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ABSTRACT

THE AVAILABILITY OF CROP RESIDUE AND
ITS POTENTIAL AS A FUEL

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The problems which could arise if too much crop residue is removed from crop production land has prompted the development of a computer program that provides scientific guidelines for residue removal. Used with a number of figures and tables the computer program not only determines the amount of crop residue available for removal without putting undue stress on the soil's productivity but the program also performs an energy balance on the crop residue removal system. All energy inputs into crop production, harvesting, post-harvest processes, transportation, nutrient replacement and conversion are accounted for.

Through numerous sample runs it has been determined that each field proposed for crop residue removal should be considered on a case-by-case basis. It has also been determined that crop residue from some soils and locations can safely be removed. The major concerns are potential increases in wind and water erosion and damage to the soil structure.

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CHAPTER ONE

INTRODUCTION

Dangers in Removing Crop Residue

There are few natural resources of greater importance to mankind than the soil. In fact, it has been said that ". . . human vanity can best be served by a reminder that whatever his accomplishments, sophistications or artistic pretensions, mankind owes his very existence to a six inch layer of topsoil". The six- to twelve-inch layer of topsoil contains the nutrients which feed the crop, and its proper maintenance determines the success of the entire agricultural endeavor. While it is a very slow process for nature to build up the topsoil, it is often destroyed very rapidly. The deterioration of productivity is usually a result of agricultural mismanagement. One of the agricultural practices which most severely affects that top layer of soil is the removal of too much of the above-ground crop.

The removal of too much of the total crop is becoming a more and more serious concern. In the past few years crop residue has received much attention as a potential energy source (Alich and Inman, 1974; Lipinsky, 1978; Steffgen, 1974). It has been shown that crop residue is a good source of energy, either burned directly for heat or converted into gaseous or liquid form for fuel. However because of low density and wide distribution the temptation of collecting too much residue from one location must be resisted. If not, depletion of the topsoil's productivity may occur.

Scientists generally do not advocate total removal of crop residue from the soil, for it is recognized that it is essential for soil erosion control and maintenance of productive capacity. Therefore, when utilization of crop residue for purposes other than soil maintenance is proposed, the first question scientists confront is, "To what extent can crop residue be removed without adversely affecting soil conservation and reducing productivity?" In addition, when crop residue is proposed as an alternate source of energy, it must be determined whether it can be grown, harvested, collected, transported, converted to a more useful form, and utilized while maintaining a positive energy balance.

In addressing the question, "How much residue can be safely removed?" the following theoretical primary functions of residue are recognized:

- provide surface protection from erosion
- act as a storehouse of nutrients
- stabilize structure and improve tilth
- reduce bulk density
- enhance water infiltration and moisture retention
- provide energy for microorganism activity
- increase cation exchange capacity
- release carbon dioxide.

Because commercial fertilizers are readily available to perform some of these functions, above-ground residue primarily provides surface protection, helps maintain the soil structure, improves water infiltration and reduces evaporation. The crop roots also play a role in fulfilling the soil requirements.

Erosion

Erosion is a process whereby, under the forces of wind and water, topsoil particles are detached from the surface and transported to a new location. While some topsoil loss from erosion in unavoidable, at tolerable levels it will permit crop production to proceed and the soil's productivity to be maintained, or perhaps increased, over time. The amount of soil loss tolerance denotes the maximum level of soil erosion that will permit crop productivity to be sustained indefinitely. Those factors which determine the soil loss tolerance include soil depth, physical properties and other characteristics affecting root development, gully prevention, on-field sediment problems, seeding losses, soil organic matter deductions and plant nutrient losses (Wischmeier and Smith, 1978).

One of the elements which keeps both water and wind erosion within the tolerable soil loss limit is the amount of crop residue on the surface. Crop residue has the tendency to trap detached soil particles and significantly reduce their transport. The residue also breaks the impact from raindrops and prevents wind from disloding soil particles.

Soil Compaction

Besides erosion, soil compaction is a major concern when residue removal is proposed. Soil compaction is an ever-increasing problem with introduction of larger and heavier agricultural machinery.

As the soil is compacted, the bulk density increases, root growth becomes inhibited, which reduces top growth. The higher the bulk density the less defined the structure and the smaller the pore space. This decreases the amount of oxygen and water infiltration, which in turn increases water runoff. With the resulting compaction more power is required to prepare the seed bed. Plant roots are the prime source of residue that combat poor soil structure. When roots alone are insufficient, above-ground residue is also needed.

Nutrient Maintenance

As a result of increasing use of commercial fertilizers, the relative importance of crop residue as a nutrient has been de-emphasized. Where crop residues and manure are the primary sources of plant nutrients, through microbial action, the nutrients are released and utilized by the crops. When commercial fertilizers are used, the crop residue, particularly those high in carbon and low in nitrogen that are left on the field have a tendency to tie-up the nutrients through microbial decomposition. The resulting nitrogen deficiencies occur mostly during the spring and early summer when the previous year's residue are decomposing (Allison, 1973). It should be noted that if not enough residue is left on the soil and erosion therefore increases, the commercial fertilizers will be lost with the soil.

Objectives

The problems which could arise if too much residue is removed have prompted the development of a computer program that will provide scientific guidelines for residue removal. To make this program accessible to the group of people most likely to be harmed by excessive removal of crop residue -- that is, farmers, it was designed to be used on a Texas Instrument's TI-59 programmable calculator. Many cooperative extension offices now have this equipment and trained personnel who can apply it to specific farms. Used in the same fashion as an ordinary calculator, it can be programmed to perform the necessary calculations to determine how much residue can be removed without exceeding soil loss tolerance.

Scientifically Determined Guidelines for Residue Removal

The program consists of the six following sections:

Section 1 - Wind Erosion Analysis;

Section 2 - Water Erosion Analysis;

Section 3 - Total Biomass in the Field;

Section 4 - Residue Available for Removal;

Section 5 - Energy Balance Analysis;

Section 6 - The Transportation System.

The Wind Erosion Section is based on the wind erosion equation, developed and verified by Woodruff and Siddoway. The Water Erosion Section is based on the water erosion equation developed and verified by Wischmeier and Smith. The other sections determine the total above-ground residue that may be removed based on crop yields, the nutritive value of the residue and a total energy balance. With the use of the water and wind equations the computer program calculates the amount of above-ground crop residue needed to keep erosion within tolerable limits. It is through an intuitive knowledge of the soil's structure that one determines the amount of residue required to maintain optimum bulk density. All these data, manipulated within the program, determine how much excess above-ground crop residue exists. By knowing the amount of excess residue and the current agricultural practices, the net energy can then be determined as can the amount of nutrient being removed with the crop residue.

The program was designed primarily for individual field analysis, with the best scientific guidelines available. It is simple to use and will give relatively conservative tolerable removal rates for actual crop residue removal.

Large Area Analysis

Although the system can be used for areas larger than single fields, when used for areas much larger than a 65 ha (160 ac) field it should be noted that the output data are rather general.

The program works well for estimating the residue available from larger pieces of land, i.e., counties, land resource areas, and so on. However, the larger the area, the more averaging and generalization of the input data must be made.

Limitations

Single Field Analysis

The model developed by the computer program is limited by how closely the data in the tables and figures represents actual field conditions. An example of the error-margin inherent in these input data would be with regard to the slope and length of slope factors used in the water erosion equation. This factor is a function of the gradient and length of the slope. The problem is one of uniformity. If the slope is uniform there will be no variance between the computer-determined LS and the actual field condition. If the slope is not uniform, however, which is generally the case, the LS factor will differ from the actual field conditions.

Another limitation is the energy data. The energy data used in this program has been determined either by energy audit (Myers et al., 1980) or by calculation (White, 1974). The figures represent the average energy requirement for specific tasks (for example, 14.0 l/ha to combine corn). The problem with this data is that the conditions for the field being analyzed and those of the input data in most cases will be different, in terms of yields, equipment used and condition of the equipment and/or field.

Another limitation is residue-to-grain ratios. The residue-to-grain ratio is used to determine the amount of above-ground residue based on the established yield per unit of land. Though these figures are averages it is very unlikely that a corn yield of 1235 kg/ha (120 bu/ac) grown in Northern Michigan with a particular hybrid will have exactly the same amount of above-ground residue as a crop of corn with a similar yield grown in lower Michigan. Therefore, when using this program, interpolating on the conservative side is advisable. For example, if a slope in a particular field is not uniform, use of an LS factor that is a little steeper than the average slope of the field being analyzed is recommended. Being on the conservative side should help avoid future problems with the soil's productivity.

Large Area Analysis

When using this program for areas much larger than 65 ha these limitations are compounded. Not only is it difficult to estimate an LS factor for a field one square kilometer in size, but even harder to come up with an average soil type or agricultural system that is uniform for the total area.

The method of minimizing these problems will be discussed in the "user's guides" in the Appendix. A full explanation of all assumptions and interpretation of the results will also be discussed, as will sample runs.

CHAPTER TWO

LITERATURE REVIEW

Soil Requirements of Crop Residue for Continued Crop Production

The potential of crop residue as an alternate source of energy is immense (Alich and Inman, 1974; Lipinsky, 1978; Steffgen, 1974). In these reports, however, it has been implied that the crop residue are waste products of agricultural production. This is not the case.

As reported by Lindstrom et al., (1979) crop residue influences soil properties, both physically and chemically, as either stable or unstable soil organic matter. This is an important factor in maintaining soil productivity. Crop residue retains plant nutrients and helps maintain soil porosity and tilth for easy soil tillage and good plant growth. When removed, residue takes with it large amounts of nutrients that must be replaced by mineral fertilizers or other sources, such as animal manure (Larson, 1979). Residue removal also inhibits water infiltration, and affects soil water storage and plant use (Larson, 1977). Left on the soil surface, residue curtails soil detachment by raindrop impact and reduces the velocity of runoff, which reduces the runoff's potential to detach and transport soil (Wischmeier, 1975).

Water Erosion

In a 1960 report, Wischmeier states that a "highly significant inverse correlation between crop yields and erosion losses was found. This report represents the results of a series of more or less independent studies of specific phases of soil and water management at 37 locations in 21 states over a 30-year period. This 30-year study, along with the previous works of other soil scientists and engineers, led to the development of a universal soil loss equation (USLE), which reflects the effects of locality differences in rainfall patterns.

Over time, the USLE has been improved and verified, the variables that make up the equation being modified and improved. "Predicting rainfall erosion losses, a guide to conservation planning" (Wischmeier and Smith, 1978) describes the USLE's current use. The USLE is "an erosion model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping and management systems." Given an accurate selection of its factors, the equation will compute the average soil loss for a multicrop system, or for a particular crop year in a rotation. Wischmeier and Smith (1978) indicate that widespread field use has substantiated its value and validity for this purpose.

Even though the USLE has been validated work is continuing to increase the equation's usefulness and accuracy. Rawls et al. (1979) studied the effects of conservation tillage on SCS runoff curve numbers. The study did not generate enough data to derive an equation for predicting the effects of conservation tillage on runoff. It was established however, that the use of conservation tillage will affect the cropping-management factors by reducing runoff.

Other work on the USLE has been done in Iowa. Taylor and Amemiya (1980) developed a computer program that can be used on the TI-59 programmable calculator, which solves the USLE as it is given in Agricultural Handbook Number 537, USDA 1978. This program not only calculates the annual soil loss but it also determines the cropping-management factor that is required to keep yearly soil loss within tolerable limits.

Wind Erosion

The problem of soil erosion is not limited to rain and water runoff as the detachment and transport medium. As reported by Hill (1966), wind erosion on upland crop soils is occurring at an increasing rate in Michigan. In 1965, based on nearly 30 years of research, and equations developed by various soil scientists and engineers, Woodruff and Siddoway developed what is the basis for the wind erosion equation (WEE) now used by the Soil Conservation Service (SCS). Since Woodruff and Siddoway's work, much has been done to simplify, verify, and extend the WEE, not all of it entirely successful.

A sliderule was developed by the SCS, the Agricultural Research Service, and the Graphic Calculator Company, which was easier to use than the original equation. This sliderule method of determining soil loss by wind erosion has been in use since the early 1970s. Leon Lyles, USDA, SEA-AR and Dwight Quisenberry, SCS, report that as of June 1981 the sliderule system should not be used (personal communication). It seems that when the sliderule was developed, a particular scale required to determine the E4 factor was assumed to be logarithmic. The scale was not logarithmic nor was it linear. Rather, it was based on actual field data developed by Woodruff and Siddoway.

Other attempts to improve the WEE have been more successful. Lyles and Allison (1980) were able to develop the equivalent residue factors for a number of crops that will work in the WEE. As mentioned in "How to Control Wind Erosion" (Woodruff et al., 1977), "Good vegetative cover on the land is the most permanent and effective way to control wind erosion." Living or dead, standing or flat, the vegetative matter protects the soil surface from wind action by reducing wind speed and by preventing much of the direct wind forces from reaching erosive soil particles. The crop residue will also trap soil particles that are being transported, which in turn prevent the normal avalanching of soil material downwind.

Soil erosion by wind was generally considered to be limited to semi-arid and arid regions. It has been now found to be a problem wherever soil, vegetative, and climate conditions are conducive. Some such conditions are as follows: (1) the soil is loose, dry, and reasonably finely divided; (2) the soil surface is smooth, bare or sparsely covered with crop residue; (3) the field is sufficiently large; and, (4) the wind is strong enough to move the soil (Skidmore and Siddoway, 1978).

One computerization of the wind erosion equation, that of Skidmore et al. (1970), contains a program to be used on a mainframe computer system in Fortran IV. The solution is similar to the manual method developed by Woodruff and Siddoway (1965). A problem with this program as well as one developed by Lyles, is that the wind erosion analysis of a particular field cannot be performed by the field worker on the initial visit to the site under investigation. However, the elimination of a nomograph with a movable scale makes these programs easier to use than the manual method and increases the accuracy of the computations.

The method of analyzing wind erosion used by the SCS has also been improved over the original WEE. Instead of graphs and nomographs with movable slides, the SCS method depends on numerous tables (SCS-Mich, 1978).

Nutrient Maintenance

Larson et al (1976) conclude that the nutritive value of the residue represents an appreciable portion of the total commercial fertilizers applied. However, when considering <u>only</u> the nutrient value of the residue it is generally more economical to provide necessary nutrients via commercial fertilizers. Normally, if a leguminous crop is turned under, about 45 kg/ha (40 lb/A) of nitrogen is made available to the succeeding crop. This seldom provides the total nitrogen requirement. And, when straw, corn stover or other crop residue low in nitrogen are incorporated into the soil, microorganism activity ties up most of the available soil nitrogen. If the roots constitute the only new residue source for humus maintenance, few problems exist. But where large amounts of both tops and roots are present a sufficiently wide carbon-nitrogen ratio may cause nitrogen deficiencies during rapid decay in spring and early summer (Allison, 1973).

Removing all above-ground organic matter and increasing the fertilizer rate will not only maintain soil fertility but, in many cases, increase it (Anon., 1964; Allison, 1973; Barber, 1978; Larson et al., 1971; Tisdale and Nelson, 1975). This does not mean residue are not required for total soil maintenance, rather just not necessary for maintaining soil fertility.

Soil Physical Properties

Crop residue functions in soil maintenance as more than just erosion control and nutrient supplement. The residue also reduce the bulk density of the soil, enhancing infiltration, moisture retention and respiration. Cation exchange capacity, aggregation and tilth maintenance are also increased by its presence. Unlike residue used for soil protection or nutrient maintenance, no easy equation or multiplier factor exists for determining the exact requirements needed to maintain ideal physical soil properties.

Many studies substantiate the necessity of residue for soil maintenance but figures vary significantly for each soil type and management practice. According to Allison (1973), root residue represent a major source of organic matter available for humus maintenance for a large portion of America's farming areas. The amount is usually inadequate to maintain humus content at high levels but will maintain the level commonly reached after 50 or more years of continuous farming. By this time, the humus level stabilizes at 30 to 50% below virgin levels. It is still adequate for many soils, especially with fertilizer supplements available. The increased plant growth due to fertilization increases the amount of root residue which, in turn, keeps humus at an acceptable level. Soil organic matter has increased where abundant plant food has been added under proper conditions.

After 12 years of experiments on a field near Lafayette, Indiana, Barber (1979) reached similar conclusions. He stated that, "soil productivity as measured by average corn yield, in years 6 through 11 was not affected by removal of residue . . . hence, we conclude that the plant roots materially contribute to maintenance of organic matter level of the soil."

After 13 years of field experiments in which five different types of biomass and amounts of 0 to 16 t/ha/yr were applied to a Marshall silty loam, Morachan et al. (1971) reported that "it was not visually evident that significant changes occurred in soil tilth because of treatment differences." Although "wet-aggregate stability and water retention were significantly increased with increasing residue content of the soil, and bulk density was significantly decreased," this soil type is a "medium texture, highly aggregated soil that seldom exhibits soil physical problems in the field". The fact that tilth was not apparently improved could be due to natural physical soil properties.

Increased bulk density of the soil due to soil compaction is well documented. Foth (1978) reported that root extension is inhibited when bulk density exceeds 1.6 g/cc. The higher the bulk density the more poorly defined the structure, and the smaller the soil space. This is usually reflected in restricted plant growth. Reduced top and root corn plant growth resulting from soil compaction is documented in Table 1 (Bertrand and Kohnke, 1957).

Resistance to root penetration is only one aspect limiting growth in high bulk density soils. Of equal or greater importance is the reduced amount of oxygen in these soils (Tisdale and Nelson, 1975; Foth, 1978). Tisdale and Nelson (1975) found 1.4 to 1.7 g/cc to inhibit seedling emergence; personal communication with Dr. Robertson in 1980 indicated he thought the threshold bulk density is about 1.3 g/cc. Furthermore, when bulk density increases from 0.90 to 1.30 g/cc, corn root growth decreases linearly (Phillips and Kirkham, 1962).

Compaction due to low organic matter adversely affects farming income as well. A $175/ha and $150/ha reduction in income was reported for no-till and spring moldboard plowing, respectively, when 50% of the stover from a continuous corn operation was harvested (Holtman et al., 1979). It was concluded that low organic matter and more trips over the field increased the bulk density of the soil. Lucas and Vitosh (1978) also reported significant changes in crop yield and other physical properties due to changes in soil organic matter content based on different manure applications, cropping systems, soil texture, erosion and tillage practices. Often, under revised cropping systems, soil structure and yields are improved while farm energy requirements may be reduced (Robertson, 1952; Anderson et al., 1975; and Robertson and Mokma, 1978).

