
4          TIMEOT = 0.
7          TIMETT=0.
10   100   TIMEO=0.
13         TIMET=0.
16         TIMEE=0.
19         TIMED=0.
22         EFF=0.
25         WRITE(6,600)
28   600   FORMAT('OENTER AREA OF FIELD IN ACRES')
31         READ(5,*) AREA
34         WRITE(6,605)
37   605   FORMAT('OENTER MAXIMUM WIDTH OF FIELD IN FEET')
40         READ(5,*) MAXWID
43         QEIRW(6,610)
46   610   FORMAT('OENTER effective width of implement')
49         READ(5,*)IMPWID
52         WRITE(6,615)
55   615   FORMAT('OENTER OPERATING SPEED IN MILES PER HOUR')
58         READ(5,*) SPDOP
61         WRITE(6,620)
64   620   FORMAT('OENTER TURNING SPEED IN MILES PER HOUR')
67         READ(5,*) SPDTN
70         TIME=(AREA * 43560.)/(5280*SPDOP*IMPWID)
73         WRITE(6,625)
76   625   FORMAT('OENTER TYPE OF OPERATING PATTERN'/'   1 FOR -
79        CONTINUOUS PATTERN'/'  2 FOR HEADLAND PATTERN'/'   3 FOR -
82        CIRCUITOUS PATTERN')
85         READ(5,*) INDEX
88         GO TO (110,150,175),INDEX
91   110   WRITE(6,630)
94   630   FORMAT('OIF TURN STRIPS ARE CULTIVATED ENTER THE STRIP -
97        WIDTH.'/'   IF NOT CULTIVATED ENTER 0.')
100        READ(5,*) SWIDTH
103        WRITE(6,632)
106   632  FORMAT ('OENTER APPROXIMATE TURN DIAMETER IN FEET')
109        READ(5,*) DIA
112        TURNS = AINT(MAXWID/IMPWID + 0.9)
115   115  IF (SWIDTH.EQ.0.0) GO TO 117
118        TURNS = TURNS + AINT(SWIDTH/IMPWID + 0.9)*2.0
121        WRITE(6,637)
124   638  FORMAT ('ENTER TRACTOR WHEEL SPACING IN INCHES')
127        READ(5,*)TRAWID
130        TRAWID = TRAWID/12.
133   117  WRITE(6,635)
136   635  FORMAT('OENTER NUMBER OF EXTRA TURNS IF REQUIRED', -
139       /' 0.0  OTHERWISE')
```

```
142       READ(5,*) ADDIT
145       TURNS = TURNS + ADDIT
148       OD = DIA + (IMPWID-TRAWID)
151       ARCRAT = (360. - 2.*57.2*ARSIN(IMPWID/(OD/2.)))/360.
154       TIMET = (TURNS*3.14159*DIA*ARCRAT)/(5280.*SPDTN)
157       WRITE(6,640) TIMEO,TIMET
160  640  FORMAT('OOPERATING TIME IS',F7.3,'HOURS'/' TURNING -
163      TIME IS',F7.3,'HOURS')
166       EFF = (TIMEO - TIMET)/TIMEO * 100.
169  120  WRITE(6,645) EFF
172  645  FORMAT9'OTHE EFFICIENCY ASSOCIATED WITH THIS FIELD IS'-
175      ,1X,F4.1,'   PERCENT')
178       TIMEOT = TIMEOT + TIMEO
181       TIMETT = TIMETT + TIMET + TIMED + TIMEE
184       WRITE(6,655)
187  655  FORMAT('OIF OTHER FIELDS ARE TO BE CONSIDERED ENTER A -
190      1.0'/'   IF NOT ENTER A 2.0'
193       READ(5,*) IN
196       GO TO (100,200),IN
199  150  WRITE(6,630)
202       READ(5,*) SWIDTH
205       OPLAND = SORT(((MAXWID**3)*SPDOP)/(43560.*AREA*IMPWID*SPDTN))
208       OPLAND = AINT(OPLAND + 0.5)
211       WRITE(6,660) OPLAND
214  660  FORMAT('OTHE OPTIMAL TOTAL NUMBER OF LANDS IS ',F4.1,/-
217      'ENTER ACTUAL NUMBER OF LANDS USED')
