TILLAGE PRACTICES FOR CORN PRODUCTION: A RESEARCH PROPOSAL FOR VENEZUELA

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ABSTRACT

TILLAGE PRACTICES FOR CORN PRODUCTION: A RESEARCH PROPOSAL FOR VENEZUELA

By

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This paper deals with an evaluation of the present status and development of tillage practices for corn production.

A primary objective in tillage research has been toward the definition of desirable soil conditions for the growing of plants in all stages while effectively conserving and utilizing the soil and water resources and to then create these conditions with tillage implements. For each use of soil, a separate and distinct soil property or condition may be required.

Water content, air content, soil temperature, and root impedance are the most important soil attributes which should be measured in understanding and evaluating tillage practices. Estimates of crop yield should be used to determine how any change in these conditions, through tillage operations, affects the final yield or ease of soil management.

Cutting tillage operations represents the greatest opportunity for reducing the costs of producing corn.

Reduced tillage can help to increase the water-holding capacity of the soil and also reduces erosion from wind and water. It can help to minimize compaction by decreasing the number of trips over the field. Some methods of reduced tillage incorporate crop residues into the soil more effectively than conventional tillage. This improves tilth and enhances air and water movement through the soil.

Systems of reduced tillage generally result in yields of corn similar to those produced with conventional tillage but the savings in time, equipment, and energy inputs make them more profitable.

A research proposal has been developed to compare conventional tillage with selected methods of reduced tillage which have been considered suitable for soil, climatic, and management conditions under which corn is produced in Venezuela.

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This work is dedicated to the late Professor Miguel Tinedo Gomez in appreciation for the enthusiasm with which he discussed the imperative need for the development of a comprehensive research program in agricultural mechanization in Venezuela, and for his tireless interest in teaching.

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INTRODUCTION

There has been a great deal of interest in tillage methods for corn in recent years. Modern farmers are operating at high levels of production, and since their costs have increased appreciably, the point has now been reached where there is a need to grow corn more economically. Reducing the number of tillage operations represents the greatest immediate opportunity for reducing the costs of producing corn. Tillage operations create peak labor requirements and effectively limit the acreage that can be handled. Reduction of tillage may ease peak labor loads and increase productive capacity of a given labor force. These factors have motivated reduced tillage operations which has recently gained popularity as a farming practice.

Within recent years, many modified methods of preparing soil for crop production have been introduced by agricultural engineers and agronomists. Emphasis has been placed on those new methods which would overcome the apparent disadvantages of the conventional and still most widely used method of seedbed preparation, which basically consists of plowing followed by disking and harrowing. With new tillage machines and progress in the use of herbicides many more choices are available for fitting the tillage practices to the needs of the soils and crops.

In Venezuela, tillage operations for corn production have experienced little change in the last 20 years. Farmers have been using tillage practices that have been directly transferred from countries with quite different ecological conditions. This has led to high production costs, undesirable soil compaction, small increases in yields--even with the introduction of improved varieties and wider use of fertilizers--and unpredictable effects upon the soil and water resources.

Therefore, it seems highly desirable to develop a rational research program in order to provide scientific information to either support or disprove the many claims made in relation to several tillage operations for modern crop production. This program would lead to the design of tillage systems that would meet the particular requirements of the soil, crops, and climate in Venezuela.

Objectives

This is an evaluation of the present status and development of tillage practices for corn production. The objectives of the study are summarized as follows:

1. To review the most significant information and advances related to tillage practices with special emphasis on corn production.
2. To compare some of the more common methods

of reduced tillage with the conventional or traditional tillage practices used to prepare seedbeds for corn.

3. To establish a research proposal to evaluate alternative methods of tillage for corn production under the particular ecological conditions of Venezuela.

I. ADVANCES IN TILLAGE OPERATIONS

1.1 Tillage Objectives

Tillage is the oldest and most fundamental activity of man in the production of crops. For many years it was looked upon as an art rather than a science. Only in recent years has research brought this subject to a more scientific level. A primary objective in tillage research has been toward the definition of desirable soil conditions for the growing of plants in all stages while effectively conserving and utilizing the soil and water resources and to then create these conditions with tillage implements (15,16,17).

Different soil types and climatic conditions require different soil and water management for most effective plant growth. Wind and water erosion are problems on some soils; in other areas moisture conservation is an important consideration; and in other places drainage is a problem. For each use of soil, a separate and distinct soil property or condition may be required. Furthermore, this required soil condition may be modified by economic factors (4,14,16,31).

Because of the infinite number of possible required conditions and the lack of quantitative descriptions for these conditions, the reasons for tillage have been used to describe the objectives of tillage (12, 31). Qualitative terms such as eradication of weeds, pulverization, and smoothing are frequently used to describe the reason for performing a particular soil manipulation. These qualitative descriptions, although very useful, have many limitations (31).

Brown (4) reports that from all the tillage experiments carried out in England during the past 30 years the general result was that the only cultivation significantly affecting final crop yield was that which achieved good control of all weeds, including seedlings. It was also shown that plants will tolerate a wide range of soil conditions.

Today it is widely accepted that cultivation is no longer the only possible method of weed control. This factor brings about the question of what general reasons remain for mechanically manipulating or cultivating the soil. Several researchers (4,16,17,31) have pointed out that in reality, only one objective exists and that is to produce a desired soil condition. The development of quantitative descriptions of soil conditions will enhance the establishment of criteria of performance.

1.2 Characterization of Soil Conditions

Recently a great deal of emphasis has been placed on determining the chemical, physical, and biological factors of the soil environment needed for crop growth (11). Complete knowledge of the changes in the soil physical conditions created with various tillage tools now in use is needed if more efficient and effective tillage techniques are to be developed.

Two soil zones have been identified in a field at the time of planting. Larson (11) termed the soil immediately around the seed and seedling roots the "row zone" or seedling environment zone and the soil between the rows the "interrow zone" or water management zone. This concept of two zones with different soil physical requirements for each is the basis of most reduced tillage systems.

Two of the most exacting requirements of a tillage system are that the seed be placed in proper position with respect to the soil and that the physical conditions of the soil be such that good stands and seedling growth are insured over a wide range of climatic conditions (4,12, 15,29,31).

In tillage, we are primarily interested in the immediate effect of tillage on soil conditions. Tillage cannot control conditions after tillage has been completed. Since a tillage operation is usually completed in a very short time, changes in soil conditions associated with time can be ignored. Usually those changes are separate and independent of tillage and may be studied by themselves (4,31).

Some attempts have been made to describe these conditions in more quantitative terms and they could be used in evaluating different tillage operations. Soil break-up, bulk density, segregation, mixing, and surface roughness are some of the soil conditions that have been measured and used to determine the performance of tillage tools and to evaluate tillage treatments (12,37).