Energy Inputs to U.S. Agriculture

As the fuel and energy situation became more critical, farmers, fuel suppliers, and others concerned with agricultural production needed a more complete report of information estimating fuel requirements for specific farming operations and overall operations of the total farm enterprise. White (1974) has compiled such a report. This report mentions that the fuel requirements for a specific operation vary widely from one section of a state to another, and even from one farm to another. This is due to such factors as weather, soil structure, topography, depth of tillage, and condition of machinery. White's data are substantiated by Berge (1974) and by Hunt (1977).

Berge (1974) has not indicated how his data was obtained but Hunt (1977) states that the data presented is "compiled from many sources, including estimates." Hunt thereby attempts to provide a range within which 90% of all actual operations fall.

Two farm energy audits which substantiates the above study were performed by Myers et al. (1980) and Kramer and Shelton (1978). The Myers et al. (1980) report was based on over 50 farm years of data for over 30 different field operations.

Crop Residue Availability

Lipinsky (1978) predicted the energy potential of biomass for the U.S. at 10% or more of current usage. This estimate, however, includes crops grown specifically for energy. An average of seven dry metric tons/ha of corn stover removed from half of America's corn crop (about 13 million hectares) could produce one quad of energy. Lipinsky indicates that it would be detrimental to the soil to remove more than half of these residues (Lipinsky, 1978).

About 360 to 590 million metric tons (400 to 650 million tons) of residue are produced annually from the nine leading crops in the U.S. (Larson, 1979; Alich and Inman, 1974). The majority of these residue come from corn, wheat and soybeans. If all of these residue were available for fuel, the potential energy content would be about 8 x 10^{14} kcal (4 x 10^{15} Btu) or only 5% of the energy used in the United States in 1977 (75 quads).

Larson (1979) suggested that realistically crop residue could provide 1 or 2% of the U.S. energy demand. Larson's estimate was based on current cropping practices and technology. Larson appears to include additional fertilizer, but other energy inputs into the system are not mentioned. The study is based primarily on the water erosion equation and computed over 100,000 times to fit various conditions. Larson also pointed out the necessity of crop residue for preventing wind erosion and maintaining nutritive value, soil porosity, tilth maintenance and water utilization. Soil scientists do not agree, however, that the residue required to reduce erosion to a tolerable level will adequately maintain the soil's physical properties.

In addition to Larson (1979) there are several updated and comprehensive reports in this area (Gupta et al., 1979; Lindstrom et al., 1979; Campbell et al., 1979; Allmaras et al., 1979, Skidmore et al., 1979; Onstad and Otterby, 1979; and Holt, 1979). After reviewing the computer program used for most of this work (Larson, 1979b), this writer found it was the only practical way to obtain an overview of the potential of crop residue. Larson et al., concluded that soil maintenance should be a prime consideration. Then, "if soil needs can be met with partial or near full removal of crop residue (along with adequate fertilization and other feasible chemical practices), there should be no objection by agriculture to their removal" (Larson, 1979). However, these predictions do not offer a practical guide for residue removal or for determining net energy gain for the farmer.

Residue Estimates and Collection

The concept of removing crop residue from the soil according to specific guidelines implies a need to determine the actual amount of residue a field requires for its surface to be protected. The SCS has three ways of making these estimates: sightings by experienced personnel, field measurements, and computations using crop yield.

Ditson (1980) has compiled a "packet" that explains how to perform two in-the-field methods of measuring crop residue, and has included over a half dozen photographs of fields containing known amounts of residue for reference in making visual estimates. Ditson describes two methods of measuring crop residue: (1) collecting, drying, and weighing crop residue from three sample plots that are one square yard each. The total weight in ounces is multiplied by 100 to determine the pounds of dry residue per acre. (2) The line-point technique. This method consists of observing 100 equally-spaced points along a 50- or 100-foot line or tape at three random locations in the field. Each point where the line touches a leaf, stem, or stalk from the previous crop is counted. The average number of points touching crop residue is equal to the "percent cover" which is translated into pounds of residue per acre with the aid of Figure 10 in the Agricultural Handbook #537 (Wischmeier and Smith, 1978). The method used to estimate the amount of crop residue left on the surface by use of the crop yields is not effective when residue are to be removed. In the yield method it is assumed that all residue remains in the field. The tillage practices and type of equipment used will determine how much crop residue will remain on the surface. (In his Technical Guide, Ditson does not cite sources for these methods.)

Very little analysis exists of the percentage of loss from harvesting equipment in crop residue removal for the simple reason that there is virtually no machinery designed specifically for the removal of crop residue, such as corn stover. Small grain straws can be harvested with close to equal efficiencies as hay but there is more shatter loss. As reported in AG Energy (1981), work by C.B. Ritchey and others at Purdue have analyzed the performance of both a big round baler and a hay stacker in collecting corn stover.

The residue were windrowed after being cut with a flail pick-up. The researchers found that they could not chop the stalks too close to the ground because the machinery picked up too much soil. The optimum setting was about 7.6 cm above the ground. At the 7.6 cm height in a field with a grain yield of 8800 kg/ha the windrow yields were 775 kg/ha (dry). The material left in the field was 380 kg/ha (dry). Applying the "rule of thumb" for corn that for each pound of grain there is a pound of stover, then about 275 kg/ha disappeared. It was assumed that this loss was caused by shatter losses from the combining and windrowing. On the average, about two-thirds of the material was collected in the windrow. This varied from 82 to 34 percent, depending on the amount the residue were trampled during combining. When the material was bailed an unexpectedly high loss was encountered. With either of the packaging systems only half of the material in the windrow was accounted for in the bales, and when transported and stored, another 23% loss resulted.

CHAPTER THREE

PROGRAM DEVELOPMENT

Theory and Assumptions

The computer model developed to be used in a TI-59 programmable calculator is actually comprised of two programs, both consisting of two magnetic cards. The first program is used to determine the amount of residue required to keep soil loss due to wind erosion within tolerable limits. The second program analyzes the water erosion constraints to residue removal, measures the minimum aboveground residue which must remain on the soil after the combined loss from wind and water erosion in order to satisfy the soil's residue requirements, and performs an energy balance on the total system. What follows is a description of each section of the program, including assumptions made during development and limitations or inaccuracies introduced with the input data.

Residue Needed to Prevent Wind Erosion

The first section of the program, Section 1, the Wind Erosion Section, is based strictly on "A Wind Erosion Equation" (Woodruff and Siddoway, 1965), and "Wind Erosion Control" (SCS, 1978). The Soil Conservation Services (SCS) publication

"Wind Erosion Control" is a technical guide prepared to make the wind erosion equation easier to use. In the SCS system there are many tables and much interpolation. Therefore, starting with the original wind erosion equation which is E = f(IKCLV) where;

E = predicted average annual soil loss (in tons per acre per year)

f = a function of

I = soil erodibility index

K = soil ridge roughness factor

C = climate factor

L = unsheltered field length in the direction of the prevailing wind

V = vegetative cover

The program has been developed to do most of the calculations. This reduces the time required to perform a field analysis and lessens the number of charts and tables.

The initial portion of the program is very straightforward. The soil erodibility index I (Tables 2 and 3) is multiplied by the knoll factor (Figure 1), and the soil ridge roughness (Figure 2) factor K. These three components are what comprise the E2 factor, which is multiplied by the climate factor C (Figure 3 or Table 4) to determine E3. The E2 and E3 factors are intermediate numbers used in the program. The computer then recalls the appropriate segment of Figure 4, finds the two curves on either side of the E2 and through two interpolations approximates the appropriate curve for the E2.

By breaking down curves 30 through 310, by 20's, i.e., 30, 50, 70, 90, and into four segments, based on the calculated distance, 10 to 60, 61 to 500, 501 to 1500, 1501 to 5000, a straight line was used to approximate these sections (Figure A). With the curves broken down into four sections the accuracy of the line segment replacing the curve is well within half the last significant figure. That is, the numbers calculated via the interpolation of line segments is more accurate than a visual reading of the movable scale in Figure 4. Due to limited capacity, the TI-59 calculator stores the slope and intercept of the line segments for distances 10 to 60 and 61 to 500 in one memory for each of the curves and the slopes and intercepts for segments 501 to 1500 and 1501 to 5000 have been stored in a separate memory.

The slopes and intercepts are stored as follows: each memory can hold a ten digit number. For the line segment from 10 to 60 and 501 to 1500 the intercept and slope are the five digits to the left of the decimal. The intercept and slope of the line segment 61 to 500 and 1501 to 5000 are stored to the right of the decimal. Using a "B" to denote the intercept and an "M" to denote the slope, a memory location would appear as follows: BBMMM. BBMMM. The slope and intercepts for the two line segments that surround the line segment E2 are then called and the line segment depicting the curve E2 is then calculated through an interpolation.

Though the scale that represents E2 is not linear nor logarithmic, an interpolation between two curves within 20 units from each other will be more accurate than can be read off the scale. The calculated distance that determines the E2 on the E2 curve is calculated in the computer program automatically by dividing the length of the field by the cosine of the deviation of the erosive wind. Then a series of "if, then" statements establishes the correct portion of the curve to be on. At this point the calculator has predicted the E2, E3, and the E2 which was dependent on the calculated distances. With the aid of Figures 5 through 8, the amount and condition of crop residue required for protection is predicted (for actual user-instructions, program listing, and explanation, see Appendix 2).

Some of the larger errors in predicting the amount of above-ground residue required to reduce wind erosion to an acceptable level are the environmental factors that are entered into the program. Starting with the soil erodibility index ("I" factor), there are generally only six different numerical values used to describe virtually any soil in Michigan (Table 3). A more accurate "I" factor can be determined by finding the dry soil fractions that are greater than 0.84 mm through a standard dry sieving process.

The percentage of soil fractions greater than 0.84 mm is then used with Table 2. The knoll erodibility factor "Is" is used to account for or analyze the erosiveness of knolls 150 meters long (500 ft) or less. The slope of the knoll and Figure 1 is used. The greater the slope the more effect it will have on the "Is" factor. As can be seen in Figure 1, the relationship is not linear. There is not too much error introduced with the soil roughness factor "K" if the field surface is very uniform. By measuring the ridges or small undulations, and with the use of Figure 2, the "K" factor is predicted.

The climatic factor "C" is given in Figure 3 (or Table 5), which has been determined by a relationship between the mean annual wind velocity for a particular location corrected to a standard height and the effective moisture. Because of the relatively few locations where the climatic data is collected, the predicted soil loss, using this "C" factor, will be less accurate for yearly predictions than it will for the ten year predictions. It is also for ten year periods that the allowable soil loss has been determined.

The amount of residue needed to keep the wind erosion under control is very sensitive to the calculated field distance for fields less than 30 meters long. Fields much greater than 30 meters do affect the amount of soil eroded but the actual field length does not have to be measured very accurately.

Residue Needed to Prevent Water Erosion

The water erosion equation, better known as the Universal Soil Loss Equation (USLE), (Wischmeier and Smith, 1978) is a much simpler equation to compute, but as is the case in the wind erosion equation, the variables and tolerable soil loss figures are for predicting long range trends and are not a means of analyzing the effects of individual weather phenomena. The equation is as follows:

A = RKLSCP, where

A = computed soil loss per unit of land

R = rainfall and runoff factor

K = soil erodibility factor

L = slope-length factor

S = slope-steepness factor

C = cover and management factor

P = erosion prevention practice factor

Because these factors are multiplied by each other the programming of this particular equation is simple. The "L" and "S" factors combine to become the "LS" factor by the following relationship (Wischmeier and Smith, 1978):

$$LS = (\lambda/72.6)^m \, (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

λ = slope length in feet

θ = angle of slope = arctan of slope steepness

m = an exponent that varies with gradient (Figure 15)

The program multiplies all the variables and stores the first four. This is done so that different "C" and "P" factors can be tried in an attempt to lower the predicted water erosion below the allowable limit. It should be noted that to be safe when a particular field is being analyzed the predicted soil loss due to water erosion combined with the predicted soil loss due to wind erosion must be lower than the tolerable soil loss.

The variable that will introduce the most error in this equation will be the "C" factor. If a "C" factor is used from Table 6, it must be recognized that the value will be an approximation of conditions in the field. The reason is that the "C" factor is based on the relationship of several factors: (1) crop stage (in terms of its maturity and canopy cover); (2) crop rotation; (3) quality and quantity of the crop residue; (4) the tillage practices and, (5) climatic conditions. The "R" factor, like the wind erosion climatic factor is based on long-term weather averages. Data are collected throughout the state and interpolations are performed to find the "isoerodents" -- that is, plotted lines on a map that connect locations with equal rainfall erosivity.

The soil erodibility factor "K" is similar to the soil erodibility factor for the wind erosion equation in that very few "K" factors are used to depict different soil types. The "K" factor is based on the percentage of silts and very find sands, organic matter, soil structure and soil permeability. If the soil breakdown is determined, the "K" factor for the specific soil can be calculated with the following equation (Wischmeier and Smith, 1978):

$$100\ K = 2.1\ M^{1.14}(10^{-4})(12-a) + 3.25\ (b-2) + 2.5(c-3)$$

where the silt fraction does not exceed 70%:

M = (silt % + very fine sand %) (100 - clay %)

a = percent organic matter

b = structure code (Figure 9)

c = profile permeability (Figure 9)

The "P" factor applies if the field slope is great enough to necessitate either contour farming or strip crop practices (Table 16). Terracing is also a practice that can be used to reduce the total amount of soil loss due to water erosion. However, the practice is used very little in this part of the country. If there is no special erosion prevention practice "P" = 1. It should be noted that both the water erosion and wind erosion sections of the program can be used independently of the rest of the program.

Total Biomass in the Field

In order for the computer program to accurately predict the annual amount of removable residue over the long run, the residue-to-grain ratios (Table 7) must be accurate for the field being analyzed. A small deviation from the actual residue-to-grain ratio for a specific hybrid will make a large difference when analyzing a 60 hectare field with yields of 6300 kg/ha per hectare. It is understood that these ratios are just "rules of thumb," and that the actual relationship between the above-ground residue and grain is not a linear one.

The effect this assumption has on the total agricultural system being analyzed is minimal as far as the soil's maintenance is concerned. But it has major implications in regard to the overall energy balance. To minimize the ill effects to the soil's productive capacity in using the results of this program, the amount of above-ground residue in the field which is determined to be necessary by the water and wind erosion analysis should be left, instead of removing the amount of crop residue this program predicts will be available. In following this procedure it is assured that an adequate amount of residue is left in the field. Because the residue-to-grain ratios are based on national averages, this procedure becomes especially advisable when the crop yields are much higher than the average and when the growing season is shorter than average.

In this section the program reduces the grain yield to a dry weight basis, with the input of either estimated or actual crop yield, and moisture content at the time of reporting. The dry weight is then used with the above-ground residue-to-grain ratio to calculate the total dry above-ground residue. Using the total amount of dry residue the energy content of the residue is determined by assuming an energy content of 1.60×10^4 kJ/kg (7000 Btu/lb).

Residue Available for Uses Other Than Soil Management

In determining the amount of residue available there are three options: the first will predict how much above-ground residue is available after soil maintenance requirements are met. The total amount of above-ground dry matter is recalled from Section 3, the grain component is subtracted, and the amount of residue required for soil maintenance is subtracted. This calculated amount of residue is then used in the following section to determine the energy balance of the system.

The second option of this section determines what the grain portion of the total yield is on a dry weight basis and then proceeds to the following section for the energy balance of the grain production. For this option either the total expected or actual yield is entered or the portion of the yield to be used for alternate energy and the amount of dry matter is calculated by removing the percentage of moisture at crop yield reporting. For example, if a field has a corn yield of 6300 kg/ha (100 bu/ac) and half of the crop will go toward alcohol production, then 3150 kg/ha (50 bu/ac) would be entered. The program would recall that moisture content for corn at yield reporting is 15.5% and from this determine the total dry matter available. The third option is used when just a portion of the total above-ground residue is to be used. One instance would be utilizing just the corn cobs. The weight of cobs per bushel of grain is entered, the reported yield is recalled from Section 3, and the program then determines the weight of cobs on a dry weight basis. The total dry weight is then carried on to the next section to calculate the energy balance.

The only places where significant errors are introduced in this section of the program are:

In option one of Section 3 the possibility of some error is present with the residue-to-grain ratio, and with how close the entered yield is to the actual yield. If both the residue-to-grain ratio and the entered yield are realistic, then the predicted amount of residue available should be very close to what can actually be removed annually. In option two, where only the grain is being analyzed, the most important input data is the crop yield. The closer this figure is to the actual yield the more realistic the calculated amount of grain will be. In this option it is assumed that all above-ground residue will be returned to the soil. Therefore, as long as there is a sufficient amount of residue being produced at the given yield to satisfy the soil's needs, there will be very little to no error introduced from the soil analysis. In option three, where just a portion of the residue are to be used, the same problems exists that affect option one. In particular when corn cobs are used the "rule of thumb" suggests that there are 4.5 kilograms (9.94 lb) of dry corn cobs per bushel of shelled corn. As in the residue-to-grain ratio, this figure is not failsafe.

Determining the Net Energy Gain

The first step in performing an energy balance is to establish a boundary. The boundary here has been selected to cover all primary energy input to the agricultural system used in the field being analyzed, excluding the sun. Therefore, the energy balance starts with seed-bed preparation, crop planting, chemical applications, harvesting, post-harvest processing and transportation to the edge of the field (Tables 8 and 9). Other aspects included in this section are the increased amount of fertilizers which are applied to replace those nutrients that are removed with the residue (Table 10), loss of residue due to handling and storage, and the bioconversion efficiency (the efficiency of converting the residue to a more useful energy source, such as converting corn to ethanol) (Table 17).

The basis on which this section will charge energy costs is dry weight. With corn, for example, where the residue-to-grain ratio is 1.0, half the energy costs should be charged to the grain production and half to the above-ground residue. Whatever amount of residue is being removed, a proportionate amount of energy inputs should be charged to the production. This accounting procedure does not hold true for the energy required to harvest the crop component that is being used for alternate use, or the post-harvesting processes. The energy inputs to the harvesting and post-harvest processing should be charged directly to the residue being converted for alternate use.