220       READ(5,*) LANDS
223       WRITE(6,635)
226       READ(5,*) ADDIT
229       TURNS = AINT(MAXWID/IMPWID + 0.9) + ADDIT
232       WRITE(6,632)
235       READ(5,*) DIA
238       IF(SWIDTH.EQ.0.) TURNS=AINT(SWIDTH/IMPWID+0.9)*2.+TURNS
241       IF(SWIDTH.EQ.0.) GO TO 174
244       TURNS = TURNS + AINT(SWIDTH/IMPWID + 0.9)*2.
247  174  TIMET = (3.14159*DIA/2. + MAXWID/(2.*LANDS) - DIA) * -
250      TURNS/(5280.*SPDTN)
253       TIMED=((LANDS-1)*AREA*43560.)/(2.*MAXWID*5280.*SPDTN)
256       WRITE(6,690) TIMEO,TIMET,TIMED, TIMEE
259       EFF=(TIMEO*100.)/(TIMEO + TIMED + TIMET)
262       EFF = (TIMEO*100.)/(TIMEO + TIMET + TIMED + TIMEE)
265  175  WRITE(6,675)
268  675  FORMAT('OENTER 1 IF 270 DEGREE TURNS ARE USED'/' OR ENTER-
271  2    IF DIAGONAL TURN STRIPS ARE USED')
274       READ(5,*)IN
277       GO TO (190,180),IN
280  180  WRITE(6,680)
283  680  FORMAT('OWHAT IS THE TURN STRIP WIDTH')
```

```
286         READ(5.*) SWIDTH
289         ROUNDS=(MAXWID - SWIDTH)/(2*IMPWID)
292         TIMET = (4*FOUNDS*SWIDTH)/(5280.*SPDTN)
295         TIMET = TIMET + (3.*SWIDTH**2)/(IMPWID*2.*5280.*SPDTN)
298         TIMED = (2*1.414 * MAXWID)/(5280. * SPDOP)
301         TRIPS = IFIX(SWIDTH/IMPWID + 0.99)
304         TIMEE = (1.414*MAXWID)/(2*5280.*SPDOP)
307         WRITE(6,690) TIMEO,TIMET,TIMED,TIMEE
310  690    FORMAT('OOPERATING TIME IS',F7.3, 'HOURS'/'  TURNING-
313        TIME IS',F7.3' HOURS'/'   TIME FOR TILLING DEAD FURROWS-
316        IS',F7.3,' HOURS'/'  OTHER TIME LOSSES ARE',F73.,' HOURS')
319         EFF = (TIMEO * 100.)/(TIMEO + TIMET + TIMED + TIMEE)
322         GO TO 120
325  190    WRITE(6,695)
328  695    FORMAT('WHAT IS TURNING RADIUS')
331         READ(5,*) RADIUS
334         TURNS = (MAXWID * 2.)/IMPWID
337         TIMET = TURNS * (1.5*3.14159*RADIUS + 2.*RADIUS - IMPWID)/-
340        (5280. * SPDTN)
343         WRITE(6,640) TIMEO, TIMET
346         EFF = (TIMEO * 100.)/(TIMEO + TIMET)
349         GO TO 120
352  200    WRITE(6,700) TIMEOT,TIMETT
355  700    FORMAT('OOVERALL OPERATING TIME IS',F7.3,' HOURS'/'-
358        TIME LOST IS',F7.3,' HOURS')
361         EFFT = (TIMEOT*100.)(TIMEOT + TIMETT)
364         WRITE(6,710) EFFT
367  710    FORMAT('OVERALL EFFICIENCY ASSOCIATED WITH THIS AREA IS'-
370        ,F4.1,' PERCENT')
370         END
```

APPENDIX D

DATA SUMMATION

TABLE 6. Summation of collected data.

Field Use	Field A Row Crop	Field B Row Crop	Field C Row Crop	Field D Row Crop	Field E Row Crop
Area (Acres)	11.07	6.75	3.5	11.5	9.5
Field Width (Feet)	792	454	210	846	297
Implement Width (Feet)	13.5	13.5	9.5	13.5	13.5
Turn Diameter (Feet)	24	24	24	24	24
Operating Speed (MPH)					
Trial 1	5	5	4.5	6.8	6.8
Trial 2	3.5	6.8			
Turn Speed (MPH)					
Trial 1	4	4	3.5	6.8	6.8
Trial 2	5.5	6.8			
Operation					
Trial 1	Herbicide Application		Cultivation		
Trial 2	Cultivation		Cultivation		
Operator, Trial 1	A	A	C	C	C
Operator, Trial 2	B	B			
Operating Time (Hours)					
Trial 1	1.690	.922	.873	1.17	1.113
Trial 2	1.560	.713			
Turning Time (Hours)					
Trial 1	.306	.183	.0895	.1418	.0396
Trial 2	.175	.084			
Number of Turns					
Trial 1	60	33	22	64	22
Trial 2	60	31			
Average Turning Time (Minutes)					
Trial 1	.3119	.3624	.2325	.1333	.1176
Trial 2	.1753	.1629			

VITA

Buford Byrle Bradley, Jr., was born in Morristown, Tennessee, on August 6, 1949. He attended public schools in that city and was graduated from Morristown High School in 1967. The following September he entered The University of Tennessee, and in August, 1972, he received the Bachelor of Science degree in Agricultural Engineering. He participated in the Cooperative Engineering Program during his undergraduate studies, working with Sperry-New Holland Machine Company in Lancaster, Pennsylvania.

Upon receiving his undergraduate degree, he accepted a research assistantship at The University of Tennessee and expects to receive his Master of Science degree in Agricultural Engineering in March, 1977. He is a member of the American Society of Agricultural Engineers and has been employed as a design engineer with the American Enka Company of Morristown since August, 1974.