Stranak (28) reports that there is evidence of close relationship between bulk density and yields of some cereals. Results from his experiments show that the best yields in all cereals were obtained on soils with the highest bulk densities. He states that the degree of soil density with cereals is decisive especially during the period from germination to tillering.

Several researchers (4,15,17,19,28,29) have reported that there is no consistent correlation between crop performance and soil structure. The reason is that a plant root system does not respond to changes in bulk density or porosity unless they are associated with changes in water content, air content, soil temperature and root impedance (4).

1.3 Soil Water

Availability of moisture to seedling plant roots is related to the soil moisture tension, the volumetric moisture content and the moisture transmission rate through the soil and across the root-soil interface (4).

Tillage will affect the soil moisture content through its effect on infiltration, runoff, temporary surface storage, internal storage and possibly drainage. It may also have some effect on evaporation (4,17,28).

The physical condition of soil surfaces often controls the amount of water entering the soil during a rain. Zone tillage in which the soil is tilled differently for the seedbed zone than for the area between crop rows offers management opportunities for conserving water and controlling erosion (4,17,20,21). In the water management zone between the crop rows, opportunities are present for influencing the surface detention of water, the porosity of the soil, and the resistance of the soil surface to change during rainfall (11,23). During an intense rain or irrigation, a soil surface with an uneven microrelief can store considerable water for later intake into the soil. Maximum surface detention of water is desirable on permeable soils where erosion control and moisture conservation are the major problems. Intermediate surface detention is desirable on slowly or moderately permeable soils where erosion control and excess moisture control are problems. In highly impermeable soils on flat topography where surface drainage is needed, little surface detention is desirable (15,16,17). Soils with uneven microrelief will often maintain a higher water intake rate than smooth soil surfaces because in the uneven microrelief the dispersed soil particles are eroded from the soil peaks into the depressions (20,21, 27).

Stranak (28) reports that the content of soil moisture increases adequately to bulk density. This indicates that the amount of water a soil retains may be influenced by the soil density and aggregate size. It has been shown that the volume of water retained per unit volume of air-dry aggregates decreased as the diameter of aggregate increased from 0.5 to 12 mm (15,16,17). When cultivation loosens the soil and increases the total porosity and proportion of large pores to the depth of working, then drainage and infiltration rates should be increased (28).

1.4 Soil Aeration

The two most important gases in the soil, oxygen and carbon dioxide, move through the soil from and to the atmosphere mainly by the process of diffusion (4).

Respiration by plant roots and by microorganisms depletes oxygen and releases carbon dioxide and minute quantities of other gases into the soil atmosphere. Therefore, a constant influx of oxygen and an outflux of respiratory gases are necessary for plant growth (15,17, 28).

Many researchers (15,16,17,28,31) have reported that insufficient oxygen in the soil frequently limits plant growth. While many measurements can be used as an index of oxygen availability to roots, the percentage of the soil occupied by air is probably as good an index as is available for field use. If the moisture percentage by weight and the bulk density of the soil are known, the air and moisture content by volume can be calculated.

In a soil with coarse aggregates and mainly large pores that are easily emptied by drainage, the concentration of oxygen in the soil air will remain close to that in the atmosphere. In soils where small pores predominate, moisture is firmly retained and oxygen movement is slower. By increasing the non-capillary pore space and assisting drainage, tillage can have significant effects on the soil atmosphere (4,17,28). Larson (16) reports that poor aeration affects corn plants in many ways, some of which are not completely understood. Symptoms may include wilting even in wet soils, greatly reduced growth rate, and lack of vigor. In prolonged cases, yellowing of the leaves is common and symptoms of various nutrient deficiencies may appear. Root hairs, important in absorption of nutrients and water, die. This is perhaps the cause of some of the symptoms shown by the above-ground plant parts (17).

1.5 Soil Temperature

Soil temperature affects plant development, grain yield, and nutrient content of corn (16,17,24,28). Most of the research on soil temperature for corn as related to tillage has been concerned with the effect of (a) microrelief, mulches, and density of the soil on temperature; (b) differences in soil temperature on corn growth during germination and seedling establishment; and (c) soil temperature on growth during the period of maximum dry matter production and shooting.

Allmaras, et al. (2) reported that corn growth early in the season increased linearly with soil temperatures from 60° to 81° F. and then decreased with further increasing temperatures at the four-inch depth. Growth rate decreases as temperature increases from 90° to 110° F. Corn growth ceases below about 50° F. and above 110° F.

Mulches or crop residues generally reduce soil temperature during the early season. The temperature of the seedling environment zone is reduced if it is in a furrow and increased if it is on a ridge or bed (14,16, 17).

1.6 Soil Resistance to Root Penetration

Soil temperature, water content and air content may affect root behavior, either by modifying the physical properties of the soil or by influencing the activity of the roots (4,9,28).

Mechanical impedance to plant roots and to plant shoots is related to the size and continuity of the soil pores and to the rigidity or mechanical strength of the soil (4,17,31). Bulk density can be used to calculate the total porosity of a soil if the particle density is known or assumed. Bulk density is a general indirect measure of mechanical impedance that can be used satisfactorily for a given soil type with a narrow range of texture and at a given moisture content.

Stranak (28) found that dense soil substantially influences the root growth of cereals. Roots do not penetrate so deeply as in loose soil, but their total number and especially the proportion of root hairs increase. He found that at the end of the tillering period of cereals the total root surface is 50 per cent higher in very dense soil when compared with loose soil.

There is evidence that heavy agricultural equipment traffic has a negative effect by excessively increasing bulk density and reducing root proliferation in a significant volume of soil (9,14). There is also evidence that this traffic reduces yield as well.

1.7 Parameters for Evaluating Tillage Systems

Larson (16) has proposed an example tillage guide for corn in the western corn-belt of the United States which consists of selected soil parameters and estimated critical limits discussed in view of research data (see Table 1).

TABLE 1.--Suggested Soil Parameters for Evaluating Tillage Systems in the Western Cornbelt and Critical Limits for Two Hypothetical Soils

Parameters	Critical Limits	
	Medial Brunizen 10% slope	Planosol < 1% slope
Water Management Zone		
Depression Storage, inches	>2.0	<1.0
Plow-layer Storage, inches[1]	>2.0	>1.5
Surface Structure Maintenance maximum rate of mulch, tons/acre	<1.0	0.0
or surface microrelief[2]	8	1.0
Seedling Environment Zone		
Soil Temperature, maximum negative deviation from standard, °F[3]	1.0	0.0
Secondary aggregate, GMD,[4] mm	5.0	5.0
Bulk Density, g/cc	1.0-1.4	1.0-1.4
Width × depth of zone, inches	6.0×7.0	6.0×7.0

[1]Expressed as inches of air porosity at field capacity in a 7-inch soil depth.