The program allows the charge of energy inputs according to any breakdown desired. So, if one wishes to charge all energy inputs to the grain production up to the additional nutrients, harvesting and post-harvesting then a zero is entered. Conversely, if all energy inputs are charged to the residue the total energy inputs from Table 8 or 9 would be entered. It is advised to charge the energy inputs to the various crop components on a dry weight basis.

The assumptions made in this section by the program are few, and they introduce only minimal error. The assumptions relate to the increased amount of energy applied to the system due to the nutrient removal. It is assumed that the amount of energy is 63500, 11340, and 9070 kJ/kg for the nitrogen, phosphorus and potassium, respectively (Myers et al., 1980). The percentage of the residue that the nitrogen, phosphorus and potassium comprises can be obtained from Table 10. The total energy charge to the residue for nutrient removal is minimal.

Assuming that the data supplied up to Section 5 is accurate, errors still will be introduced with the energy accounting system, owing to the fact that the data used for energy input are in the form of averages based on the "Michigan Farm Energy Audit" (Myers et al., 1980). Unless a farmer keeps unusually accurate records on total fuel and fertilizers used, however, a better energy input figure will not be easily found.

Two other factors that will significantly affect the final output are the amount of field loss from handling, processing, and storage, and the bioconversion efficiency for the particular conversion process.

The Transportation System

The last section of the program predicts how far the residue can be transported and still maintain a postive net energy yield, as well as the total number of loads it will take to get the crop residue to a bioconversion facility, taking several energy factors into account.

First, the net energy for transport is determined. If all the energy was used for transport then nothing would be available after conversion. Once the operator has determined the amount of energy available (from harvest of the residue) for transport, the type of fuel and the fuel consumption and the cargo space of the transport vehicle is entered. The bulk density of the crop residue along with the moisture content at the time of transport is also entered. In determining the total distance the residue can be transported the program assumes the empty return trip of the transport vehicle.

The problem in this phase of the program is that the energy potential of the transport fuel is compared with that of the alternate fuel being produced at the conversion facility. If ethanol is being produced at the facility and the transport vehicle is operating on that same fuel then there is no problem. However, if, for example, corn cobs are being transported by a diesel rig to a gasification facility, the comparison becomes complicated. Even though the conversion of diesel fuel to work is accounted for in the fuel consumption and the conversion efficiency (Table 17) of cobs to producer gas has been accounted for, it is not an accurate assumption that the producer gas would perform similarly to the diesel fuel. In current practice energy balance is computed strictly on the heating value of the energy inputs and outputs. To be even more realistic, the quality of the alternate fuel should be accounted for.

CHAPTER FOUR

SINGLE FIELD SAMPLE RUNS

Purpose of Sample Runs

In an attempt to demonstrate what factors are used in the program, how certain variants will affect the amount of residue available and how the program is used, two hypothetical fields in Ingham County have been analyzed. In this field analysis of two different soil types, two different crops (corn and wheat), have been used, as well as two different slopes (2% and 6%). The input data, explanation of assumptions, and a discussion of the results follow.

Input Data for Sample Runs

The two fields which were run in the sample are each 32 hectares (80 ac). One of the fields in an Owosso sandy loam soil. The second field is a Spinks loamy sand soil. The yield for each field is: 7540 kg/ha (120 bu/A) for corn and 2700 kg/ha (40 bu/A) for wheat. There were four runs per field. The first run assumed a slope of 2% and corn as the crop. The second run assumed a 6% slope with corn as the crop. The third and fourth runs assumed slopes of 2% and 6% with the crop being winter wheat. All the other inputs were held constant. The data used in the order it is entered into the program are:

(1) the wind erosion analysis (Section 1 of the program); soil erodibility index for field #1 is 86, for field #2, 134; knoll factor, 1; soil roughness factor, 1; climatic factor, 8%; field length, 400 meters (1320 ft); wind deviation, 45°; no wind breaks.

(2) the water erosion analysis (Section 2 of the program); rainfall factor, 75; soil erodibility factor for field #1 is 0.28, with a tolerable soil loss of 6.7 t/ha, for field #2 the soil erodibility factor and tolerable soil loss are 0.17 and 11.1 t/ha respectively; the slope length factor for the 2% slope is 0.46 and 2.5 for the 6% slope; the support practice factor is 1.

(3) prediction of total crop and residue and the energy potential in the field (Section 3 of the program); expected yields are 7540 kg/ha (120 bu/ac) and 2700 kg/ha (40 bu/ac) for corn and wheat, respectively; residue-to-grain factors are 1.0 and 1.7 for corn and wheat, respectively; moisture content at yield reporting is 15.5 and 14 percent for corn and wheat, respectively.

(4) determination of the amount of excess residue available for removal (Section 4 of the program); option 1 (see Chapter 3) was chosen because all available residue is desired.

(5) determination of the energy balance (Section 5 of the program); handling losses 50%; bioconversion efficiency, 100% (it is assumed that the residue will be burned in a furnace. This does not indicate that the furnace is 100% efficient, rather than 100% of the heat made available by the burning of the residue is available for the furnace). The energy inputs in crop production for both corn and wheat are porportional to the residue-to-grain ratio. They are 2,500,000 kJ/ha (950,000 btu/ac) and 1,400,000 kJ/ha (540,000 Btu/ac) for corn and wheat. The energy to harvest these residue was (assuming windrowing the residue and baling in small rectangular bales) 1,700,000 kJ/ha (650,000 Btu/ac) and 850,000 kJ/ha (325,000 Btu/ac) for corn and wheat. No post-harvest processing was performed. The nitrogen, phosphorus and potassium factors were 0.0111, 0.0018, and 0.0133 for corn and 0.0067, 0.0007 and 0.0097 for wheat, respectively.

(6) the transportation system (Section 6 of the program); it is assumed that 50% of the equivalent energy is wanted for work; the fuel used for transport is diesel; fuel consumption is 2 km/l (5 mpg); hauling capacity of the truck is 68 m^3 (2400 ft^3); the bulk density of the residue baled is 160 kg/m^3 (10 lb/ft^3), and the moisture content at harvest is 20% (see Table 11 for list of input data).

Results of the Sample Runs

Table 12 contains all the results generated for the sample fields in the six sections of the program. In the first two sections the soil loss for wind and water erosion are found for the particular cropping and management system. The combined losses must be less than the tolerable soil loss for the field in question. One can see that for field #1 it is only when the slope is 2% that the calculated and combined soil loss is less than the tolerable limit. If the cropping rotation was changed and a year or two of meadow was introduced then it is possible that residue would be available from field #1 with a 6% slope. The cropping rotation assumed that only corn and wheat were being produced in the examples. To be within the tolerable soil loss of 6.7 t/ha for field #1, 2800 kg/ha of residue was required to hold wind erosion to 2.2 t/ha. 2200 kg/ha was required to keep water erosion to 4.2 t/ha.

Section 3 calculated that the total above-ground matter, grain and residue, for the entire field #1 was 412,800 kg (dry weight basis). Section 4 then subtracts the grain portion and the amount of residue that must remain for soil maintenance and computes a total of 116,000 kg (dry weight) available. Based on 1.63×10^4 kJ/kg (7000 Btu/lb) the gross energy potential is determined and then all the appropriate energy inputs are subtracted.

The result is the net energy available for use and/or for transport. The last section (Section 6), for field #1 with a 2% slope planted in corn determines what the greatest distance is that the residue can be transported and the required number of loads. With 50% of the energy allocated for transport, the maximum distance is 1550 km for each of the seven loads.

When compared to the corn grown in field #2 with a 2% slope, one sees that not as much residue is available. At first this seemed strange because the soil of field #2 is more susceptible to wind erosion, as can be seen by comparing the soil losses. Field #1, with 2800 kg/ha left in the field, has losses of about 2.2 t/ha, whereas field #2 with 2500 kg/ha of residue left in the field will have losses of about 7.8 t/ha. The reason more residue can be removed from field #2 is because the tolerable soil loss is 11.1 t/ha as compared to 6.7 t/ha for field #1. It is this higher tolerable soil loss limit that allows residue to be removed from field #2 with a 6% slope whereas in field #1, with a 6% slope no residue can be removed due to water erosion.

Usage of Results

Once a field has been analyzed, as have fields #1 and #2, the results can be applied to a situation where the crop residue is to be used for some purpose other than returning it to the soil. The first step in applying the results is to plan on leaving the residue required to maintain the soil's productive capacity. It must be noted that the amount of residue required for soil maintenance was calculated for a given management system. For the sake of the soil, adherence to the management system is imperative. In the case of field #1, in order to keep the water erosion level down to 4.2 t/has the field must be strip tilled with 2200 kg/ha (dry weight) of residue remaining. If the energy balance is positive, as it was in all the sample runs where residue could be removed, one can assume that there will be more energy available than that used in producing the residue. To keep the energy balance positive, the residue cannot be transported farther than determined in Section 6. It is unlikely the residue would be transported further than that, because of the economics involved. The economics of the total system are not considered in the program at all. If the results indicate that a system for residue removal and conversion is viable, it cannot be assumed that the economics will create a positive return.

When using the results of an area study to plan an energy conversion center one must be careful. A realistic amount of field, handling and storage losses of the residue must be used to determine how much residue the facility will have to process. Knowing the amount of residue available at the site of the conversion center will help in determining the appropriate size of the facility.

CHAPTER FIVE

RESULTS AND DISCUSSION OF CROP RESIDUE AVAILABILITY PROGRAM

Using the tables and figures contained in this paper, together with the computer program, much of the agricultural land east of the Rockies can be analyzed. The author is aware of no other program that will analyze a single field's potential for alternate energy. Nor is the author aware of any large-scale program that is capable of analyzing both water and wind erosion constraints to residue removal, along with an energy balance of all primary energy inputs including increased fertilization, for the total system.

Comparisons With Other Works

There are computer programs available that will perform sections of the crop residue availability program presented here. Dr. Bill Larson has a program that estimated the amount of residue available in the twelve states comprising the North Central section of the United States. Larson's program, however, analyzed only the eastern part of this area for water erosion constraints and only the western section of the area for wind erosion. There is no energy balance or economics involved in his program. The program developed by Larson was intended only to approximate the amount of crop residue available, with future planning and policy-making in mind. It can be seen from the results on the two fields in Ingham County that one cannot assume water erosion is the limiting factor to residue removal for some states or regions and that wind erosion is the limiting factor for others. From Table 12 it is seen that the Owosso sandy loam was limited in residue removal by water erosion whereas the Spinks loamy sand was limited by wind erosion. With 2200 kg/ha of residue (dry weight) left in each of these fields with a 2% slope the water erosion soil loss was 4.2 t/ha for the Owosso, whereas on the Spinks the soil loss due to water erosion was only 2.7 t/ha. Wind erosion caused soil loss of 2.1 t/ha and 7.8 t/ha for the Owosso and Spinks soils, respectively, when 2500 kg/ha of residue (dry weight) was left in the field.

Versatility of the Program

In an effort to enhance its flexibility, the program was developed so that various sections could be used completely independently. The two most readily usable sections of the program are Sections 1 and 2, the wind erosion equation and the water erosion equation.

Wind Erosion Section

The wind erosion section is a vast improvement over the manual method first developed by Woodruff and Smith (1965) and the later version now used by the Soil Conservation Service for analyzing the soil loss for a particular field. The major improvement over the earlier system is the computerization of a nomograph with a sliding scale. Once the scale has been cut out of the figure, the possibility of losing the sliding scale and the probability of poor interpolation creates a much higher potential incidence of error and inconvenience. The improvement over the system now used by the Soil Conservation Service consists primarily of the reduction in the number of tables that are used. The possibility of faulty interpolation is also minimized.

Water Erosion Section

In the water erosion section there are three elements which improve the use of the USLE. The first is the speed with which a field can be analyzed, and, once run, how rapidly changes in the annual soil loss relative to changes either in the cropping-management or erosion prevention practices can be predicted. This capability is important mostly to a field agent working directly with a farmer. The agent can determine in a matter of seconds what the predicted soil loss will be given that farmer's agricultural practices, and how the loss would change with a change in the agricultural practices.

Another improvement over the manual system is the direct computation of the slope length (LS) factor as opposed to obtaining the LS factor from a graph. This accomplishes two things: first, the total time is reduced for determining the various factors that represent the field being analyzed; secondly, the possibility of misreading the figure is eliminated. The most significant improvement is the reduction of the number of tables and the probability of faulty interpolation of the various factors and end results. Section 2, compared either to the original manual method developed by Wischmeier and Smith or the system used by the Soil Conservation Service, provides greater accuracy than can be gotten by reading factors off the graphs or taking interpolations from the tables.

The Energy Balance

Like the two sections that analyze erosion phenomena, Sections 5 and 6 can be used independently of the rest of the program. The two sections can be used for studying the energy balance associated with crops, or portions thereof. Though it is recognized that this section does not have the potentially wide-spread use as does Sections 1 and 2, it will be useful in analyzing community size alcohol stills or other bioconversion facilities that utilize the grain or residue component of a crop. This feature of the program enables the operator to determine whether more premium fuels, such as diesel or LP gas, are being consumed in the production of the crop than the portion of grain or residue being converted to other forms will yield. To perform this analysis one must know how much energy is going into the bioconversion facility, and must have on record how many liters of fuel were used during total crop production.

Limitation of the Program

With the crop residue availability program caution must be used in selecting the variables that match the agricultural system being analyzed. At best, the data generated will be only an estimate of actual conditions. Because of this when choosing input data it is advisable to use approximations on the conservative side.

Because of the approximations in much of the input data (see Chapters 1 and 3) caution must be used in interpreting the results of the program. The soil structure should be examined after a year or two and the agricultural practices modified as indicated by the results. If the soil structure is deteriorating, more of the crop residue must remain on the field, with the possible addition of manure; if the soil structure remains the same, or improves, then present practices may continue.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

Summary

Where crop residue removal is proposed, the field in question should first be studied to determine the possible ill effects on the soil's productivity from such removal. The premise is that, in terms of commonly accepted principles of soil management, only the residue can be safely removed which is in excess of that required to maintain adequate soil conservation practices and promote the soil's productivity. It is necessary, therefore, to devise a means of measuring the variables involved in soil maintenance to determine how much residue can be removed, for any given combination of variables, and whether the resulting energy balance will be positive or negative.

To accomplish the above a computer program was developed for use on the TI-59 programmable calculator. This program using previously developed wind (Woodruff and Siddoway, 1965) and water (Wischmeier and Smith, 1978) erosion equations and knowledge of the soil's physical characteristics, determines two pieces of information. First, the amount of residue which exists in a field in excess of that required for soil preservation is estimated.

Taking into account the current agricultural practices in that field, the second aspect the program addresses is an energy balance. The energy balance portion of the program considers the process from seed-bed preparation through post-harvest processes, and current levels of fertilizer application, and analyzes the transportation system involved in moving the residue to a bioconversion center. The final output of the program is the net energy gain (or loss) from residue removal from a given field. Based on the transportation system involved, the distance the residue can be transported and how many loads of residue there will be is also calculated. Economic considerations involved in the total system are not addressed.

Conclusions

After a review of the literature and an analysis of the sample runs described in this writing it was determined that:

1) Each field proposed for crop residue removal should be considered on a case-by-case basis, analyzing as accurately as possible the conditions of that particular field, and avoiding generalizations;
2) Such a field should be analyzed in terms of the potential increase in wind and water erosion and soil compaction from the removal of residue, and

whether the residue to be removed constitutes an excess of that required for proper soil maintenance;

3) This "tool" is the best available means of calculating how much crop residue can be removed. It also gives insight into the energy balance and distance the residue can be transported;

4) Crop residue from some soils and locations can safely be removed.

CHAPTER SEVEN

RECOMMENDATIONS FOR FURTHER RESEARCH

Program Development

The following recommendations are made to increase the ease of operation and the accuracy of the program.

In Section 1, the Wind Erosion Section, determining a mathematical relationship for Figure 5 would reduce the inaccuracies introduced when reading the E4 factor. The problem encountered with this nomograph is that the scale is not logarithmic, though it closely resembles a logarithmic scale. When an approximate logarithmic interpretation of this scale is attempted, the lower end, that is, from an E4 of ten downward, is unacceptable. The error increases as the field size is reduced. It was found that a straight interpolation between the other segments of E4 will be well within allowable tolerances, however, this option is limited by computer space. Either some further curve fitting techniques or a large computer should be tried.

Figure 6 should also be reduced to a mathematical expression. With three coordinates this figure becomes a relatively uniform surface (see Figure 11). The axes for both the "E" and the "E4" are logarithmic.

In Section "2" the Water Erosion Section, computerizing the cropping-management (C) factor would greatly increase the resemblance of the model to actual field conditions. The manner in which the C factor is calculated is described in Wischmeier and Smith (1978), owing to limited computer space, this procedure was not incorporated into this program.

Another major change in the program that would increase its accuracy relates to the manner in which the energy inputs are charged against that portion of the crop being studied. How this should be accomplished is not clear. A comprehensive and widely accepted method should be developed.

Verification of Program

A long-term study of residue removal, and the actual effects it has on the soil's condition, is recommended. Actual long-term (10 years or more) data collected on erosion, compaction, and energy inputs into the system as related to residue removal would enable researchers to determine the extent to which the model actually represents the field that is being analyzed. With this information, changes could be made in the various input factors which would be more representative of actual conditions. Also, an indepth study of the affects of residue removal in small increments, say, by 100 kg/ha, rather than by 500 kg/ha would be of interest. If increments this small make significant differences in soil structure, fertility, and soil loss, then methods of determining the amounts of residue which should remain in the field need to be refined.

APPENDICES

APPENDIX A

TABLES

TABLE 1

THE EFFECT OF MOISTURE, FERTILITY LEVEL, AND DEGREE OF SOIL COMPACTION ON CORN PLANT GROWTH

Treatments	Weight of tops (g)	Weight of roots (g)	Top:root ratio (g)	Weight of total plant (g)
Loose, wet, fertilized	39.4	14.8	1:0.38	54.2
Loose, wet, unfertilized	23.5	10.1	1:0.43	33.7
Loose, dry, fertilized	27.5	9.3	1:0.34	36.8
Loose, dry unfertilized	20.3	9.3	1:0.46	29.6
Compact, wet, fertilized	16.0	6.5	1:0.40	22.5
Compact, wet, unfertilized	17.0	7.7	1:0.45	24.7
Compact, dry, fertilized	20.1	11.3	1:0.56	31.4
Compact, dry, unfertilized	19.3	9.9	1:0.51	29.2

Source: Bertrand and Kohnke, 1957.

TABLE 2

SOIL ERODIBILITY INDEX (I) FOR SOILS WITH DIFFERENT PERCENTAGES OF NONERODIBLE FRACTIONS AS DETERMINED BY STANDARD DRY SIEVING[1]

Percentage of dry soil fractions > 0.84 mm	Units									
	0	1	2	3	4	5	6	7	8	9
tens	t/A									
0	-	310	250	220	195	180	170	160	150	140
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2	-	-	-	-	-	-	-	-	-

[1]For a fully crusted soil surface, regardless of soil texture, the erodibility "I" is, on the average, about 1/6 of that shown.

Source: Woodruff and Siddoway, 1965.

TABLE 3

SOIL ERODIBILITY INDEX (I)

Soil Textural Classes	Percent of Dry Soil Aggregates Over 0.84 mm Percent	Soil Erodibility Index (I)
Very fine sand, fine sand, or coarse sand.	1	310
Loamy very fine sand, loamy fine sand, loam sand, loamy coarse sand, or sapric organic soil materials.	10	134
Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam	25	86
Clay, silty clay, non-calcareous clay loam, or silty clay loam with more than 35% clay content.	25	86
Calcareous loam and silt loam, or calcareous clay loam and silty clay loam.	25	86
Noncalcareous loam and silt loam with less than 20% clay content, or sandy clay loam, sandy clay, and hemic organic soil materials.	40	56
Noncalcareous loam and silt loam with more than 20% clay content, or noncalcareous clay loam with less than 35% clay content.	45	48
Silt, noncalcareous silty clay loam with less than 35% clay content and fibric organic soil material.	50	38
Soils not suitable for cultivation due to coarse fragments or wetness, wind erosion not a problem.	--	--

Source: Soil Conservation Service, 1978.

TABLE 4

PREVAILING WIND EROSION DIRECTION[1,2]

Location	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Battle Creek,MI	248	248	248	270	247	248	248	270	270	225	225	225
Cadillac,MI	248	248	292	292	225	225	247	225	246	203	203	247
Duluth,MN	292	270	293	90	90	248	270	68	270	248	293	293
Flint,MI	225	270	248	248	247	248	248	225	225	225	225	225
Green Bay,WI	292	228	225	247	225	225	225	225	225	225	270	227
Marquette,MI	0	338	0	0	0	180	202	0	180	180	180	180
Mt. Clemens,MI	225	225	225	203	180	201	202	180	180	202	203	225
Muskegon,MI	248	270	248	225	205	225	225	203	203	203	225	270
Oscoda,MI	338	315	270	239	227	270	202	225	248	224	226	315
Pellston,MI	270	270	270	270	248	248	248	248	248	248	292	270
Sault St. Marie, MI	292	293	293	293	293	293	293	293	293	293	293	292
South Bend,IN	225	270	90	315	338	338	338	0	180	180	225	225
Toledo,OH	247	247	248	247	247	225	204	225	248	225	220	225
Traverse City,MI	203	202	202	202	203	225	203	203	202	202	180	225
Ypsilanti,MI	248	270	270	270	270	270	270	270	270	248	248	248

[1]Prevailing wind erosion direction -- direction of winds over 12 mph 1 ft above ground surface.

[2]"Direction" means degrees, measured in a clockwise direction from north which is 0°.

Source: U.S. Soil Conservation Service, 1973.

TABLE 5

MONTHLY CLIMATIC FACTORS "C" FOR EACH COUNTY IN MICHIGAN

County	Monthly Value of "C"											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alcona	7	7	8	7	6	3	3	3	4	5	7	7
Alger	5	4	6	6	2	3	2	2	4	4	5	3
Allegan	7	10	12	9	7	5	4	4	4	5	8	7
Alpena	7	7	8	8	6	4	3	3	5	6	7	7
Antrim	6	7	8	8	7	4	3	3	5	5	8	8
Arenac	8	7	8	7	5	3	3	2	4	5	7	7
Baraga	5	4	7	5	2	3	3	2	4	5	5	3
Barry	7	9	10	7	5	4	3	3	4	5	7	7
Bay	7	7	8	7	5	3	3	2	4	5	7	7
Benzie	7	8	10	9	8	5	4	3	5	6	9	8
Berrien	7	10	10	9	8	5	4	3	5	5	8	8
Branch	7	8	9	8	5	4	3	2	4	5	7	7
Calhoun	7	8	9	7	5	4	3	2	4	5	7	7
Cass	7	9	9	8	7	4	3	3	5	5	7	7
Charlevoix	6	7	9	9	7	5	3	3	5	5	7	7
Cheboygan	6	7	8	8	6	4	3	3	5	5	7	7
Chippewa	6	5	7	7	7	4	3	2	4	5	6	4
Clare	7	7	8	7	5	3	3	2	4	5	7	7
Clinton	6	6	8	7	4	2	2	2	2	3	7	4
Crawford	7	7	8	7	6	4	3	2	4	5	7	7
Delta	7	5	7	7	5	4	2	4	5	5	7	5
Dickinson	6	5	7	7	5	4	2	3	5	5	7	5

Count
Eaton
Emmet
Genes
Gladw
Gogel
Granc Tra
Grat
Hill
Houg
Hurc
Ingl
Ion
Ios
Iro
Isa
Jac
Kal
Kal
Ker
Kew
Lak
Lap
Lee

TABLE 5 -- (Cont'd.)

County	Monthly Value of "C"											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eaton	6	8	9	7	5	3	3	2	3	4	7	7
Emmet	6	7	8	9	7	5	3	3	5	5	7	7
Genesee	7	7	8	7	4	3	2	2	3	5	7	7
Gladwin	7	7	8	7	5	3	3	2	4	5	7	7
Gogebic	5	5	8	9	6	4	5	4	5	8	9	5
Grand Traverse	7	7	8	8	7	5	3	2	4	5	7	7
Gratiot	6	7	8	7	5	3	2	2	2	4	7	6
Hillsdale	7	8	9	8	5	4	3	2	4	5	7	7
Houghton	5	4	7	5	2	3	2	3	5	6	6	3
Huron	8	7	8	8	5	3	3	2	5	5	8	7
Ingham	6	8	8	7	5	3	3	2	2	4	7	7
Ionia	6	7	8	8	5	3	2	2	3	3	7	7
Iosco	7	7	8	7	5	3	3	2	4	5	7	7
Iron	5	5	7	7	6	4	3	3	5	7	8	4
Isabella	7	7	8	7	5	3	3	2	3	5	7	7
Jackson	7	8	9	7	5	4	3	2	4	5	7	7
Kalamazoo	7	8	9	8	6	4	3	3	4	5	7	7
Kalkaska	7	7	8	7	6	4	3	2	4	5	7	7
Kent	7	8	10	10	6	4	3	3	4	4	7	7
Keweenaw	5	4	7	5	3	3	2	3	5	6	5	3
Lake	7	8	10	7	6	5	3	3	4	5	7	7
Lapeer	8	7	8	7	5	3	3	2	4	5	7	7
Leelanau	7	8	10	9	8	5	4	3	5	6	10	9

TABLE 5 -- (Cont'd.)

County	Monthly Value of "C"											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lenawee	8	9	10	7	5	4	3	2	4	5	8	7
Livingston	7	7	8	7	5	3	3	2	3	4	7	7
Luce	5	5	6	7	4	3	3	2	4	5	5	5
Mackinac	6	6	7	8	6	4	3	2	4	5	5	6
Macomb	10	10	10	10	6	5	4	3	5	6	10	10
Manistee	7	8	10	8	8	5	4	3	5	6	8	8
Marquette	4	4	6	5	2	3	2	2	4	4	5	3
Mason	7	9	12	8	8	5	3	4	5	6	8	7
Mecosta	7	7	9	7	5	4	3	2	4	5	7	7
Menominee	7	6	8	9	7	5	4	3	6	8	9	8
Midland	7	7	8	7	5	3	3	2	4	5	7	7
Missaukee	7	7	8	7	5	4	3	2	4	5	7	7
Monroe	10	10	10	9	5	4	3	3	4	5	8	7
Montcalm	7	7	8	7	5	3	3	2	3	4	7	6
Montmorency	7	7	8	7	6	4	3	3	5	6	7	7
Muskegon	8	10	12	12	6	5	3	5	4	5	8	7
Newaygo	7	8	10	8	6	5	3	3	4	5	7	7
Oakland	9	7	10	7	5	4	3	2	4	5	8	9
Oceana	8	10	12	12	7	5	3	5	5	5	8	7
Ogemaw	7	7	8	7	5	3	3	2	4	5	7	7
Ontonagon	5	4	8	7	6	4	4	3	5	8	7	4
Osceola	7	7	8	7	5	4	3	3	4	5	7	7
Oscoda	7	7	8	7	6	4	3	2	4	5	7	7

Count
Otseg
Ottaw
Presq
Rosco
Sagin
St. C
St. J
Sanil
Schoo
Shiaw
Tusco
Van B
Washt
Wayne
Wexf

Sour

TABLE 5 -- (Cont'd.)

County	Monthly Value of "C"											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Otsego	6	7	8	7	6	4	3	3	5	5	7	7
Ottawa	7	10	12	12	7	5	3	5	4	5	8	7
Presque Isle	6	7	8	8	6	4	3	3	5	6	7	7
Roscommon	7	7	8	7	5	3	3	2	4	5	7	7
Saginaw	7	7	8	7	5	3	2	2	3	5	7	6
St. Clair	10	10	10	10	5	4	3	3	5	6	10	10
St. Joseph	7	8	9	8	6	4	3	3	4	5	7	7
Sanilac	8	9	9	8	5	3	3	2	5	5	8	7
Schoolcraft	6	5	6	7	5	4	3	3	4	4	6	4
Shiawassee	7	7	8	7	4	2	2	2	2	3	7	4
Tuscola	7	7	8	7	5	3	3	2	4	5	7	6
Van Buren	7	10	10	9	7	5	4	3	5	5	8	8
Washtenaw	7	8	10	7	5	4	3	2	4	5	7	7
Wayne	9	8	10	10	6	4	3	3	5	5	8	9
Wexford	7	7	8	7	5	5	3	2	4	5	7	7

Source: SCS, 1978.

TABLE 6

... FOR CONSERVATION TILLAGE, MICHIGAN, LOWER PENINSULA

TABLE 6

CROPPING-MANAGEMENT VALUES FOR CONSERVATION TILLAGE, MICHIGAN, LOWER PENINSULA

Variable[5]	Till plant, chisel plow & rotary strip tillage[1]					Zero tillage-no-till or slot planting[2]				
	lb corn residue on surface/Acre[3]					lb corn residue on surface/Acre[3]				
	1000-2000	2000-3000	3000-4000	4000-6000	6000+	1000-2000	2000-3000	3000-4000	4000-6000	6000+
1. Cont. corn[4]	.355	.244	.189	.131	.080	.284	.193	.131	.070	.030
2. Cont. corn[4] RdR, cover crop RdL	.343	.239	.219	.206		.253	.196	.180	.163	
3. RRROx[4]	.185	.136	.111	.085	.062	.150	.097	.080	.052	.034
4. RROx[4]	.125	.097	.083	.068	.056	.103	.079	.062	.045	.036
5. RROOM[4]	.149	.109	.086	.069	.051	.122	.088	.065	.043	.028
6. RRROMM[4]	.125	.092	.072	.058	.043	.102	.074	.055	.036	.024
7. RROM[4]	.094	.074	.063	.052	.043	.079	.060	.047	.035	.028
8. RROMM[4]	.076	.060	.051	.042	.035	.064	.048	.038	.029	.023
9. RROMMM[4]	.064	.050	.043	.036	.030	.054	.041	.033	.025	.020
10. ROM		.042					.036			
11. ROMM		.032					.028			
12. ROMMM		.027					.023			
13. ROMMM		.023					.020			
14. OMMMM										

[1]Includes tillage systems which leave residues on 66% or more of the soil surface after planting.

[2]Includes tillage systems which leave residues on 90% or more of the soil surface after planting.

[3]One pound of residue from small grain, hay crops, and soybeans is equivalent to 2 lbs. of corn residue.

[4]When soybeans are grown continuously--increase "C" factor by 20-25%; one-half of R crop--increase "C" factor by 15; one-third of R crop--increase "C" factor by 10%. (When computing corn residue, assume that there will be 1 lb of stalks with each pound of grain produced. Corn (shelled) equals 56 lb/bu. Therefore, 110 bu of corn will yield 6160 lb of residue.

[5]R=row crop, O=small grain crop, Ox=small grain with winter cover, M=meadow.

SOURCE: U.S. Soil Conservation Service, 1973.

TABLE 7

CROP SPECIFICS

Crop	Unit	Net Weight kg (lb)	Bulk Density[1] Kg/m^3 (lb/ft^3)	Moisture content %	Residue/ grain ratio
Barley	bu	22 (48)	615.0 (38.4)	14	1.5
Corn	bu	25.4 (56)	717.5 (44.8)	15.5	1.0
Grain sorghum	bu	25.4 & 22.7 (56 & 50)	717.5 & 640.7 (44.8 & 40.0)	14	1.0
Hay	t	-	-	-	-
Loose	-		48.1 (3)		
Bailed	-	-	128.1 - 224.2 (8-14)		
Pellets	-	-	640.7 (40)		
Oats	bu	14.5 (32)	410.0 (25.6)	14	2.0
Rye	bu	25.4 (56)	717.5 (44.8)	14	1.5
Soybeans	bu	27.2 (60)	768.8 (48.0)	13	1.5
Wheat summer	bu	27.2 (60)	768.8 (48.0)	14	1.3
winter	bu	27.2 (60)	768.8 (48.0)	14	1.7

[1]Boyd, 1973.
[2]Gupta et al., 1979.

TABLE 8

ESTIMATED RANGE OF FUEL REQUIREMENTS FOR SELECTED FARMING OPERATIONS

Operation	Btu/ac		J/ha	
Tillage Operations:				
Moldboard plow	1.6×10^5	6.4×10^5	6.9×10^7	2.8×10^8
Chisel plow	9.9×10^4	4.0×10^5	5.3×10^7	1.4×10^8
Heavy tandem disk	6.8×10^4	2.7×10^5	2.9×10^7	5.8×10^7
Standard tandem disk				
Plowed soil, first time over	5.6×10^4	2.2×10^5	2.4×10^7	9.6×10^7
Plowed soil, second time over	4.3×10^4	1.7×10^5	1.9×10^7	7.4×10^7
Corn stalks, etc.	5.0×10^4	2.0×10^5	2.1×10^7	8.5×10^7
Spring-tooth harrow	3.7×10^4	1.5×10^5	1.6×10^7	6.4×10^7
Spike-tooth harrow	2.5×10^4	9.9×10^4	1.1×10^7	4.3×10^7
Field Cultivator	6.2×10^4	2.5×10^5	2.6×10^7	1.1×10^8
Planting Operations:				
Row-crop planter (with fertilizer, etc.)				
40" rows	5.6×10^4	1.3×10^5	2.4×10^7	5.6×10^7
30" rows	7.4×10^4	1.7×10^5	3.2×10^7	7.1×10^7
Grain drill	4.3×10^4	9.3×10^4	1.9×10^7	4.0×10^7
Potato planter	1.1×10^5	2.5×10^5	4.8×10^7	1.1×10^8
Vegetable planter (direct)	1.1×10^5	2.5×10^5	4.8×10^7	1.1×10^8
Transplanter	1.5×10^5	3.4×10^5	6.4×10^7	1.4×10^8
Crop Cultivation:				
Row crops, first cultivation	5.0×10^4	1.1×10^5	2.1×10^7	4.8×10^7
Row crops, second cultivation	4.3×10^4	9.3×10^4	1.9×10^7	4.0×10^7
Vegetable crop cultivation	6.8×10^4	1.5×10^5	2.9×10^7	6.4×10^7
Rotary hoe	1.9×10^4	5.0×10^4	7.9×10^6	2.1×10^7

TABLE 8 (Cont'd.)

Operation	Btu/ac		J/ha	
Harvesting Operations:				
Cutterbar mower	5.0×10^4	1.1×10^5	2.1×10^7	4.8×10^7
Mower-conditioner (pto)	8.1×10^4	1.9×10^5	3.4×10^7	3.4×10^7
Mower-conditioner (self-propelled)	1.2×10^5	2.6×10^5	5.0×10^7	5.0×10^7
Hay Rake	2.5×10^4	5.6×10^4	1.1×10^7	1.1×10^7
Baler, hay	1.2×10^5	2.6×10^5	5.0×10^7	5.0×10^7
Baler, straw	9.3×10^4	2.0×10^5	4.0×10^7	4.0×10^7
Forage harvester (flail-type)				
Green chop	6.3×10^5	6.3×10^5	1.2×10^8	2.7×10^8
Dry hay or straw	1.4×10^5	3.2×10^5	1.4×10^8	1.4×10^8
Forage harvester (cylinder or flywheel type)				
Haylage	6.3×10^5	6.3×10^5	2.7×10^8	2.7×10^8
Dry hay or straw	1.2×10^4	2.8×10^5	1.2×10^8	1.2×10^8
Row crop				
40" rows	2.7×10^5	6.0×10^5	1.1×10^8	2.5×10^8
30" rows	6.7×10^6	6.7×10^5	1.3×10^8	2.9×10^8
Combine harvester				
Small grain	1.2×10^4	2.8×10^5	5.3×10^7	1.2×10^8
Pea beans and soy beans	1.4×10^5	3.1×10^5	5.8×10^7	1.3×10^8
Corn, 40" rows	1.5×10^5	3.3×10^5	6.4×10^7	1.4×10^8
Corn, 30" rows	1.7×10^5	3.9×10^5	7.4×10^7	1.7×10^8
Corn picker				
40" rows	1.1×10^5	2.4×10^5	4.5×10^7	1.0×10^8
30" rows	1.2×10^5	2.6×10^5	5.0×10^7	1.1×10^8
Picker-sheller and picker-grinder				
40" rows	1.2×10^4	2.8×10^5	5.3×10^7	1.2×10^8
30" rows	1.5×10^5	3.3×10^5	6.4×10^7	1.4×10^8
Potato harvester	1.8×10^5	4.1×10^5	7.7×10^7	1.7×10^8

TABLE 8 (Cont'd.)