[2]This value corresponds to one of a series of photographs showing various microreliefs.

[3]The standard temperature is defined as the average soil temperature at the 4-inch soil depth on the given soil with no mulch or crop cover and smooth microrelief.

[4]GMD = Geometric Mean Diameter.

Source: Taken from Larson (16).

The desired requirements listed for the seedling environment zone reflect the conditions generally thought necessary for good germination and growth of the seedling. The requirements for both the water management and seedling environment zones apply equally well for tillage systems where the entire soil surface is tilled, where only a portion of the surface is tilled, or where no tillage other than seed placement is done (4,12,16,17,31).

Brown (4) has proposed a list of parameters to evaluate the effect of tillage operations on soil conditions. Some of these parameters can be measured in space and in time, but others must await further development of adequate techniques (see Table 2).

Many experiments (3,4,8,17,20,21) to evaluate different tillage operations have relied on the yield of test crops as a measure of the response to a given treatment. It should be kept in mind that crop yield depends on many other factors and interactions. However, estimates of crop yields, plant population stands, height of the plants, and yield of green mass may be useful in evaluating tillage systems. These measures give an indication of how changes in soil physical conditions produced by tillage affect the final yield.

In addition to the parameters discussed above there are several other factors which have been widely used in tillage experiments for evaluating different treatments (3,4,15,16,17,30,31,32). Among these are the following:

TABLE 2.--Parameters to Evaluate the Effect of Tillage Operations on Soil Physical Conditions

Factor	Variables (Time and Space)		
	Intensity	Capacity	Rate
1. Soil Water	Water Potential	Volumetric Moisture Content	Permeability
2. Soil Air	Partial Pressure of Important Components	Volumetric Gas Content	Diffusion Coefficient
3. Soil Temperature	Temperature	Specific Heat	Thermal Conductivity
4. Root Impedance	Root Pressure	Root Volume	Root Extension

Source: Taken from Brown (4).

a. Energy requirements

b. Labor-time requirements (field capacity)

c. Operation costs

d. Soil nutrient contents as affected by tillage operations

e. Microorganism activity

f. Soil losses (erosion)

The use of particular parameters is closely related to the objectives pursued with tillage operations. For instance, some of the parameters that would be used where the major consideration is control of wind and water erosion probably would be different from those used where the economic conditions are limiting.

II. TILLAGE PRACTICES FOR CORN PRODUCTION

2.1 Tillage Methods

Today there are numerous systems of tillage used in the United States and other developed countries, but the most prevalent system for row crop production includes the use of a moldboard plow, chisel plow, or rotary tiller. Field operations with these tools are known as "primary tillage." In the "cornbelt" of the United States such operations are regularly performed in the fall or winter on clay loam or clay soils with slope < 2-4 per cent, but should be delayed until a few weeks before planting on soils with a surface texture containing less than 30 per cent of clay or where erosion is a hazard (30).

Secondary tillage before planting may employ a variety of tools in one or more operations: disking, spiketooth and springtooth harrowing, or field cultivation.

In recent years, the trend has been toward reduction of tillage between plowing and planting. Many devices have evolved that till a strip of soil in the row to facilitate satisfactory planter functioning with soil between the rows left untouched.

In the following sections definitions for different tillage methods for corn are given.

Conventional.--A system of soil preparation for planting, customarily used in the "cornbelt" of the United States, which includes plowing with a moldboard plow, disc harrowing two or more times, and planting. The conventional plowing system usually prepares a firm seedbed that is relatively free of clods and composed of finely divided soil aggregates.

Minimum tillage.--Minimum tillage, also called reduced tillage, is any soil preparation method for planting in which the number of operations and trips over the field is less than in the conventional system of practices. The term is used to refer to variations ranging from slightly modified tillage systems to elimination of preplanting soil preparation (3,6,8,13,14,17).

Modified tillage systems which do not eliminate soil preparation operations include "wheel track," "plow-plant," "moldboard listing," "chisel-planter," and rotary "tiller-planter." These systems reduce the number of field operations, but do not necessarily reduce the power and energy requirements or the extent of soil working. Other systems such as till planting and mulch planting nearly eliminate soil tillage and seeding is accomplished with compatibility with the existing surface materials (1,14,17,30,32).

Plow-plant.--The plow-plant method includes the plowing, conditioning the row zone and planting operation in one field operation. Planting units are mounted on the plow or tractor.

Wheel-track.--After plowing in a previous, separate operation the planting is done in the firmed soil of a wheel track. A number of commercial wheel-track planters are available (17).

Listing.--In this method, sweeps or lister moldboards are used to construct deep, open furrows. Seed is placed in the bottom of the furrow in one operation. Listing after plowing is called loose-ground listing; listing unplowed ground is called hard-ground listing.

Strip.--A strip method of soil preparation is any method in which soil conditioning for planting is limited to strips in and adjacent to the seed row. The remaining area may or may not be tilled. Commercial implements that mount on the planter or immediately precede the planter are available (1,17).

Till-planting.--In this method, the soil is loosened with a sweep, followed by a light tillage tool in the row, such as a few wheels of a rotary hoe, and a planting unit. A number of till planters are available commercially (1,17).

Rotary tillage.--A rotary tiller usually consists of spring steel hooks or knives that rotate at very high speed while the implement is drawn through the soil. It offers an opportunity to chop residues, loosen the soil, break clods, and thus prepare a seedbed in one trip over the field. In recent years, rotary tillers with many variations have become available on the market.

2.2 Comparison of Tillage Systems for Corn

The apparent major benefits from a given tillage treatment differ somewhat according to climate, topography and soil type.

Extensive research by many scientists in recent years has to some extent provided estimates of these benefits. It has at the same time exposed numerous related factors requiring subsequent investigation. In the following sections the effects of reduced tillage operations on soil conditions, crop response, and many other important aspects of corn production, as compared to the conventional tillage systems will be discussed.

2.3 Effect on Soil Physical Conditions

Swamy *et al.*(29) found that minimum tillage (wheel-track) produced lower bulk density throughout the growing season and even after winter weathering. Although minimum tillage resulted in lower bulk density, both in corn rows and in the compacted tractor rear wheel tracks, the difference due to tillage was more evident in the latter case. Table 3 presents the reported changes in soil conditions due to tillage treatment.