Operation	Btu/ac		J/ha	
Harvesting Operations (Cont'd.)				
Sugar beet harvester	1.7×10^5	3.8×10^5	7.4×10^7	1.6×10^8
Vegetable harvester	2.0×10^5	4.5×10^5	8.5×10^7	1.9×10^8
Tree fruit harvester (shaker)	3.3×10^5	7.4×10^5	1.4×10^8	3.2×10^8
Miscellaneous Operations:				
Row crop sprayer (each operation)	1.2×10^4	3.1×10^4	5.3×10^6	1.3×10^7
Orchard sprayer (each operation)	6.2×10^4	1.4×10^5	2.6×10^7	6.1×10^7
Stalk shredder	7.4×10^4	1.7×10^5	3.2×10^7	7.1×10^7
Fertilizer spreader (bulk, spinner)	1.9×10^4	3.7×10^4	2.9×10^6	1.6×10^7
Anhydrous ammonia applicator	1.3×10^5	3.0×10^5	5.6×10^7	1.3×10^8
Vine topper (beets, potatoes)	1.7×10^5	3.9×10^5	7.4×10^7	1.7×10^8
Pea bean puller and windrower	5.0×10^4	1.1×10^5	2.1×10^7	4.8×10^7
Forage blower				
Dry hay or straw	6.8×10^4	1.5×10^5	2.9×10^7	6.4×10^7
Haylage or corn silage	1.2×10^5	2.6×10^6	5.0×10^7	1.1×10^8
Hay cuber	3.8×10^4 -	5.1×10^5 Btu/t	4.4×10^7	5.9×10^7 J/t
Irrigation	4.3×10^6 Btu/A		1.8×10^9 J/ha	
Corn drying with LP gas				
30% to 14% M.C.	2.5×10^4 Btu/bu		2.6×10^7 J/bu	
28% to 14%	2.1×10^4 Btu/bu		2.2×10^7 J/bu	
25% to 14%	1.6×10^4 Btu/bu		1.7×10^7 J/bu	
20% to 14%	8.0×10^3 Btu/bu		8.4×10^6 J/bu	
Gasoline	124,000 Btu/gal		3.5×10^7 J/1	
Diesel fuel (no. 2)	140,000 Btu/gal		3.9×10^7 J/1	
LP gas	96,000 Btu/gal		2.7×10^7 J/1	

SOURCE: White, 1974

TABLE 9

FUEL CONSUMPTION OF FIELD OPERATIONS IN DIESEL EQUIVALENTS

Operation	Michigan Energy Audit Study[1] Gal/ac	Michigan Energy Audit Study[1] l/ha	Data from other states[2] Gal/ac Low	Average	High
Tillage					
Chisel Plow	1.2	11.2	0.5	1.1	2.3
Moldboard Plow	1.7	15.9	0.6	1.9	4.3
Secondary Tillage	0.9	8.4	0.1	0.7	1.7
Planting					
Conventional Planter	0.5	4.7	0.2	0.5	0.9
Grain Dril	0.7	6.6	0.2	0.4	0.4
Potato Planter	1.0	9.4	0.4	0.9	1.5
Seeding Broadcast	0.4	3.7		0.2	
Vegetable Planter	1.0	9.4	0.4	0.9	1.5
Crop Cultivation					
Cultivation	0.5	4.7	0.2	0.4	0.6
Harvesting					
Baler or Stacker	1.1	10.3	0.4	0.6	1.5
Beet Harvester	1.3	12.2	0.8	1.4	2.1
Chop Dry Material	0.8	7.5	0.4	0.9	2.4
Chop Wet Material	3.0	28.1	1.0	2.1	3.3
Combine or Picker	1.5	14.0	0.6	1.3	1.8
Conditioning	0.2	1.9	0.2	0.3	0.4
Mower - Conditioner	0.8	7.5	0.5	0.7	1.5
Pull and Windrow Dry Beans	0.4	3.7	0.2	0.4	0.6
Rake	0.4	3.7	0.2	0.3	0.5
Miscellaneous					
Chemical Application	0.3	2.8	0.1	0.3	0.5
Chemical Incorporation	1.1	10.3	0.3	0.3	1.4
Knife in Fertilizer	0.6	5.6	0.8	0.9	1.5
Stone Removal	0.2	1.9			
Surface Apply Fertilizer	0.2	1.9	0.1	0.2	0.2
Top Sugar Beets	0.7	6.6	1.0	1.5	2.1

[1]Myers et al., (1980).

[2]Ayres, G.E. (1976).

Berge, O.I. (1974).

Kramer, J.A., M.D. Schrock, and D.P. Shelton (1978).

White, R.G. (1974).

TABLE 10

AVERAGE N, P, AND K CONCENTRATIONS
IN CROP RESIDUE

Crop	(In percent)		
	N	P	K
Barley	0.75	0.11	1.25
Corn	1.11	0.18	1.33
Cotton	1.75	0.22	1.45
Oats	0.63	0.16	1.65
Rice	0.60	0.09	1.16
Rye	0.50	0.12	0.70
Sorghum	1.08	0.15	1.32
Soybeans	2.25	0.22	1.05
Wheat	0.67	0.07	0.97

SOURCE: Larson, W.E., 1976.

TABLE 11

INPUT DATA FOR SAMPLE RUNS

		Field No. 1				Field No. 2			
		Corn		Wheat		Corn		Wheat	
		Slope		Slope		Slope		Slope	
Section	Variable	2%	6%	2%	6%	2%	6%	2%	6%
Wind Erosion	I	86	86	86	86	134	134	134	134
	K	1	1	1	1	1	1	1	1
	C	8	8	8	8	8	8	8	8
	Length (km)	400	400	400	400	400	400	400	400
	Deviation	45°	45°	45°	45°	45°	45°	45°	45°
	Wind Break	0	0	0	0	0	0	0	0
Water Erosion	R	75	75	75	75	75	75	75	75
	K	0.28	0.28	0.28	0.28	0.17	0.17	0.17	0.17
	LS	0.46	2.5	0.46	2.5	0.46	2.5	0.46	2.5
	P	1	1	1	1	1	1	1	1
Total Biomass	Yield(kg/ha)	7540	7540	2700	2700	7540	7540	2700	2700
	R/G	1.0	1.0	1.7	1.7	1.0	1.0	1.7	1.7
	MC	15.5	15.5	14.0	14.0	15.5	15.5	14.0	14.0
Available residue	Option No.	1	1	1	1	1	1	1	1

TABLE 11 (Cont'd.)

Section	Variable	Field No. 1				Field No. 2			
		Corn		Wheat		Corn		Wheat	
		Slope		Slope		Slope		Slope	
		2%	6%	2%	6%	2%	6%	2%	6%
Energy balance	Losses	50	50	50	50	50	50	50	50
	Conversion efficiency	100	100	100	100	100	100	100	100
	Crop production (kJ/ha)	2,500,000	2,500,000	1,400,000	1,400,000	2,500,000	2,500,000	1,400,000	1,400,000
	Harvest (kJ/ha)	1,700,000		850,000	850,000	1,700,000	1,700,000	850,000	850,000
	Post Harvest	0	0	0	0	0	0	0	0
	N	0.0111	0.0111	0.0067	0.0067	0.0111	0.0111	0.0067	0.0067
	P	0.0018	0.0018	0.0007	0.0007	0.0018	0.0018	0.0007	0.0007
	K	0.0133	0.0133	0.0097	0.0097	0.0133	0.0133	0.0097	0.0097
Transport	Energy for work	50 ------------→							
	Fuel	Diesel ------------→							
	Fuel consumption(l/km)	2 ------------→							
	Trailer space (m^3)	68 ------------→							
	Bulk Density (kg/m^3)	160 ------------→							
	M.C.	20 ------------→							

TABLE 12

RESULTS OF SAMPLE ANALYSIS

Variable	Field No. 1				Field No. 2			
	Corn		Wheat		Corn		Wheat	
	2%	6%	2%	6%	2%	6%	2%	6%
E2	86	→	→	→	134	→	→	→
E3	6.88	→	→	→	10.72	→	→	→
E2'	81.5	→	→	→	134	→	→	→
E4	5.5	→	→	→	10	→	→	→
V(kg/ha)	2800	2800	890	890	2500	4500	1100	2300
E(T/ha)	2.2	→	→	→	7.8	3.4	2.2	2.2
A+E(T/ha)	6.4	10.5	6.4	10.5	10.5	8.3	4.9	7.1
T	6.7	→	→	→	11.1	→	→	→
C	0.2	0.07	0.2	0.07	0.2	0.07	0.2	0.07
V(kg/ha)	2200	4500	1100	2200	2200	4500	1100	2200
A(T/ha)	4.2	8.3	4.2	8.3	2.7	4.9	2.7	4.9
Total Biomass (kg)	412,800	412,800	204,100	204,100	412,800	412,800	204,100	204,100
Energy in Field (kJ)	6.04×10^9	6.04×10^9	3.0×10^9	3.0×10^9	6.04×10^9	6.04×10^9	3.0×10^9	3.0×10^9
Residue Available	116,000	NONE	93,000	NONE	123,400	61,700	93,000	56,700
Total kJ	6.8×10^8		5.9×10^8		7.3×10^8	3.1×10^8	5.9×10^8	3.3×10^8
Radius (km)	1550		1600		1570	1300	1690	1562
No. of Loads	7		5		7	4	5	3

Soil
Ahme
Alco
Allo
Alpe
Amas
Ark
Bara
Bark
Blou
Blu
Boh
Boy
Bre
Bro
Cad
Cas
Cel
Cha
Cha
Che
Col
Cov
Cri
Cro
Dee
Dee
Del
Joh
Ka
Kl
Ka
Ke
Ke
Ke
Ki
Ki
La
Le
Lo
Ma
Ma
Ma
Mo
M
M
M
M

TABLE 13

SOIL ERODIBILITY "K" VALUES AND TOLERABLE SOIL LOSS
"T" VALUES (t/ac)

Soil Series	"K"	"T"	Soil Series	"K"	"T"
Ahmeek	.37	4	Michigamme	.32	1
Alcona	.32	2	Dighton	.43	2
Allouez	.24	3	Dowagiac	.32	2
Alpena	.24	1	Dresden	.32	2
Amasa	.32	2	Dryburg*	.24	3
Arkport	.32	2	Dryden	.32	2
Baraga	.24	1	Duel	.17	2
Barker	.37	2	East Lake	.17	5
Blount	.43	2	Eastport	.17	5
Blue Lake	.24	2	Elmdale*	.32	2
Bohemian	.32	3	Elo	.37	2
Boyer	.24	3	Emmet	.28	2
Brems*	.17	5	Fairport	.37	2
Bronson	.24	2	Fence*	.32	3
Cadmus	.37	2	Fox	.32	2
Casco	.24	2	Froberg	.49	2
Celina	.37	2	Fulton	.49	2
Champion	.37	2	Gagetown	.37	3
Chatham	.32	2	Gilchrist	.17	5
Chelsea	.17	5	Gogebic	.32	2
Coloma	.17	5	G-odman*	.37	3
Coventry	.37	2	Graycalm	.17	5
Crivitz	.17	5	Grayling	.17	5
Croswell	.20	5	Guelph	.37	2
Deer Park	.17	5	Hillsdale	.32	3
Deerton	.17	2	Huron	.49	2
Del Rey	.43	2	Ionia	.32	2
Johnswood	.37	2	Iron River	.32	2
Kalamazoo	.32	2	Oakville	.17	5
Klakaska	.17	5	Oakley	.37	3
Karlin	.24	2	Ocqueoc*	.24	2
Kendallville	.37	2	Omega	.17	5
Kent	.49	2	Omena*	.32	2
Keweenaw	.24	2	Onaway	.32	2
Kibbie	.37	3	Onota	.32	1
Kiva	.24	1	Ontonagon	.43	2
Lapeer	.28	2	Oshtemo	.24	2
Leelanau	.24	2	Ottawa	.17	5
Longrie	.32	2	Ottokee	.17	5
Mancelona	.24	2	Owosso	.28	3
Manistee	.28	3	Padus*	.32	2
Marlette	.37	2	Parma	.32	1
McBride	.32	2	Pence	.24	1
Melita	.17	5	Perrin	.24	2
Menominee	.28	3	Plainfield	.17	5
Metea	.28	3	Rimer	.24	3
Miami	.37	2	Roselms	.49	1

TABLE 13 (Cont'd.)

Soil Series	"K"	"T"	Soil Series	"K"	"T"
Rousseau	.24	4	Shelldrake	.17	5
Rubicon	.17	5	Sisson	.37	3
Montcalm	.24	2	Sparta	.17	5
Morley	.43	2	Spinks	.17	5
Munising	.32	2	Stambaugh	.37	2
Nappanee	.49	2	Steuben	.32	2
Nester	.43	2	Ubly	.28	3
Newaygo	.32	2	Vilas	.17	5
Nunica*	.37	2	Volinia	.32	2
St. Clair	.49	2	Waiska	.24	1
St. Ignace	.32	1	Wakefield*	.37	2
Summerville	.32	1	Wallace	.17	5
Sunfield*	.32	2	Watton	.43	2
Superior	.32	2	Yalmer	.17	5
Trenary	.32	2			
Tuscola	.37	3			
Seward	.24	3			

SOURCE: U.S. Soil Conservation Service, 1973.

*Tentative series.

TABLE 14

COMPUTED K AND T VALUES FOR SOILS ON EROSION RESEARCH STATIONS

Soil	Source of Data	Computed K	"T"
Dunkirk silt loam	Geneva, NY	*0.69	2
Keene silt loam	Zanesville, OH	.48	2
Shelby loam	Bethany, MO	.41	3
Lodi loam	Blacksburg, VA	.39	3
Fayette silt loam	LaCrosse, WI	* .38	3
Cecil sandy clay loam	Watkinsville, GA	.36	3
Marshall slit loam	Clarinda, IA	.33	2
Ida silt loam	Castana, IA	.33	2
Mansic clay loam	Hays, KS	.32	3
Hagerstown silty clay loam	State College, PA	* .31	3
Austin clay	Temple, TX	.29	3
Mexico silt loam	McCredie, MO	.28	2
Honeoye silt loam	Marcellus, NY	* .28	2
Cecil sandy loam	Clemson, SC	* .28	4
Ontario loam	Geneva, NY	* .27	3
Cecil clay loam	Watkinsville, GA	.26	3
Boswell fine sandy loam	Tyler, TX	.25	4
Cecil sandy loam	Watkinsville, GA	.23	4
Zaneis fine sandy loam	Guthrie, OK	.22	4
Tifton loam sand	Tifton, GA	.10	3
Freehold loamy sand	Marlboro, NJ	.08	3
Bath flaggy silt loam with surface stones 2" removed	Arnot, NY	* .05	2
Albia gravelly loam	Beemerville, NJ	.03	3

*Evaluated from continuous fallow. All others were computed from rowcrop data.

SOURCE: Wischmeier and Smith, 1978.

TABLE 15

"m" FACTORS FOR DETERMINING LS

Percent Slope of Gradient	m Factor
0 - 1	0.2
1 - 3	0.3
3.5 - 4.5	0.4
5 - up	0.5

SOURCE: Wischmeier and Smith, 1978.

TABLE 16

EROSION PREVENTION PRACTICE FACTOR[1] "P"

Percentage Slope	Contouring	Strip cropping[2]	Terracing and contouring
Parallel to field boundary	0.8[3]	--	--
1.1 - 2	0.6	0.30	--
2.1 - 4	0.5	0.25	0.10
4.1 - 7	0.5	0.25	0.10
7.1 - 12	0.6	0.30	0.12
12.1 - 18	0.8	0.40	0.16
18.1 +	0.9	0.45	--

[1] If no prevention practice P = 1.

[2] A system using 4-year rotation of corn, small grain, meadow, meadow.

[3] For slope up to 12% only.

SOURCE: Schwab et al., 1966.

TABLE 17

BIOCONVERSION EFFICIENCIES

Conversion	Percent
Thermo-chemical	
Direct combustion[1]	100
Pyrolysis[2]	70 - 95
Gasification[3]	60 - 95
Biological	
Alcoholic fermentation[4]	50 - 85
Anaerobic fermentation[5]	40 - 70

[1]Assumes all biomaterial can be burned.

[2]Boyd, M. et al. (1979).

[3]R.O. Williams and B. Horsfield.

[4]R. Ofoli (1980).

[5]W. Rose et al. (1979).

APPENDIX B

FIGURES

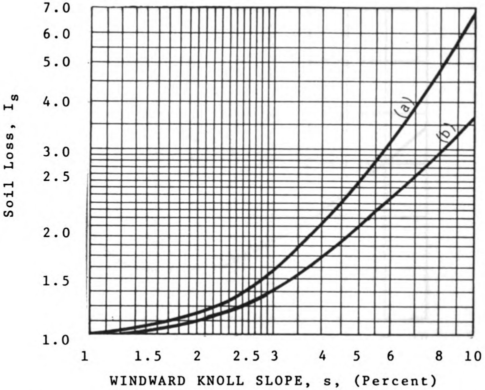

FIGURE 1.--Potential soil loss from knolls factor, expressed as percentage of that on level ground: (a) from top of knoll, (b) from that portion of windward slope where drag velocity and wind drag are the same as on top of knoll (from about the upper third of the slope).

SOURCE: Woodruff and Siddoway, 1965.

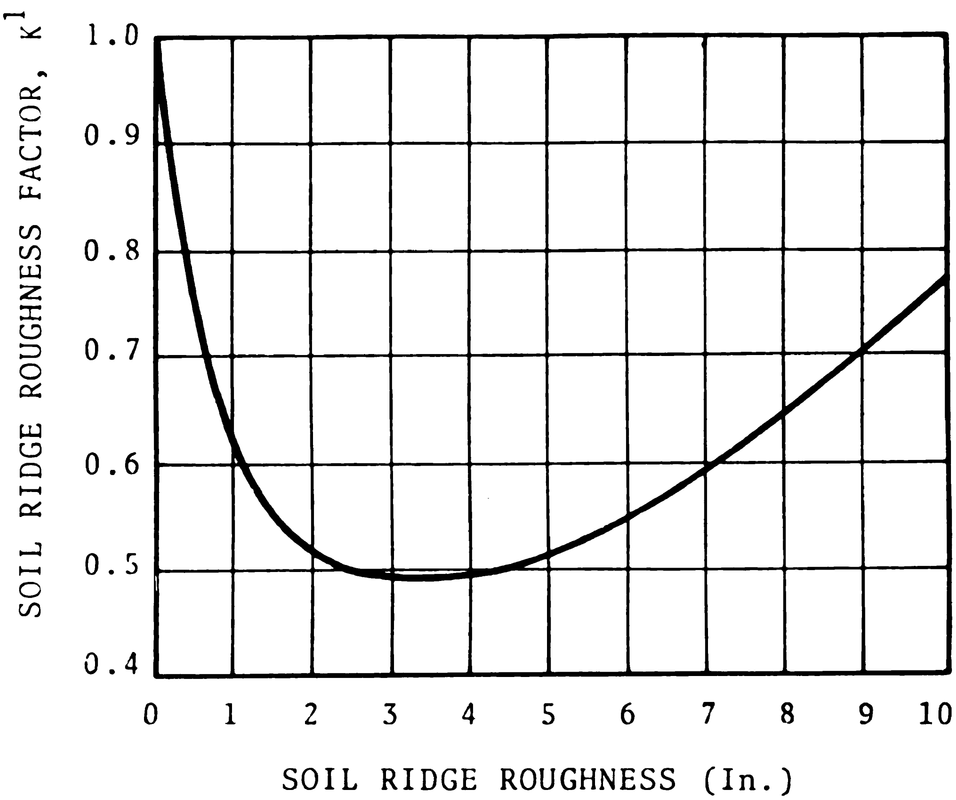

FIGURE 2.--Soil ridge roughness factor chart determines soil ridge roughness factor "K" from the soil ridge roughness.

SOURCE: Woodruff and Siddoway, 1965.

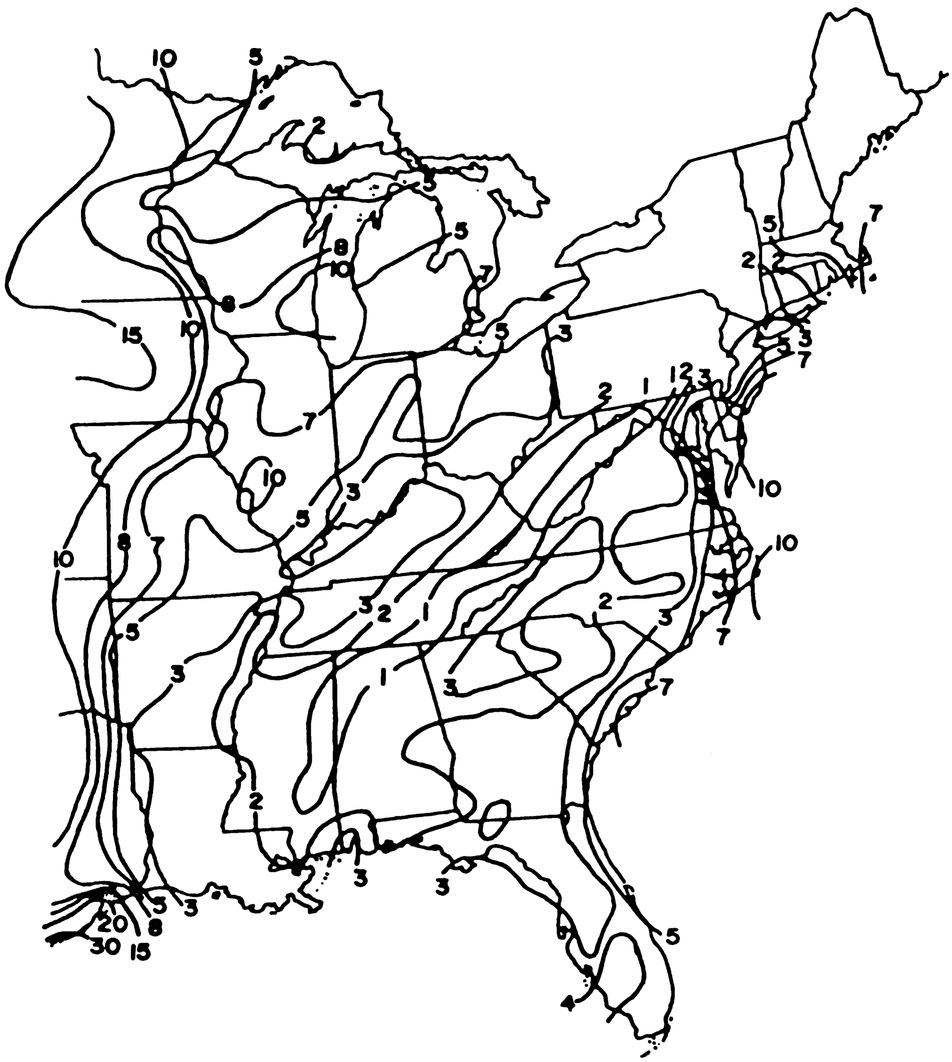

FIGURE 3. -- Annual climatic factor "C" (percentage) based on the average wind velocity and on the precipitation evaporation index (when using use Decimal Form).

SOURCE: U.S. Soil Conservation Service, 1973.

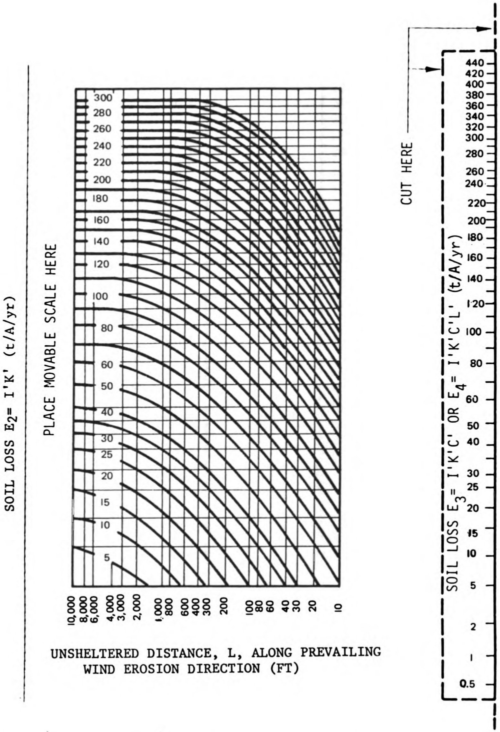

FIGURE 4.--Chart to determine soil loss E4. E4 = I'K'C'L' from soil loss E_2 = I'K' and E_3 = I'K'C' and from unsheltered distance L' across the field.

SOURCE: Woodruff and Siddoway, 1965.

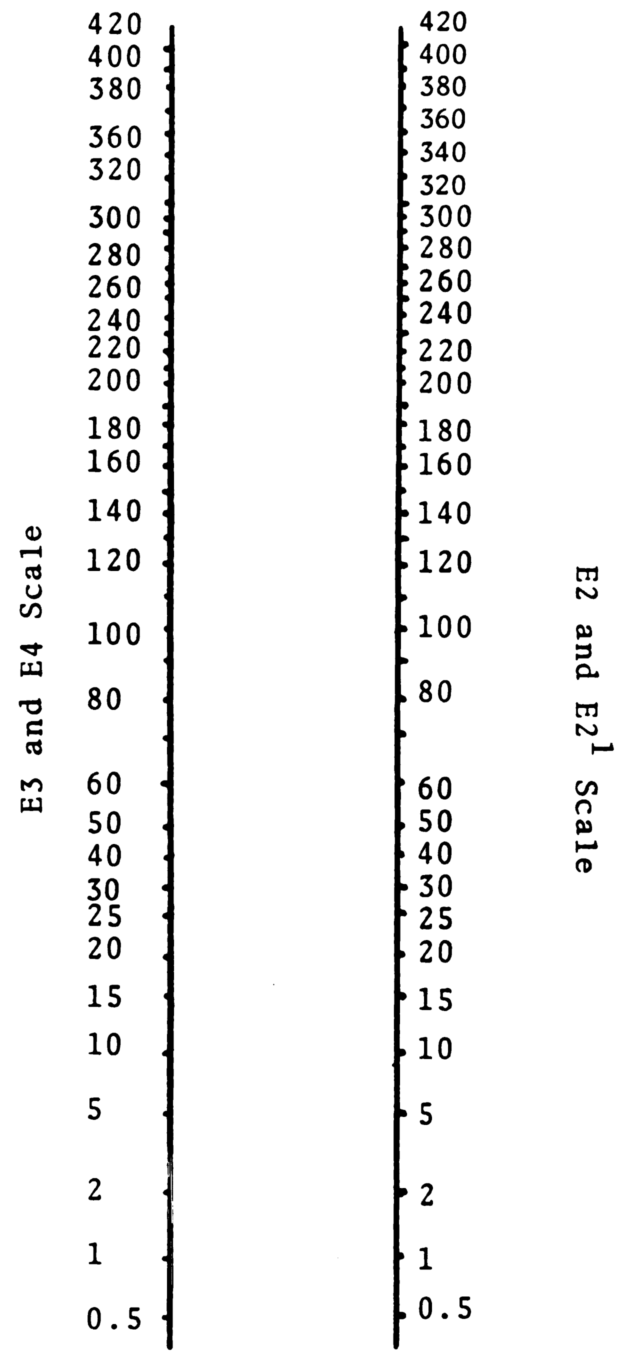

FIGURE 5.--New method of determining E4 from E2, E4, and $E2^1$. (Draw a line from E2 to E3; next draw a line parallel to line E2-E3 starting at $E2^1$. The point of interception of the E3 and E4 scale is E4.

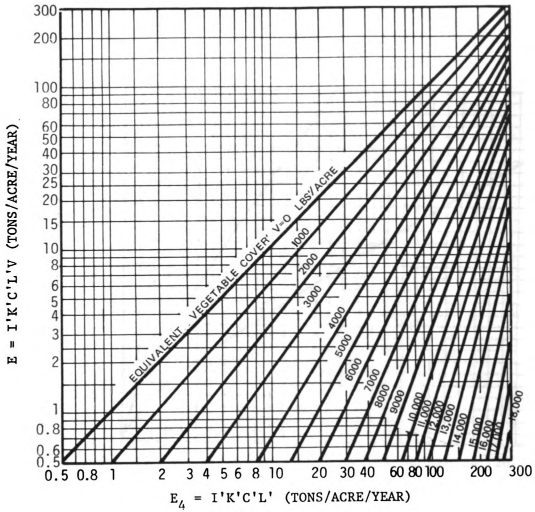

FIGURE 6.--Vegetative equivalent chart to determine soil loss E = I'K'C'L'V from soil loss E_4 = I'K'C'L' and from the vegetative cover factor, V. The chart can be used in reverse to determine V needed to reduce soil loss to any degree.

SOURCE: Woodruff and Siddoway, 1965.

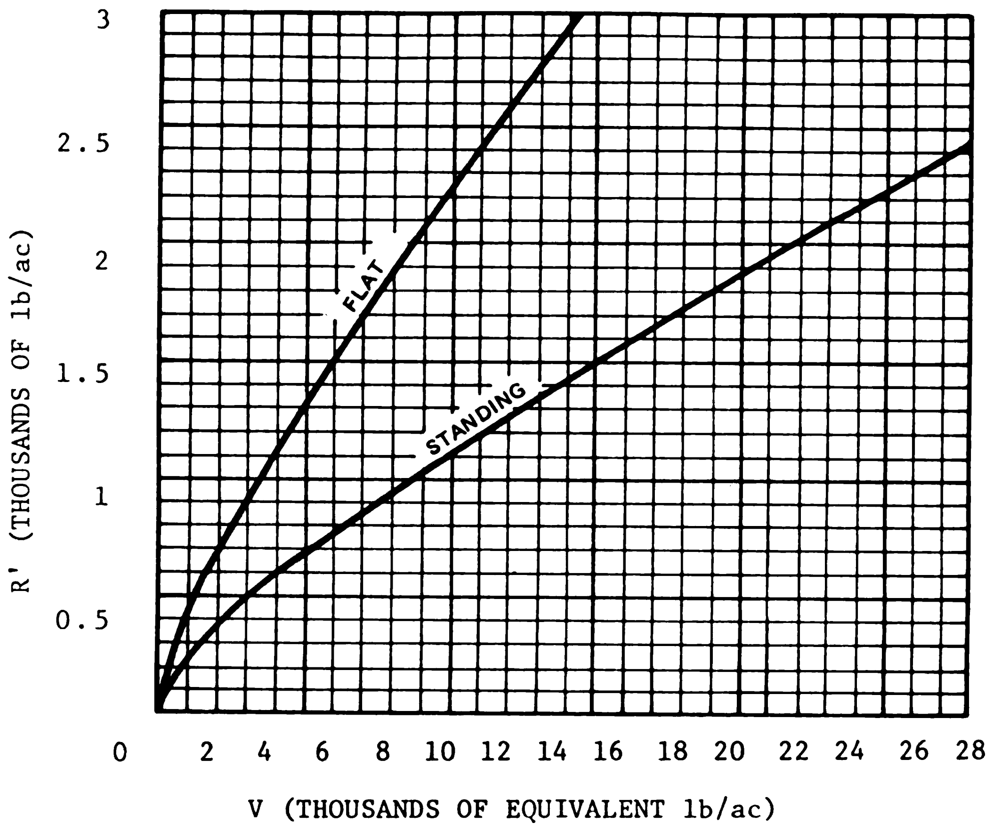

FIGURE 7.--Residue for small grain stubble including stover. Chart to determine V from R' or R' from V of standing and flat anchored small grain stubble with any row width up to 10 in., including stover.

SOURCE: Woodruff and Siddoway, 1965.

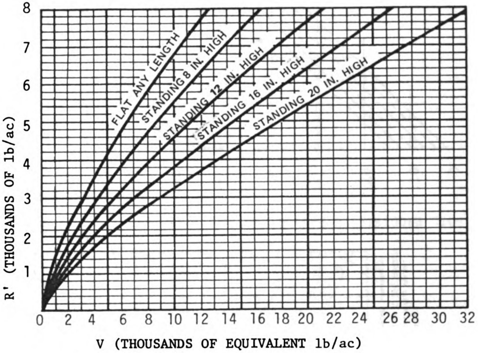

FIGURE 8.--Residue for grain sorghum and corn. Chart to determine V from R' or R' from V of standing and flat grain sorghum and corn stubble of average stalk thickness, leafiness, and quantity of tops on the ground.

SOURCE: Woodruff and Siddoway, 1965.

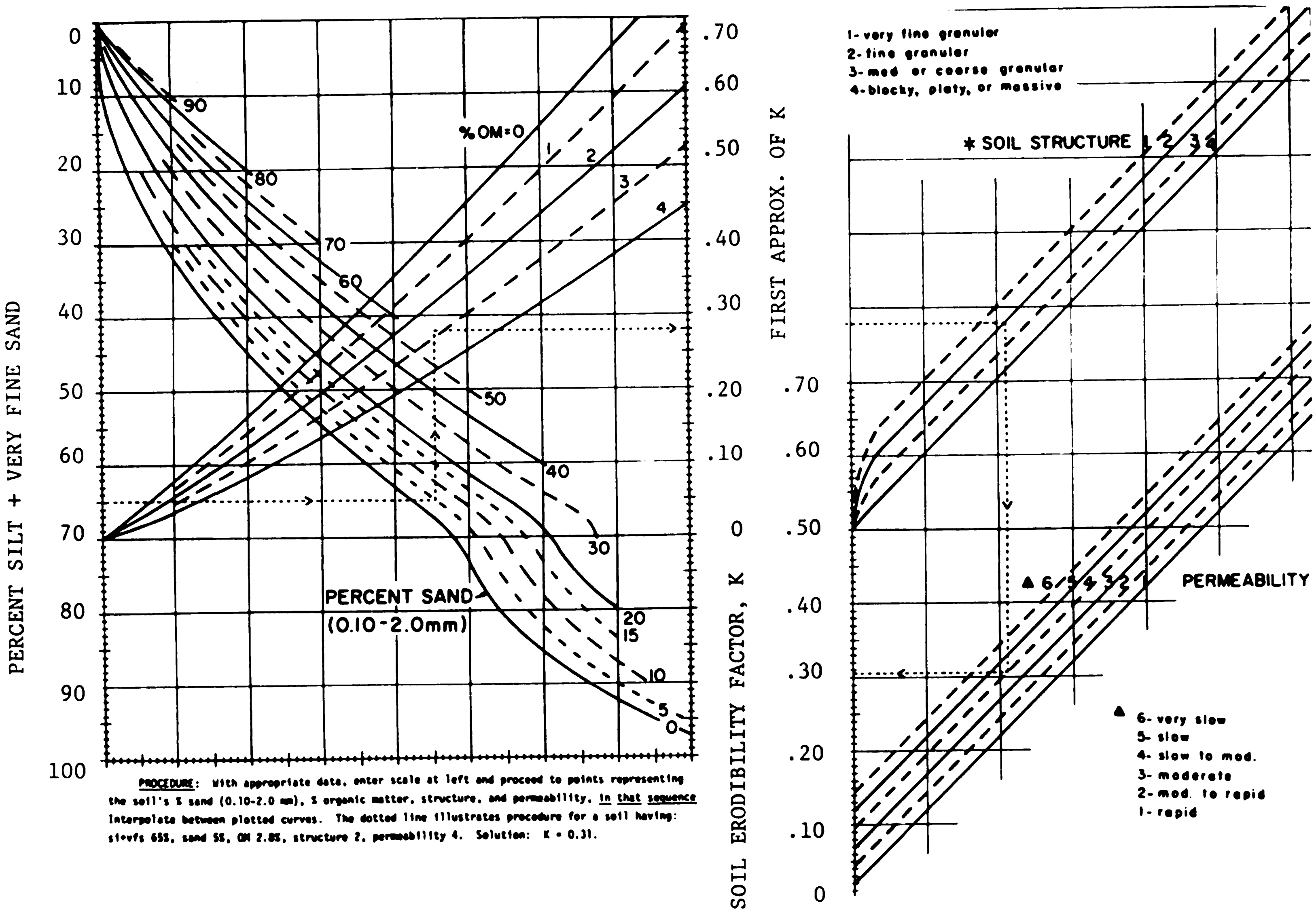

FIGURE 9.--Method for determining the actual soil erodibility factor.