TABLE 3.--Changes in Soil Physical Measurements Due to Tillage Treatments

Soil Physical Property	Conventional Tillage	Minimum Tillage	Change for Minimum Tillage Percent[1]
Infiltration rate, 1"/hr[2]	7.7	14.1	+83
Resistance to penetration, blows to 8" depth[2]	32	16	-50
Bulk density, g/cc[2]	1.23	1.14	- 7
Soil moisture, percent	26.3	25.9	- 2
Clod size			
Above 9.5 mm			
After planting, percent	30	34	+13
After winter weathering	12	10	-17
Below 1.2 mm			
After planting, percent	25	15	-40
After winter weathering	61	61	0

[1]Conventional tillage equals 100.

[2]Averages for all four sampling times in the corn row.

Source: Taken from Swamy, *et al*. (29).

According to these data, minimum tillage resulted in the following improved soil physical conditions:

Higher rate of infiltration

Less soil resistance to penetration

Lower bulk density

Less soil compaction

Mannering et al. (20,21) found that aggregation, organic matter content and porosity were slightly higher on minimum tillage.

When using the till-plant system, the soil within the rows is not subjected to pressure from the wheels of tractors or implements and the root action maintains soil bulk density at a satisfactory level. With narrow rows (50 cm) the compaction from tractor tires may radiate from the point of contact to a position under the row. With wide rows (90-100 cm) this has not proved to be a problem (23).

There is conclusive evidence that heavy tractor traffic increases bulk density of soil and reduces root proliferation in a significant volume of soil. There is evidence that this traffic also reduces yield. Therefore, running over the tilled soil with heavy equipment is not a proper procedure for crop production where maximum soil compaction is not the objective (14,23).

2.4 Effect on Infiltration, Runoff and Erosion

A number of experiments have been concerned with the effect of various tillage treatments for corn on runoff, infiltration and erosion.

Wittmuss (32) found that soil losses from corn stubble prior to tillage are very low (1 ton per acre). Soil losses were increased 200 per cent by till planting and 1,000 per cent by conventional tillage (see Table 4).

TABLE 4.--Average Soil Loss and Water Infiltration Capacity Using Simulated Rainfall on Runoff Plots at North Platte, Nebraska[1]

	Soil Loss per Rainfall[2] tons/acre	Infiltration inches
Non-tilled[3]	0.7	1.2
Till-planted	3.3	1.0
Conventional tillage	9.4	1.1

[1]Simulated rainfall applied after corn was planted but prior to the development of a crop canopy cover.

[2]Values are an average of one 2.5 iph 60 minute and one 4.0 iph 18 minute rainstorm.

[3]No crop planted on non-tilled plots.

Many researchers (3,6,17,20,21) have reported the beneficial effects of surface residues retained by seeding without tillage. Mannering *et al*. (20) found that the relative soil loss reduction attributed to minimum tillage declined from first through fifth year of corn after-meadow. Reductions in soil loss from minimum tillage when compared with conventional tillage were 44 per cent, 34 per cent, and 27 per cent, respectively, from 1, 3, and 5 years of corn after meadow.

Traditional tillage practices of plowing and plowing followed by disking and harrowing usually leave the soil surface "clean" or void of crop residues. Rain falling on these bare surfaces washes fine soil into the depressions and open channels, resulting in progressive soil sealing (5,6).

Burwell, *et al*. (5,6) found that average infiltration of rainfall before runoff began on freshly plowed surfaces was at least twice that on freshly plowed-disked-harrowed or rotary tilled surfaces. Correlation analyses were made to test the influence of the soil parameters listed in Table 5 on infiltration. Random roughness alone accounted for 50 per cent of the variation in initial runoff; all parameters jointly accounted for 59 per cent. Thus, the random roughness of freshly tilled surfaces has considerable influence on infiltration before initial runoff. Therefore, if water is to be retained, clean tillage practices should create rough soil surfaces that resist sealing. The findings of Burwell, *et al*., emphasize the need to use crop residues as surface mulches on cropland where traditional tillage practices limit rainfall infiltration in the early part of the cropping season when runoff and erosion are most likely to occur.

Tillage practices that employ sweeps and lister moldboards also leave considerable amounts of plant residues on the surface which protect the surface from the energy of raindrops and, hence, help prevent sealing (17).

TABLE 5.--Simple Relationship of Soil Parameters to Infiltration

Soil Parameter	Range After Tillage	To Initial Runoff		Range at Initial Runoff	During 2-inch Runoff	
		B values	r^2 values[1]		B values	r^2 values
Random Roughness	0.28"-2.29"	3.38	0.50	0.23"-1.93"	1.12	0.16
Pore Space (Tilled layer)	3.63"-6.82"	0.43	0.04	3.16"-6.67"	0.10	0.01
Particle Size (Tilled layer)						
Sand	28.4%-47.8%	0.08	0.06	28.4%-47.8%	0.06	0.19
Silt	22.8%-41.7%	0.01	0	22.8%-41.7%	0.01	0
Clay	16.9%-40.1%	0.07	0.06	16.9%-40.1%	0.06	0.22
Antecedent Moisture	5.8%-34.6%[a]	0.07	0.10	0.5%-22.1%[b]	0.01	0

B = linear coefficient of correlation. r^2 = quadratic coefficient of correlation.

[1] r^2, when all parameters were considered jointly, was 0.59.

[a] Antecedent moisture for zero to .6-inch tilled layer.

[b] Antecedent moisture variable is the inches of water applied to initial runoff.

Source: Taken from Burwell, *et al.* (7).

2.5 Effect on Time, Equipment and Energy Savings

Each field operation can be performed over a period of time, but there is only one point of time when conditions are optimum for its performance. Deviations from that optimum period incur costs in terms of reduced yields. Tillage operations cannot be performed instantaneously, so farmers attempt to minimize losses from untimeliness of operations by starting a little early and ending a little after the optimum time.

All operations are subject to losses from untimeliness, but planting of corn is considered to be a more sensitive factor than any of the other preharvest operations (13).

Wittmuss (32) reports 2.05 man hours per acre for corn production by conventional tillage versus 1.19 hours per acre when tillage operations are eliminated (see Table 6).

According to the data presented, the labor required for till-planted and lister-planted was respectively 35 per cent and 42 per cent less than for conventionally planted corn.

Morris (23) indicated that mechanical energy inputs are reduced approximately 40 horsepower hours per acre by till-planting as compared to conventional tillage. The operating costs thus saved are real and creditable to increased profit.