SOURCE: Wischmeier and Smith, 1978.

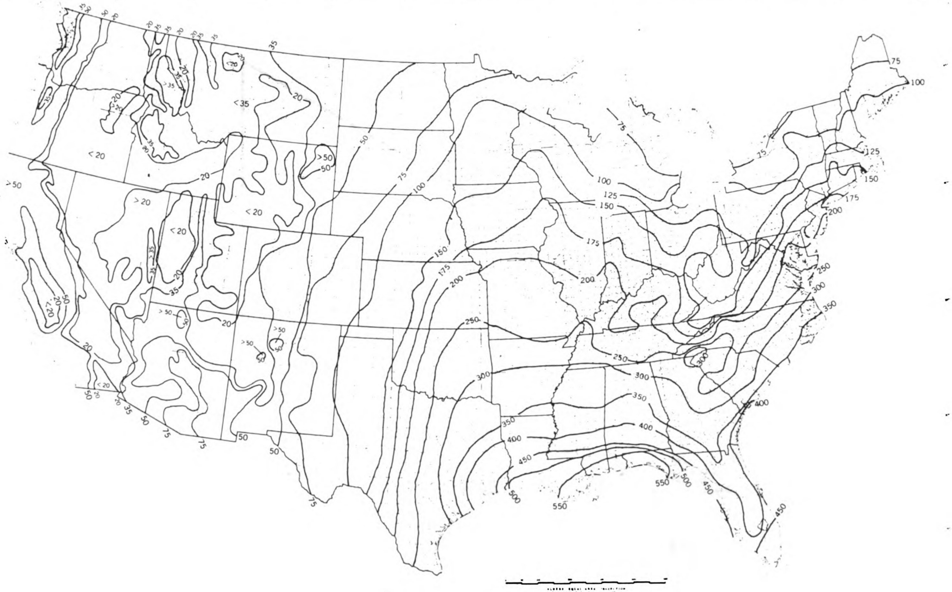

FIGURE 10.--Average annual values of rainfall erosion factor (Source: Wischmeier and Smith, 1978).

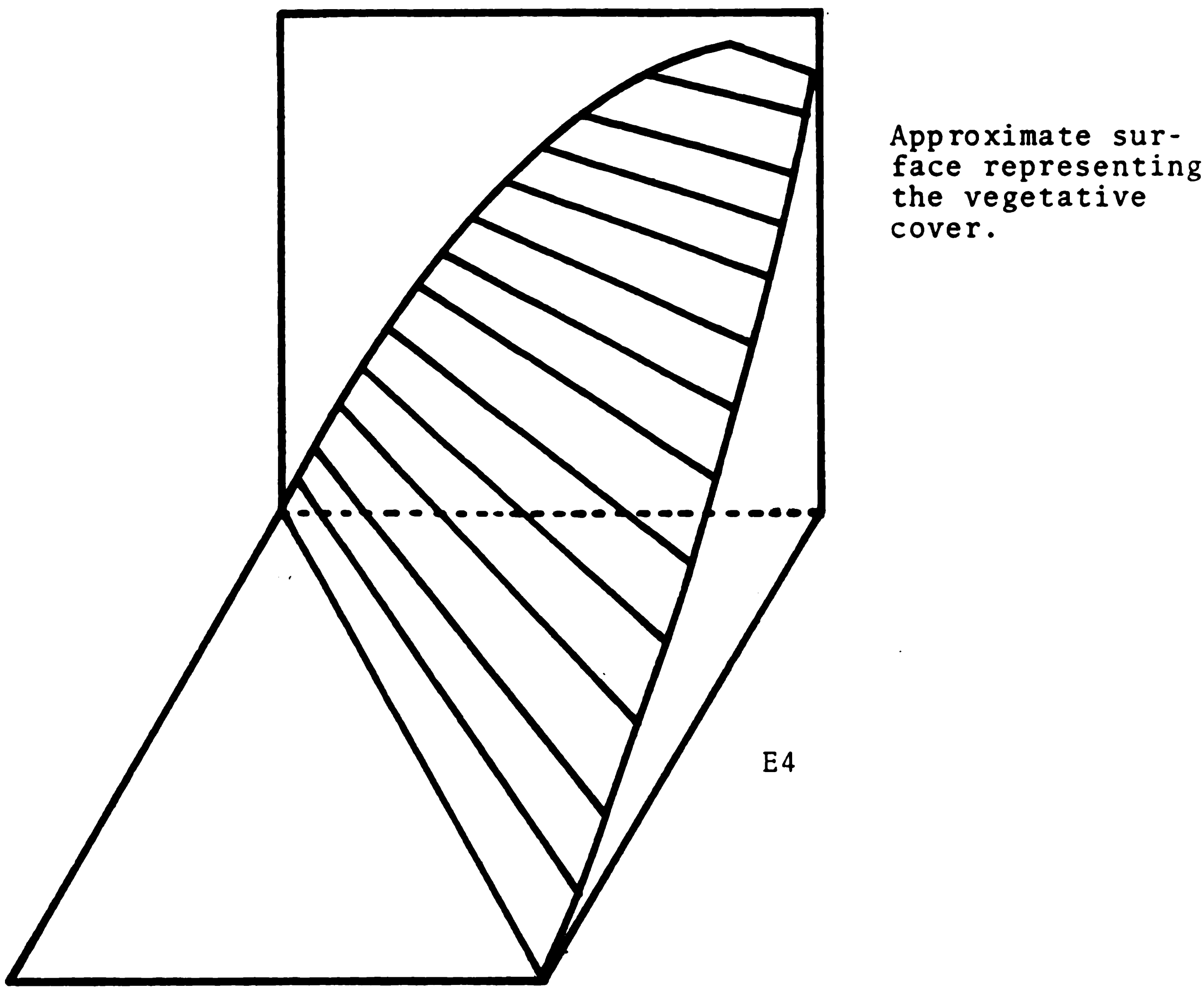

FIGURE 11.--Three-dimensional view of Figure 6.

APPENDIX C

CROP RESIDUE AVAILABILITY PROGRAM

This part of the total program contains Section 1, the wind erosion section. The operating instructions and program listings are listed below.

Comment	Load	Press	Print
1. Initial Run			
a. Repartition computer	5	2nd op 17	--
b. Load cards 1 and 2, all four sides			
2. Section 1 (Wind Erosion)	--	A Key	--
a. Soil erodibility index "I", Tables 2 or 3	"I"	R/S	"I"
b. Knoll factor "Is", Figure 1	"Is"	R/S	"Is"
c. Soil roughness factor "K", Figure 2	"K"	R/S	"K"
d. Climatic factor "C" in decimal form Table 5 or Figure 3.	"C"	R/S	"C"
e. Field length	Length	R/S	Length
f. Wind deviation (in Degrees) from Field length Table 4	Deviation	R/S	Deviation
g. Wind Break height	Height	R/S	Height
The calculator then computes and prints "E2," "E3," and "E2'."	--	--	E2
	--	--	E3
	--	--	E2'

These numbers are used with Figure 5 to determine E4. With E4,"T" (tolerable soil loss, Table 13 or 14) and Figure 6, the vegetative cover is determined. With Figure 7 and 8 the actual amount of crop residue required in the field is determined.

Sample Print Out (English Units)

134.	I
1.	Is
1.	K
0.06	C
1320.	Dist. Ft.
45.	Dev. Degrees
0.	Breaker Height
34.	E2
10.72	E3
137.	E2'

Listing of Subroutines and Program Sections

001	44	SUM
019	53	(
040	35	1/X
057	24	CE
074	23	LNX
089	45	YX
104	61	GTO
111	43	RCL
118	54	)
127	33	X²
152	52	EE
170	34	√X
183	11	A
240	18	C'
251	17	B'
295	16	A'
321	12	B
365	13	C
391	14	D
405	10	E'
465	19	D'
523	15	E

Computer Program

Wind Erosion Data Stored in Memory

Data	Memory
0.	00
0.	01
0.	02
0.3295	03
20999.02532	04
6676.16385	05
8672.2332	06
17562.28274	07
23498.34219	08
27430.36218	09
30387.38208	10
33355.40187	11
35349.43167	12
37348.45144	13
40315.47132	14
41302.4911	15
43289.51093	16
46254.53076	17

Data stored in locations 03 to 17 house the intercept and slope for line segment. On the left side are data for field distances of 10 to 60 feet; the right side of the decimal stores the intercept and slope of line segments for field distances of 61 to 500 feet.

Data	Memory
428.22128	18
18276.31098	19
28185.34094	20
33159.39067	21
36139.45027	22
39129.48013	23
45073.5	24
46078.51	25
49049.52	26
51031.53	27
53018.54	28
55004.55	29
56000.56	30
57000.57	31
57000.57	32

Data stored in locations 18 to 32 house the intercepts and slopes for the line segments for distances 501 to 1500 feet on the left side of the decimal and for distances of 1501 to 5000 feet on the right side.

Computer Program (Cont'd)

Subroutines

Steps	Code	Operation
000	76	LBL
001	44	SUM
002	55	÷
003	01	1
004	00	0
005	95	=
006	59	INT
007	85	+
008	01	1
009	95	=
010	55	÷
011	02	2
012	95	=
013	59	INT
014	85	+
015	01	1
016	95	=
017	92	RTN

Subroutine SUM locates memory location for distances 10 to 500 feet

Steps	Code	Operation
018	76	LBL
019	53	(
020	65	×
021	02	2
022	95	=
023	85	+
024	01	1
025	95	=
026	65	×
027	01	1
028	00	0
029	95	=
030	42	STO
031	36	36
032	85	+
033	02	2
034	00	0
035	95	=
036	42	STO
037	37	37
038	92	RTN

Subroutine C determines the upper and lower segment numbers to be interpolated between

Computer Program (Cont'd.)

Subroutines (Cont'd.)

Steps	Code	Operation
039	76	LBL
040	35	1/X
041	73	RC*
042	01	01
043	59	INT
044	55	÷
045	01	1
046	00	0
047	00	0
048	00	0
049	95	=
050	59	INT
051	55	÷
052	01	1
053	00	0
054	95	=
055	92	RTN

Subroutine 1/X obtains the intercept of the line segment for distances 10 to 60 and 501 to 1500

Steps	Code	Operation
056	76	LBL
057	24	CE
058	73	RC*
059	01	01
060	22	INV
061	59	INT
062	65	×
063	01	1
064	00	0
065	00	0
066	95	=
067	59	INT
068	55	÷
069	01	1
070	00	0
071	95	=
072	92	RTN

Subroutine CE determines the intercept for distances 61 to 500 and 1501 to 5000

Computer Program (Cont'd.)

Subroutines (Cont'd.)

Subroutine LNX determines the slope of the line for distances 61 to 500 and 1501 to 5000

Steps	Code	Operation
073	76	LBL
074	23	LNX
075	73	RC*
076	01	01
077	22	INV
078	59	INT
079	65	×
080	01	1
081	00	0
082	00	0
083	95	=
084	22	INV
085	59	INT
086	95	=
087	92	RTN

Subroutine Y^x determines the slope of the line for distances 10 to 60 and 501 to 1500

Steps	Code	Operation
088	76	LBL
089	45	Y^x
090	73	RC*
091	01	01
092	59	INT
093	55	÷
094	01	1
095	00	0
096	00	0
097	00	0
098	95	=
099	22	INV
100	59	INT
101	95	=
102	92	RTN

Subroutine GTO interpolates the slope of the desired line segment.

Steps	Code	Operation
103	76	LBL
104	61	GTO
105	71	SBR
106	33	X^2
107	42	STO
108	41	41
109	92	RTN

Subroutine RCL interpolates the intercept of the desired line segment.

Steps	Code	Operation
110	76	LBL
111	43	RCL
112	71	SBR
113	33	X^2
114	42	STO
115	40	40
116	92	RTN

Computer Program (Cont'd.)

Subroutines (Cont'd.)

Steps	Code	Operation
117	76	LBL
118	54	)
119	85	+
120	01	1
121	05	5
122	95	=
123	42	STO
124	01	01
125	92	RTN

Subroutine > in conjunction with subroutine SUM locates the memory locations for distances 501 to 5000 feet.

Steps	Code	Operation
126	76	LBL
127	33	X^2
128	53	(
129	43	RCL
130	38	38
131	75	-
132	43	RCL
133	39	39
134	54	)
135	55	÷
136	02	2
137	00	0
138	65	×
139	53	(
140	43	RCL
141	33	33
142	75	-
143	43	RCL
144	36	36
145	54	)
146	85	+
147	43	RCL
148	39	39
149	95	=
150	92	RTN

Subroutine X^2 performs the actual interpolation.

Computer Program (Cont'd.)

Subroutines (Cont'd.)

Subroutine EE changes the sign for the intercepts of various line segments.

Steps	Code	Operation
151	76	LBL
152	52	EE
153	43	RCL
154	40	40
155	94	+/-
156	42	STO
157	40	40
158	43	RCL
159	39	39
160	94	+/-
161	42	STO
162	39	39
163	43	RCL
164	38	38
165	94	+/-
166	42	STO
167	38	38
168	92	RTN

Subroutine $\sqrt{X}$ rounds off the data generated.

Steps	Code	Operation
169	76	LBL
170	34	√X
171	52	EE
172	95	=
173	58	FIX
174	40	IND
175	35	35
176	52	EE
177	22	INV
178	52	EE
179	22	INV
180	58	FIX
181	92	RTN

Computer Program (Cont'd.)

Steps	Code	Operation
182	76	LBL
183	11	A
184	91	R/S
185	99	PRT
186	65	×
187	91	R/S
188	99	PRT
189	65	×
190	91	R/S
191	99	PRT
192	95	=
193	42	STO
194	33	33
195	65	×
196	91	R/S
197	99	PRT
198	95	=
199	42	STO
200	34	34
201	91	R/S
202	99	PRT
203	55	÷
204	91	R/S
205	99	PRT
206	39	COS
207	95	=
208	75	-
209	53	(
210	01	1
211	00	0
212	65	×
213	91	R/S
214	99	PRT
215	54	)
216	95	=
217	42	STO
218	00	00
219	32	X:T
220	02	2
221	42	STO
222	35	35
223	32	X:T
224	71	SBR
225	34	√X
226	42	STO
227	00	00

This section of the program is where all the input data are loaded. Also, the calculated field length equivalent is determined.

Computer Program (Cont'd.)

Steps	Code	Operation
228	05	5
229	00	0
230	00	0
231	32	X⇌T
232	43	RCL
233	00	00
234	22	INV
235	77	GE
236	18	C'
237	61	GTO
238	14	D
239	76	LBL
240	18	C'
241	06	6
242	00	0
243	32	X⇌T
244	43	RCL
245	00	00
246	77	GE
247	12	B
248	61	GTO
249	17	B'

Depending on the calculated field length, this section takes the program to the location needed for interpolating for the line segment associated with the distance.

Computer Program (Cont'd.)

This section will compute the intercept and slope for line segments associated with distances of 10 to 60 feet.

250	76	LBL
251	17	B'
252	43	RCL
253	33	33
254	71	SBR
255	44	SUM
256	42	STO
257	01	01
258	75	-
259	02	2
260	95	=
261	71	SBR
262	53	(
263	43	RCL
264	37	37
265	71	SBR
266	44	SUM
267	42	STO
268	01	01
269	71	SBR
270	35	1/X
271	42	STO
272	38	38
273	43	RCL
274	36	36
275	71	SBR
276	44	SUM
277	42	STO
278	01	01
279	71	SBR
280	35	1/X
281	42	STO
282	39	39
283	71	SBR
284	43	RCL
285	06	6
286	09	9
287	32	X:T
288	43	RCL
289	33	33
290	77	GE
291	16	A'
292	71	SBR
293	52	EE
294	76	LBL
295	16	A'
296	43	RCL
297	37	37
298	71	SBR
299	44	SUM
300	42	STO
301	01	01
302	71	SBR
303	45	Y^X
304	42	STO
305	38	38
306	43	RCL
307	36	36
308	71	SBR
309	44	SUM
310	42	STO
311	01	01
312	71	SBR
313	45	Y^X
314	42	STO
315	39	39
316	71	SBR
317	61	GTO
318	61	GTO
319	15	E

Computer Program (Cont'd.)

This section will compute the intercept and slope for the line segment associated with distances of 61 to 500 feet.

```
320  76  LBL
321  12  B
322  43  RCL
323  33  33
324  71  SBR
325  44  SUM
326  42  STO
327  01  01
328  75  -
329  02  2
330  95  =
331  71  SBR
332  53  (
333  43  RCL
334  37  37
335  71  SBR
336  44  SUM
337  42  STO
338  01  01
339  71  SBR
340  24  CE
341  42  STO
342  38  38
343  43  RCL
344  36  36
345  71  SBR
346  44  SUM
347  42  STO
348  01  01
349  71  SBR
350  24  CE
351  42  STO
352  39  39
353  71  SBR
354  43  RCL
355  04  4
356  09  9
357  32  X:T
358  43  RCL
359  33  33
360  77  GE
361  13  C
362  71  SBR
363  52  EE
364  76  LBL
365  13  C
366  43  RCL
367  37  37
368  71  SBR
369  44  SUM
370  42  STO
371  01  01
372  71  SBR
373  23  LNX
374  42  STO
375  38  38
376  43  RCL
377  36  36
378  71  SBR
379  44  SUM
380  42  STO
381  01  01
382  71  SBR
383  23  LNX
384  42  STO
385  39  39
386  71  SBR
387  61  GTO
388  61  GTO
389  15  E
```

Computer Program (Cont'd.)

Steps 386 to 400 determine whether the program should go to step 401 or Section D' which is dependent on the distance.

Steps 401 through 458 calculate the intercept and slope for the desired line segment associated with distances 501 to 1500 feet.

```
390  76  LBL
391  14  D
392  01  1
393  05  5
394  00  0
395  00  0
396  32  X:T
397  43  RCL
398  00  00
399  22  INV
400  77  GE
401  10  E'
402  61  GTO
403  19  D'

404  76  LBL
405  10  E'
406  43  RCL
407  33  33
408  71  SBR
409  44  SUM
410  71  SBR
411  54  )
412  75  -
413  01  1
414  07  7
415  95  =
416  71  SBR
417  53  (
418  43  RCL
419  37  37
420  71  SBR
421  44  SUM
422  71  SBR
423  54  )
424  71  SBR
425  35  1/X
426  42  STO
427  38  38
428  43  RCL
429  36  36
430  71  SBR
431  44  SUM
432  71  SBR
433  54  )
434  71  SBR
435  35  1/X
436  42  STO
437  39  39
438  71  SBR
439  43  RCL
440  43  RCL
441  37  37
442  71  SBR
443  44  SUM
444  71  SBR
445  54  )
446  71  SBR
447  45  YX
448  42  STO
449  38  38
450  43  RCL
451  36  36
452  71  SBR
453  44  SUM
454  71  SBR
455  54  )
456  71  SBR
457  45  YX
458  42  STO
459  39  39
460  71  SBR
461  61  GTO
462  61  GTO
463  15  E
```

Computer Program (Cont'd.)

This section computes the intercept and slope for the desired line segment associated with distances 1501 to 5000 feet.

```
464  76 LBL        493  54  )
465  19 D'         494  71 SBR
466  43 RCL        495  24 CE
467  33  33        496  42 STO
468  71 SBR        497  39  39
469  44 SUM        498  71 SBR
470  71 SBR        499  43 RCL
471  54  )         500  43 RCL
472  75  -         501  37  37
473  01  1         502  71 SBR
474  07  7         503  44 SUM
475  95  =         504  71 SBR
476  71 SBR        505  54  )
477  53  (         506  71 SBR
478  43 RCL        507  23 LNX
479  37  37        508  42 STO
480  71 SBR        509  38  38
481  44 SUM        510  43 RCL
482  71 SBR        511  36  36
483  54  )         512  71 SBR
484  71 SBR        513  44 SUM
485  24 CE         514  71 SBR
486  42 STO        515  54  )
487  38  38        516  71 SBR
488  43 RCL        517  23 LNX
489  36  36        518  42 STO
490  71 SBR        519  39  39
491  44 SUM        520  71 SBR
492  71 SBR        521  61 GTO
```

Computer Program (Cont'd.)

This section computes E2' and prints E2, E3, and E2'.

```
522  76 LBL
523  15  E
524  43 RCL
525  41  41
526  65  ×
527  53  (
528  43 RCL
529  00  00
530  23 LNX
531  54  )
532  85  +
533  43 RCL
534  40  40
535  95  =
536  22 INV
537  23 LNX
538  42 STO
539  42  42
540  98 ADV
541  43 RCL
542  33  33
543  99 PRT
544  98 ADV
545  43 RCL
546  34  34
547  99 PRT
548  98 ADV
549  43 RCL
550  42  42
551  32 X:T
552  02  2
553  42 STO
554  35  35
555  32 X:T
556  71 SBR
557  34 ΓX
558  99 PRT
559  91 R/S
```

APPENDIX D

CROP RESIDUE AVAILABILITY PROGRAM, SECTIONS TWO - SIX

This part of the program contains sections two through six; the operating procedures and various options are explained below.

Comment	Area	Press	Print
1. Initial run			
a. Load card 1 and 2, all four sides			
b. Store area of field in memory 00	Area	Sto 00	--
2. Section 2 (Water Erosion)	--	B key	--
a. Rainfall factor "R" from Figure 10	"R"	R/S	"R"
b. Soil erodibility factor "K" from Tables 13 and 14 or Figure 9	"K"	R/S	"K"
c. Field length "L"	"L"	R/S	"L"
d. Factor for slope "M", Table 15	"M"	R/S	"M"
e. Slope gradient "S" (%)	"S"	R/S	"S"
f. Cropping management factor "C", Table 6	"C"	R/S	"C"
g. Erosion prevention practice "P", Table 16	"P"	R/S	"P"
Calculator now computes annual soil loss "A" if "A" + "E" (from Sectionl) >"T" (tolerable soil loss, Table 13 and 14, then try a different "C" and "P"			
h. To try different cropping management factor and erosion prevention practice		2nd B'	--
i. New "C" factor, Table 6	"C"	R/S	"C"
j. "P" factor, Table 16	"P"	R/S	"P"
New annual soil loss is computed; if "A" + "E" (Section 1) is $\leq$ "T", Tables 13 and 14, then note the amount of residue required to prevent erosion.			
3. Section 3, total crop and residue yield		A key	--
a. Estimated or actual yield	Yield	R/S	Yield
b. Residue-to-grain ratio, Table 7	Res./Grain	R/S	Res./Grain
c. Weight per unit of yield, Table 7	Weight	R/S	Weight
d. Moisture content in decimal form (i.e., 15% mc = .15) at crop yield reporting, Table 7	mc	R/S	mc
Calculator determines total above-ground yield of grain and residue (dry weight basis);	--	--	Above ground yield
also calculates in-field energy potential.	--	--	Energy potential in-field

Computer Program (Cont'd.)

Comment	Load	Press	Print
4. Section 4, Available Residue			
This section has three options: Option 1 is used to determine amount of crop residue available. Press "C". Option 2 determines amount of grain that is available, press 2nd C'; option 3 will calculate the amount of a portion of crop residue available i.e., corn cobs, press D'			
a. Determine Option	--	Option key, C, C', or D'	--
b. Depending on option load; for C total amount of residue needed for soil protection (dry weight)	Residue needed for soil	R/S	Net amount of residue available
or for C', total amount of grain to be used for conversion to fuel	Grain	R/S	total dry weight of grain available.
for D', enter weight component of desired residue as compared to units of yield, i.e., 9 lb. of cobs per buschel of grain	Residue component wanted	R/S	total dry amount available
5. Section 5, the energy balance		D	--
a. Estimated field, handling and storage losses in decimal form	Losses	R/S	Losses
b. Bioconversion efficiency, Table 17, in decimal form	"Eff"	R/S	"Eff"
c. Energy input into production of crop component, Tables 8 or 9	Production	R/S	Production
d. Energy input into component harvesting, Tables 8 or 9	Harvest	R/S	Harvest
e. Energy input into post-harvest processing, Tables 8 or 9	Post Har.	R/S	Post Har.
f. Nitrogen component factor for residue Table 10	"N"	R/S	"N"
g. Phosphorus component factor for residue, Table 10	"Ph"	R/S	"Ph"
g. Potassium component factor for residue, Table 10	"K"	R/S	"K"
Calculator determines net energy available	--	--	Net energy available

Computer Program (Cont'd.)

Comment	Load	Press	Print
6. Section 6, Transport Section		E	
a. Enter, in decimal form, amount of net energy wanted for work, not transport, i.e., 0.75 for work 0.25 for transport	Work	R/S	Work
b. Enter energy content of fuel used in transport vehicle, Table 9	Fuel	R/S	Fuel
c. Fuel consumption of transport vehicle	Consump.	R/S	Cons.
d. Volumetric space of transport vehicle	Space	R/S	Space
e. Bulk density of crop residue, Table 7	Bulk	R/S	Bulk
f. Moisture content of crop component at harvest not at crop yield reporting	MC	R/S	MC
Calculator then determines maximum radius each load can be transported.	--	--	Radius
and total number of loads	--	--	Loads

END OF PROGRAM.

Sample Print Out (English Units)

100.	"R"	
0.32	"K"	
100.	Dist.	
0.4	"M"	
4.	Slope	Section 2
0.07	"C"	
1.	"P"	
0.9	"A"	
100.	Yield (bu/Ac)	
1.	Residue/Grain	
56.	Lbs/Bushel	Section 3
0.155	Moisture content at crop reporting	
1100000.	Total dry pounds of crop above ground	
7700000000.	In-field energy potential (Btu)	
100.	Grain used (Bushels/Acre)	Section 4
568000.	Total dry pounds of grain available	Option 2
0.15	Losses	
0.6	Conversion efficiency	
7480000.	Crop production energy	Section 5
260000.	Harvest energy	
2000000.	Post-harvest energy	
0.0111	N factors	
0.0018	P factors	
0.0133	K factors	
6.8 08	Net energy available	
0.5	Portion of energy for work	Section 6
140000.	Energy content of fuel	
5.	Fuel consumption (mpg)	
2400.	Space, ft^3	
44.8	Bulk Density	
0.25	Moisture content at harvest	
1010.	Mile Radius	
6.	No. of Loads	

Listing of Sections and Subroutines

001	11	A
083	12	B
156	17	B'
181	13	C
214	18	C'
233	19	D'
250	32	XIT
264	14	D
378	15	E
450	34	ΓX

Computer Program, Section 3

This is Section 3 of the total program. The total amount of above-ground crop and residue are determined here as is the in-field energy potential. This will work for both English and metric units. However, for metric steps 65 through 68 must be changed to 16,000 KJ/kg instead of 7000 Btu/lb.

```
000  76  LBL
001  11   A
002  25  CLR
003  91  R/S
004  99  PRT
005  42  STO
006  01   01
007  65   ×
008  43  RCL
009  00   00
010  95   =
011  42  STO
012  02   02
013  65   ×
014  91  R/S
015  99  PRT
016  95   =
017  42  STO
018  03   03
019  85   +
020  43  RCL
021  02   02
022  95   =
023  42  STO
024  04   04
025  65   ×
026  91  R/S
027  99  PRT
028  42  STO
029  24   24
030  95   =
031  42  STO
032  05   05
033  65   ×
034  53   (
035  01   1
036  75   -
037  91  R/S
038  99  PRT
039  54   )
040  42  STO
041  25   25
042  98  ADV
043  95   =
044  32  X:T
045  01   1
046  42  STO
047  29   29
048  32  X:T
049  71  SBR
050  34  ΓX
051  42  STO
052  07   07
053  32  X:T
054  01   1
055  42  STO
056  29   29
057  32  X:T
058  71  SBR
059  34  ΓX
060  99  PRT
061  98  ADV
062  43  RCL
063  07   07
064  65   ×
065  07   7
066  00   0
067  00   0
068  00   0
069  95   =
070  42  STO
071  08   08
072  32  X:T
073  02   2
074  42  STO
075  29   29
076  32  X:T
077  71  SBR
078  34  ΓX
079  99  PRT
080  98  ADV
081  91  R/S
```

Computer Program, Section 2

This is Section 2 of the total program, the Water Erosion Section. The amount of soil loss due to water erosion is calculated here. Metric units or English units can be used. The input data presented in the tables and figures for this section are only given in English units.

```
082  76  LBL
083  12   B
084  25  CLR
085  91  R/S
086  99  PRT
087  65   X
088  91  R/S
089  99  PRT
090  95   =
091  42  STO
092  14   14
093  53   (
094  91  R/S
095  99  PRT
096  55   ÷
097  07   7
098  02   2
099  93   .
100  06   6
101  54   )
102  45  YX
103  91  R/S
104  99  PRT
105  95   =
106  42  STO
107  15   15
108  91  R/S
109  99  PRT
110  65   X
111  93   .
112  00   0
113  01   1
114  95   =
115  22  INV
116  30  TAN
117  38  SIN
118  42  STO
119  16   16
120  33  X²
121  65   X
122  06   6
123  05   5
124  93   .
125  04   4
126  01   1
127  95   =
128  85   +
129  53   (
130  04   4
131  93   .
132  05   5
133  06   6
134  65   X
135  43  RCL
136  16   16
137  54   )
138  95   =
139  85   +
140  93   .
141  00   0
142  06   6
143  05   5
144  95   =
145  65   X
146  43  RCL
147  15   15
148  54   )
149  65   X
150  43  RCL
151  14   14
152  95   =
153  42  STO
154  06   06
155  76  LBL
156  17  B'
157  25  CLR
158  43  RCL
159  06   06
160  65   X
161  91  R/S
162  99  PRT
163  65   X
164  91  R/S
165  99  PRT
166  98  ADV
167  95   =
168  42  STO
169  09   09
170  32  X:T
171  01   1
172  42  STO
173  29   29
174  32  X:T
175  71  SBR
176  34  ΓX
177  99  PRT
178  98  ADV
179  91  R/S
```

Computer Program, Section 4

This is Section 4. It is comprised of 3 options, which can use either metric or English units. The dry weight amount of the crop component is determined.

Option 1 determines total crop residue available (dry weight) by entering residue needed for the soil's maintenance.

Option 2 determines total grain available (dry weight) by entering amount of grain/hectare or acre to be used.

Option 3 determines portion of residue available, i.e., corn cobs by entering amount of portion compared to yield, i.e., 10 lbs. of cobs per bushel of grain.

Option 1

180	76	LBL
181	13	C
182	25	CLR
183	91	R/S
184	99	PRT
185	65	×
186	43	RCL
187	00	00
188	95	=
189	42	STO
190	10	10
191	43	RCL
192	07	07
193	75	-
194	43	RCL
195	10	10
196	95	=
197	42	STO
198	11	11
199	75	-
200	43	RCL
201	02	02
202	65	×
203	43	RCL
204	24	24
205	65	×
206	43	RCL
207	25	25
208	95	=
209	42	STO
210	12	12
211	61	GTO
212	32	X:T

Option 2

213	76	LBL
214	18	C'
215	25	CLR
216	91	R/S
217	99	PRT
218	65	×
219	43	RCL
220	00	00
221	65	×
222	43	RCL
223	24	24
224	65	×
225	43	RCL
226	25	25
227	95	=
228	42	STO
229	12	12
230	61	GTO
231	32	X:T

Option 3

232	76	LBL
233	19	D'
234	25	CLR
235	91	R/S
236	99	PRT
237	65	×
238	43	RCL
239	01	01
240	65	×
241	43	RCL
242	00	00
243	65	×
244	43	RCL
245	25	25
246	95	=
247	42	STO
248	12	12
249	76	LBL
250	32	X:T
251	98	ADV
252	43	RCL
253	12	12
254	32	X:T
255	02	2
256	42	STO
257	29	29
258	32	X:T
259	71	SBR
260	34	√X
261	99	PRT
262	98	ADV

Computer Program, Section 5

This is Section 5, the Energy Balance. It is set up for English units now. To change into the metric units change:

Steps 279 to 282 from 7,000 to 16,000.
Steps 316 to 320 from 27,778 to 63,500.
Steps 330 to 333 from 4,960 to 11,340.
Steps 344 to 347 from 3,968 to 9,070.

263	76	LBL
264	14	D
265	25	CLR
266	53	(
267	01	1
268	75	-
269	91	R/S
270	99	PRT
271	54	)
272	65	×
273	43	RCL
274	12	12
275	95	=
276	42	STD
277	12	12
278	65	×
279	07	7
280	00	0
281	00	0
282	00	0
283	95	=
284	42	STD
285	13	13
286	65	×
287	91	R/S
288	99	PRT
289	75	-
290	91	R/S
291	99	PRT
292	65	×
293	43	RCL
294	00	00
295	75	-
296	91	R/S
297	99	PRT
298	65	×
299	43	RCL
300	00	00
301	75	-
302	91	R/S
303	99	PRT
304	65	×
305	43	RCL
306	00	00
307	95	=
308	42	STD
309	14	14
310	43	RCL
311	12	12
312	65	×
313	91	R/S
314	99	PRT
315	65	×
316	02	2
317	07	7
318	07	7
319	07	7
320	08	8
321	95	=
322	42	STD
323	15	15
324	43	RCL
325	12	12
326	65	×
327	91	R/S
328	99	PRT
329	65	×
330	04	4
331	09	9
332	06	6
333	00	0
334	95	=
335	42	STD
336	16	16
337	43	RCL
338	12	12
339	65	×
340	91	R/S
341	99	PRT
342	98	ADV
343	65	×

Computer Program, Section 5 (Cont'd.)

344	03	3
345	09	9
346	06	6
347	08	8
348	95	=
349	42	STO
350	17	17
351	43	RCL
352	14	14
353	75	-
354	43	RCL
355	15	15
356	75	-
357	43	RCL
358	16	16
359	75	-
360	43	RCL
361	17	17
362	95	=
363	42	STO
364	18	18
365	32	X:T
366	02	2
367	42	STO
368	29	29
369	32	X:T
370	71	SBR
371	34	ΓX
372	52	EE
373	95	=
374	98	ADV
375	99	PRT
376	91	R/S

This
Eng
tot

Computer Program, Section 6

This is Section 6, the Transportation Section. It will work in either English or metric units. This section calculates maximum radius and total number of loads of crop residue.

377	76	LBL
378	15	E
379	22	INV
380	52	EE
381	25	CLR
382	43	RCL
383	18	18
384	65	×
385	53	(
386	01	1
387	75	-
388	91	R/S
389	99	PRT
390	54	)
391	55	÷
392	91	R/S
393	99	PRT
394	95	=
395	42	STO
396	19	19
397	65	×
398	91	R/S
399	99	PRT
400	55	÷
401	02	2
402	95	=
403	42	STO
404	20	20
405	91	R/S
406	99	PRT
407	55	÷
408	91	R/S
409	99	PRT
410	35	1/X
411	95	=
412	42	STO
413	21	21
414	43	RCL
415	12	12
416	55	÷
417	53	(
418	01	1
419	75	-
420	91	R/S
421	99	PRT
422	98	ADV
423	54	)
424	55	÷
425	43	RCL
426	21	21
427	95	=
428	42	STO
429	22	22
430	43	RCL
431	20	20
432	55	÷
433	43	RCL
434	22	22
435	95	=
436	42	STO
437	23	23
438	32	X:T
439	02	2
440	42	STO
441	29	29
442	32	X:T
443	71	SBR
444	34	ΓX
445	99	PRT
446	98	ADV
447	43	RCL
448	22	22
449	32	X:T
450	00	0
451	42	STO
452	29	29
453	32	X:T
454	71	SBR
455	34	ΓX
456	99	PRT
457	98	ADV
458	91	R/S

Computer Program (Cont'd.)

Subroutine

Subroutine $\sqrt{X}$ is used to round off the various output data generated throughout the program.

```
459  76 LBL
460  34 √X
461  52 EE
462  95  =
463  58 FIX
464  40 IND
465  29  29
466  52 EE
467  22 INV
468  52 EE
469  22 INV
470  58 FIX
471  92 RTN
```

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