TABLE 6.--Labor Requirements for Three Crop Production Methods

Operation[1]	Man Hour per Acre		
	Conventional	Lister	Till-Plant
Cut stalks	0.14	0.14	0.14
Disk	0.14	0.14	--
Plow[2]	0.39	--	--
Harrow	0.14	--	--
Plant	0.21	0.21	0.21
Rotary hoe	0.10	--	--
Cultivate	0.23	0.14	0.14
Cultivate	0.14	0.14	0.14
Harvest	0.56	0.56	0.56

[1]Field efficiencies taken at 80 per cent for all operations except planting and harvest, 65 per cent. Operating speed taken at 5 mph except for planting, 4 mph; rotary hoe, 7 mph; first cultivation, 3 mph; harvest, 3 mph.

[2]Width for all equipment taken at 15 ft, except plow at 5-1/3 ft (4-16").

Source: Taken from Wittmuss (32).

Rossman and Cook (26) reported that the power consumption for rotary tillage as compared with eight other treatments including different implements and combinations of implements was approximately two or three times the horsepower of any of the other systems.

2.6 Economic Factors: Costs and Returns

Wittmuss (32) reported that the tillage costs were respectively \$7.54, \$8.79 and \$14.12 per acre for till-planted, lister planted and conventionally planted corn (see Table 7). The till-planted and lister-planted tillage costs were respectively reduced 47 per cent and 38 per cent compared to conventionally planted corn.

TABLE 7.--Field Costs for Three Crop Production Methods

Operation	Dollars per Acre[1]		
	Conventionally Planted	Lister Planted	Till Planted
Cut stalks[2]	$ 1.62	$ 1.62	$ 1.62
Disk	1.58	1.58	--
Plow	3.52	--	--
Harrow	1.20	--	--
Plant[3]	1.95	2.31	2.64
Rotary hoe	0.97	--	--
Cultivate[4]	1.64	1.64	1.64
Cultivate[4]	1.64	1.64	1.64
Total Field Costs per Acre	$14.12	$ 8.79	$ 7.54

[1]Farm custom rates paid in Nebraska in 1966, University of Nebraska, E.C. 87-806 used to compute costs.

[2]Stalk-cutting operation replaces one disking operation.

[3]All planters equipped with fertilizer and band application attachments.

[4]Cultivators equipped with fertilizer attachments.

Source: Taken from Wittmuss (32).

The approach used by Wittmuss involves the use of custom rates that include all costs: fixed and operating, including labor.

Linear programming solutions using the assumption that the average yield from reduced tillage does not differ significantly from that for conventionally planted corn planted on the same day is another approach which may be used to compare costs for different tillage operations (14,23).

Holler and Van Arsdall (13) evaluated conventional tillage with selected methods of reduced tillage on Illinois grain farms. Under the conditions of this study it was estimated that conventional tillage requires 12 separate pieces of equipment, two of which are 40-drawbar horsepower tractors. The combination of decreasing number of implements with increasing size of tractor leaves annual overhead cost, based on new equipment, at about the same level for each of the methods of tillage (see Table 8).

TABLE 8.--Investment and Overhead Costs of Equipment for Selected Methods of Tillage and for Harvesting, 1965*

Operation	Number of Implements	Drawbar HP of Tractors[1]	Initial Investment	Annual Overhead Cost[2]
Conventional Tillage	12	40, 40	$14,270	$2,295
Wheel-track Tillage	10	40, 56	15,380	2,404
Rotary Tillage	6	40, 70	14,615	2,374
Harvesting[3]	6	----	9,255	1,514

*Based on four-row equipment needed for handling a rotation including 50 per cent of tillable acres in corn, 30 per cent in soybeans, 15 per cent in small grain, and 5 per cent in grass and legumes.

TABLE 8.--Continued.

[1]Two tractors are used.

[2]Annual overhead costs range from 11 to 18 per cent of initial investment depending on the equipment.

[3]The complement of harvesting equipment is not affected by the method of tillage.

Source: Taken from Holler and Van Arsdall (13).

Savings in operating costs as a result of reduced tillage, however, more than offset the higher overhead costs of those systems. Total preharvest and harvest labor and variable machinery costs average $7.34 per tillable acre when the conventional method of tillage is used. Wheel-track planting reduces these costs to $6.75 per tillable acre. Rotary tillage cuts costs to $5.90 per acre, $1.44 less than with conventional tillage (13).

Holler and Van Arsdall also report that the cost advantage over conventional tillage is $364 for wheel-track planting and $1,073 for rotary tillage. With only 100 tillable acres, rotary tillage performs more economically than conventional tillage, but wheel-track planting does not have a cost advantage until nearly 200 acres are handled (see Table 9).

TABLE 9.--Comparison of Total Labor and Machinery Costs for Preharvest Operations, Adjusted for Differences in Harvesting Costs, for Selected Methods of Tillage, Illinois, 1965[a]

Number of Tillable Acres	Total Labor and Machinery Costs			Cost Advantage of	
	Conven-tional	Wheel-Track	Rotary-Tillage	Wheel-Track over Conventional	Rotary-Tillage over Conventional
100	$2,741	$2,790	$2,676	$-49[b]	$ 65
200	3,187	3,177	2,972	10	215
400	4,079	3,951	3,582	128	497
600	4,971	4,725	4,186	246	785
800	5,863	5,499	4,790	364	1,073

[a]Cost estimates are based on use of new equipment with each method.

[b]Conventional tillage has cost advantage of indicated amount.

Source: Taken from Holler and Van Arsdall (13).

2.7 Effects on Germination, Stand and Yield Performance

Uniform placement of seed in firm contact with moist soil is more characteristic of planting with minimum tillage than with conventional tillage systems. This is particularly true if unfavorable conditions exist, e.g., cloddy soil, stony soil or shortage of moisture. Consequently, germination is often 3 to 5 days earlier (14). With minimum tillage, however, it has been found (3) that in some cases minimum tillage tended to produce an uneven rate of planting of corn, and uneven germination, expecially on soils with a high clay content.

Stand and yields are not consistently and significantly different between minimum and conventional tillage systems. Where similar plant populations occur, corn yields have usually been about equal from reduced and conventional tillage systems (3,14,17,18,23). The possibility of yield increases exists, but evidence is insufficient to justify such a claim at present.

Reduced tillage of the space between the rows discourages the growth of weeds while at the same time creating a more favorable medium for the spread of corn roots. Corn requires a seedbed of a fine granular consistency that can be firmed around the seed for quick germination. Conventional tillage provides such a seedbed, but it also provides an ideal environment for germination of weed seeds between the rows of corn. Most reports involving little or no tillage suggest chemical weed control.

Olson and Schoeberl (24) compared the average yield of corn harvested as grain from four types of tillage treatments. The 4-year averages for the years 1965, 1966, 1967 and 1968 are shown in Table 10. Analysis of variance disclosed no significant difference in corn yield in any year or in the 4-year average. The two non-plowing treatments, till-planting and listing, tended to have higher average yields than either of the two plowing treatments. Conventionally tilled corn averaged the least grain yield in each year, except 1966 when wheel-track-planted corn yielded slightly less.

TABLE 10.--Average Grain Yields from Each of Four Tillage Methods for Corn (Yield, kg/ha)

	Tillage Method			
Year	Conventional	Wheel-track	Till-plant	Listed
1965	2,486	2,730	3,207	2,517
1966	2,850	2,781	2,988	3,145
1967	2,027	2,360	2,630	2,931
1968	2,910	3,062	3,197	3,012
Average	2,568	2,733	3,006	2,901

Source: Taken from Olson and Schoeberl (24).

Table 11 shows the effect of tillage operations on stand, weed control and yield using different preplant

TABLE 11.--Effect of Preplant Herbicides and Tillage Operations on Stand, Weed Control, and Yield--1969

	Plants/A x 10^{-3}	Weed* Rating	Yield bu/A @ 15.5%
Ramrod + Atrazine 2+1			
Disk	22.4	1.3	125
Strip rotary	24.0	1.3	127
Till plant	20.0	2.6	101
No till (FC)	23.7	1.6	120
Atrazine 3			
Disk	22.2	0.9	123
Strip rotary	24.4	0.9	132
Till plant	19.4	1.9	97
No till (FC)	23.9	1.5	116
Ramrod pre Atrazine post			
Disk	22.3	1.9	121
Strip rotary	23.6	2.2	123
Till plant	21.0	3.0	108
No till (FC)	23.5	2.9	111
No chemical			
Disk	16.2	5.0	71
Strip rotary	15.7	4.4	76
Till plant	20.5	4.7	102
No till (FC)	18.2	4.8	91

*0-5; 0 = no weeds.

Source: Taken from Lovely and Buchele (18).

herbicides. According to these data, strip rotary systems resulted in a higher stand per acre when preplant herbicides were applied. When no chemical was applied, till-plant systems resulted in appreciably higher population of plants per acre. When herbicides were used, the relative weed population was higher under the till-plant system as compared to the other methods. No significant differences were observed in weed population for any of the tillage methods when no chemical was applied. Strip-rotary system and conventional tillage resulted in greater yields when preplant herbicides were applied and till-plant was more productive under no chemical application (18).

2.8 Other Effects

Several researchers have been concerned about the potential effect of tillage, through its influence on crop residues, on harboring insects and pathogenic organisms and vectors.

Morris (23) cites that till-planting delays root worm infestation by 5 to 10 days, perhaps resulting from scraping the egg-laden layer away from the seed row in planting.

Kleis (14) cites research information which indicates that crop residues do not significantly carry over into subsequent years. By harvest the till-planted field can hardly be differentiated from the pretilled field.

There is evidence that tillage operations influence the nutrient availability in soil through their modifying influence on soil, water, soil air, soil temperature, and root growth (17).

Table 12 indicates the soil PH, available phosphorus, and available potassium for ridge and conventional

TABLE 12.--Soil PH, Available Phosphorus and Available Potassium for Ridge and Conventional Planting* Ames, Iowa, 1968

	PH		P - lbs/A		K - lbs/A	
	Ridge	Flat	Ridge	Flat	Ridge	Flat
In row						
0-3 inches	5.98	6.10	226	81	717	191
3-6 inches	6.26	6.19	158	72	577	147
6-9 inches	6.42	6.54	124	76	420	152
9-12 inches	6.55	6.91	105	53	389	153
12-15 inches	6.91	6.67	82	23	398	102
7.5 in. from row						
0-3 inches	6.17	6.40	183	77	636	221
3-6 inches	6.34	6.45	122	76	454	185
6-9 inches	6.57	6.54	104	71	413	165
9-12 inches	7.02	7.12	67	42	400	126
12-15 inches	7.11	7.41	40	15	386	57
15 in. from row						
0-3 inches	6.30	6.39	160	67	612	106
3-6 inches	6.49	6.47	109	78	539	209
6-9 inches	7.00	6.52	80	58	478	172
9-12 inches	7.22	6.97	98	33	450	117
12-15 inches	7.20	7.12	61	14	507	94

*Following 4 years of continuous corn.

Source: Taken from Lovely and Buchele (18).

planting after following four years of continuous corn. These data show that the ridge-planting system substantially affects the phosphorus and potassium availability as compared to the conventional system (18).

2.9 Practical Limitations of Reduced Tillage

Most reduced tillage methods now in use in the cornbelt of the United States either combine conventional operations or use a machine that requires a large tractor. This often results in excess tractor capacity for farm operations other than tillage (13).

Farmers commonly correct errors from preceeding tillage operations in the following operation. A disadvantage of till-planting is that operations are reduced so much that little opportunity to correct errors is provided (13,23).

Use of some methods of reduced tillage may limit the size of an opertion more than the use of conventional equipment and methods. Some methods of reduced tillage can be performed only with two- or four-row equipment because of high power requirements or size of equipment available. Also, successful use of a reduced tillage system usually requires a high level of management. Some farmers have neither the soil condition nor the managerial ability to handle reduced tillage successfully (13).

Another limitation for most farmers to change from one method of tillage to another is the consideration of possible losses that might be incurred in trading existing conventional equipment for equipment required for reduced tillage operations. The advantage of reduced tillage systems over conventional tillage decreases when useable equipment must be traded or sold. Holler (13) indicates that 700 tillable acres are needed to justify changing from conventional equipment at half life to wheel-track planting.

III. RESEARCH PROPOSAL

Project Title: Evaluation of Tillage Systems for Corn Production in Venezuela

3.1 Justification

3.1.1 Importance of Corn Production in Venezuela

Corn is one of the most important crops in Venezuela. In 1969 corn was grown on 641,053 hectares throughout the nation. This figure represents 34 per cent of the total crop land harvested and about 84 per cent of the land used for cereals the same year. The value of corn production represented 6.3 per cent of the total value of agricultural production in 1969 (22).

Special promotion for corn production in Venezuela has been sponsored by the Ministry of Agriculture and Livestock and some other official institutions. The number of small farmers--campesinos--involved in this promotional effort in 1970 was 25,566. The most important technological advances used under this plan include: soil improvement, appropriate soil preparation, use of improved varieties and hybrids, weed control, fertilization practices, and harvesting and storage facilities (9,10). Despite this tremendous effort to increase the production of corn in Venezuela, yields have continued almost at the same level during the past ten years.

Table 13 shows a comparison of international corn yields for the year 1967.

TABLE 13.--International Comparison of Yields of Corn, 1967

Country	Yield (kg/ha)
Canada	5,310
United States	4,930
Chile	3,930
Argentina	2,470
Peru	1,630
Brazil	1,390
Paraguay	1,300
Mexico	1,200
Venezuela	1,194
Bolivia	1,190
Colombia	950
Ecuador	630
Uruguay	520

Source: Taken from Ministerio de Agricultura y Cría (22).

This table shows that corn yield in Venezuela is still considerably below the yields reached in more developed countries. One reason for this situation could be the fact that about 350,000 ha (more than 50 per cent of the total) of corn is grown on marginal lands where the average yield is below 700 kg/ha. However, on larger farms, which account for about 100,000 ha, the average yield of 1,800 kg/ha is still very low.

3.1.2 Tillage Practices for Corn Production in Venezuela: Current Situation

Tillage practices for corn production in Venezuela have not changed very much since 1950. Most Venezuelan farmers work a seedbed until it is fine and firm. To get this kind of seedbed many tillage operations are required.

Some years ago it was popular among farmers to use disk plows for primary tillage. Under proper conditions two trips with a disk plow over the field were considered necessary. After primary tillage, two or more disking operations (disk harrows) were used and in some cases farmers used a spike-tooth harrow to smooth the seedbed.

Because of the high cost of tillage operations and the need to prepare the soil during short intervals of time, the trend in recent years has been toward the elimination of plowing operations. But in order to get a fine and firm seedbed, several disk-harrowing operations are needed in each field. There is no available information on the number of trips with the disk-harrow used. Opinions about the amount of tillage a soil requires to produce an appropriate environment for the seed vary from one farmer to another and from one place to another.

Tillage has received little attention from research workers in Venezuela, particularly in relation to operation costs, effects on soil physical properties and crop yields.

Some experimentation in this field has been initiated in the Shell Agricultural Experimental Station in Cagua, but few results are available. FOREMAIZ, an institution devoted to the development of corn production in Venezuela, has carried on some experimentation related to planting systems for corn (9,10).

Many of the small farmers in the western part of the country have used cultivation in lands where the seasonal rainfall is too high and poor drainage is the limiting factor.

Planting corn on the ridge has reportedly increased yields from 930 kg/ha (under conventional planting) to 2,000 kg/ha in these areas. In this method the soil is prepared in the conventional way and the planting operation is done using an implement which builds the ridge (9,10).

Significant differences exist in the ecological conditions of the regions where corn is planted. In the eastern part of the country corn is planted later in the season and moisture deficiency is a serious limitation for corn production. In many other regions corn is planted on lands subjected to serious erosion. However, the tillage practices are nearly the same for the different physiographic areas no matter what the management problems are. High tillage operation costs, soil structure deterioration, and yield reductions are some of the most significant consequences of this situation. These considerations seem to indicate the need for a wide research program in land preparation for corn production in Venezuela.

3.2 Research Objectives

1. To compare under experimental conditions various forms of reduced tillage with conventional practices followed by Venezuelan farmers. Accomplishing this first objective would provide experimental information for immediate use by farmers concerning the effects of several tillage treatments in relation to the following items:
   a. Effect on soil physical properties;
   b. Corn response to tillage treatments;
   c. Economic feasibility of the tillage systems under study; and
   d. Provide information for further research.
2. To investigate the effect of tillage treatments, over a period of years, on selected soil properties and to determine tillage needs for corn production for specific geographical regions in Venezuela. In order to accomplish this second long-term objective, the following aspects would be investigated:
   a. To characterize the soil physical properties and corn response to tillage treatments in heavy textured soils, which account for about two-thirds of the cultivated land in the country;

b. To establish the relationship between specific soil parameters and corn yields;

c. To determine residual effects of several tillage treatments on soil properties with emphasis on the conservation of soil and water resources.

3.3 Selecting the Experimental Site

It was shown in previous sections of this report that reduced tillage methods permit the production of corn at levels close to that normally obtained with conventional tillage. In many cases the profit picture, even with reduced yields, favors the reduced tillage procedures. It is accepted that needless or detrimental tillage operations should be avoided, and that by discontinuing them the profit may increase due to reduced expenditures and, in some cases, due to increased yield.

The key to success with minimum tillage is to adapt the selected method to the soil conditions and climatic characteristics of a given region.

It would be most desirable to start a research program on tillage practices for corn production in the physiographical region of Portuguesa State.

Portuguesa State is the region where the most intensive crop production is carried out in the country. The corn harvested area in Portuguesa State reached 116,104 ha in 1969, with a total production of 131,894 tons and an average yield of 1,136 kg/ha (22).

Corn in this region is planted shortly after the rainy season starts (April). Because of high precipitation in the region (see Table 14) farmers have available only a few days to prepare the soil in time to plant during the right period. If they do not do so, there is no assurance that the weather conditions will permit planting later in the season.

The average rainfall for the two years given in Table 14, during the period from April to September, was approximately 48 inches, which is much greater than the annual rainfall for the same period in the so-called corn-belt of the United States. The average normal rainfall in this region varies between 13.7 and 26.2 inches (1,22).

Soils in Portuguesa State are generally alluvial soils, ranging from well drained and highly developed alluvial soils with a medium-textured surface to poorly drained soils characterized by a medium to heavy-textured surface and low permeability. Slopes vary from nearly level land to gently or moderately sloping (7). One of the chief soil-management problems in this region is the drainage of the bottom lands with low permeability.

Even with little research information available, it seems logical to speculate that erosion problems arising from intensive cropping over a long period of time using traditional tillage practices should also receive special attention.

TABLE 14.--Rainfall in Portuguesa State (Colonia Turen 1968-1969)

Year	Months											
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1968	2.7	2.3	0.3	24.5	271.3	374.6	227.7	160.9	139.1	97.6	75.3	40.4
1969	4.9	18.6	1.2	109.1	162.7	319.9	257.3	272.1	112.2	102.6	68.8	43.6

Source: Taken from Ministerio de Agricultura y Cría (22).

Another soil-management problem which should be considered in this region is the deterioration of soil structure by excessive traffic.

3.4 Selection of Treatments

Considering the soil characteristics, rainfall distribution, soil-management problems and management conditions for corn production in the region of Portuguesa State, it is assumed in this proposal that any tillage system recommended should meet the following requirements:

1. Soil conditions should be created which provide just adequate contact between the seed and the soil. Any extra harrowing will make the field look better but it probably would not help the corn.

   Arthur Peterson of the University of Wisconsin points out that a field serves as a seedbed for no more than five per cent of the growing season. The other 95 per cent of the time finds it working as a root bed (1).

   A finely worked seedbed not only is unnecessary but also is more likely to seal over when it rains thus increasing runoff and erosion.

2. Soil conditions created by the tillage operation should be such that surplus moisture can be eliminated as quickly as possible, avoiding death of many plants by drowning.

3. Soil losses should be minimized and water intake maximized. A rough surface will erode less from water or wind than a smooth one.

4. Cost of operation should be reduced for higher returns in corn production. This can be possible by cutting out some of the usual trips over the field.

Considering the factors enumerated above the following experimental treatments should be included in this proposed research project:

Conventional tillage system.--The common practice used in this region which consists of several harrowing operations until a firm and fine seedbed is obtained.

Wheel-track system.--This method usually works well on clay soils following sod and even after row crops or small grains if the soil moisture is just right. It has the advantage that planting can be done when the soil is slightly too wet to disk or harrow.

It would consist of plowing at the time when the soil moisture is just right and planting as soon as possible on the tracks of the tractor or special wheels ahead of the corn planter. The field should be planted a few days after plowing; otherwise additional harrowing would be required to kill weeds.

Reduced tillage on early plowed field.--This would be a treatment similar to fall plowing in the United States.

It is considered the easiest way for managing heavy soils (1).

It would include the following operations:

a. Plowing early in the season. If a previous crop has been grown on the same land, it would be desirable to plow right after harvest has been completed.

b. Disking or harrowing once, then planting. An alternative way could be the use of chemical weed control in place of harrowing and then planting.

This method has the advantage that it requires no special equipment and it is suited to any soil that can be early plowed.

Ridging.--This method is being currently practiced in Venezuela. With ridging, soil is prepared in the conventional way and the planting operation is done using an implement which also builds the ridge.

Early-plowing-ridging combination.--This combination theoretically brings together the advanteges of the individual methods used for heavy soils. It would consist of:

a. Plowing early in the season;

b. Harrowing or chemical weed control;

c. Ridging and planting in one operation.

Till-planting.--This system was used on an estimated 212,194 acres in Iowa in 1970 (18). The planter performs several essential operations in one trip. Wittmuss and Lane (32) of the University of Nebraska have used a till-planter which is capable of planting at 2 to 6 miles per hour in a silty clay loam soil.

3.5 Evaluation Parameters

3.5.1 Soil Conditions

A set of soil parameters which could be used to adequately evaluate tillage practices is proposed. This approach can be used to evaluate tillage needs for other crops.

3.5.1.1 Soil Water

--Infiltration rate

--Soil moisture

3.5.1.2 Soil Structure Parameters

--Bulk density. Initial bulk density and bulk density following the tillage operations.

--Mean weight diameter. An absolute measure of change can be obtained by determining the sizes before and after manipulation.

--Clod size and segregation. Changes may be determined through the calculation of pulverization modules.

3.5.1.3 Surface Changes

3.5.1.4 Soil Temperature

3.5.1.5 Root Impedance

--Soil compaction

--Root volume

--Root extension

The use of this set of parameters would provide a research basis for the selection of the critical limits for describing needed tillage operations for a given combination of soil, crop, and climatic conditions. It is felt that it will also serve (a) as a field reference for evaluating current tillage practices, (b) as an aid in designing new practices, and (c) as a framework upon which new research can be directed.

3.5.2 Crop Responses

--Seed germination

--Stand count

--Weed population

--Crop yield

3.5.3 Cost Analysis

--Overhead costs of tillage equipment

--Operation costs

--Total costs

The determination and measurement of parameters listed in sections 3.5.2 and 3.5.3 would provide factual information for immediate use of farmers. In addition, estimates of crop responses should make it possible to determine those changes which cultivation produces in the physical environment of corn and the effect of changes in soil conditions on the final yield or ease of soil management.

3.6 Experimental Conditions

3.6.1 Experimental Design

It is suggested that a randomized block design with three replications be used. Careful consideration should be given to limitation of time, material, and cost in deciding the number of observations in each experimental plot. Nevertheless, care must be taken to make at least a satisfactory number of observations for a comprehensive statistical analysis.

Treatments would be established in at least two different soil types typical of the region. Soil of the series Fanfurria and Mendez (7) are proposed initially because they represent the set of conditions described above.

The net area of each individual plot will be 10 m x 30 mt. Thus, experimental observations would be taken within a plot of these dimensions. However, it seems desirable that larger plots be used to establish each treatment to permit easy equipment operation.

The experiments should be established in the San Nicolas Experimental Station. This is an experimental station administrated by the Central University of Venezuela and is located in a strategic point within the area under study. The physiographic characteristics of the lands in this station are quite representative of the Portuguesa region. The existence of a great number of agricultural machinery distributors in the nearby cities of Guanare and Acarigua, and modern soil laboratory facilities are additional advantages of this site.

After the first year, consideration should be given to the establishment of the most promising systems in semi-commercial operations.

3.6.2 Cultivation Practices

Certified seed of the corn hybrid best adapted to the ecological conditions should be planted at the same rate for all treatments. Fertilization practices should be the same for all treatments. Weeding operations should be maintained at the same level and frequency for all treatments; however, if weed population should reach "unsafe levels" in any treatment, appropriate measures should be taken.

3.7 Equipment and Personnel

The broad scope of the project presented here calls for the cooperation of a team of workers. Strong cooperation between agronomists, agricultural engineers, agricultural economists and extension people is considered vital for the success of this study and therefore should be encouraged.

Similarly, cooperation between several institutions concerned with the problem of increasing corn productivity will result in optimum use of available resources.

3.7.1 Machinery

--Disk plow

--Disk harrow

--Tractor (< 50 HP)

--Conventional corn planter

--Ridge planter

--Till-planter

--Sprayer

--Mechanical cultivators

3.7.2 Instrumentation

--Penetrometer

--Core sample

--Thermocouples and potentiometer

--Infiltrometer

--Instrumentation for roughness measurement

--Instrumentation for determination of soil moisture

Some of the machinery and instrumentation listed are already available or could be borrowed from some of the participating agencies. In some cases it would be necessary to develop some special instrumentation such as the instrument for measurement of the roughness coefficient.

3.7.3 Personnel

--Agricultural Mechanization specialist

--Soil Science specialist

--Crop Science (corn) specialist

--Technical personnel (machinery operator, soil technicians, agricultural technician)

--Workers

3.7.4 Cooperating Agencies

--Central University of Venezuela through their Agricultural Engineering, Soil Science, and Crop Science Departments (Faculty of Agronomy)

--Ministry of Agriculture

--FOREMAIZ

--Ministry of Public Works

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