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No-Tillage Agriculture

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For over 100 years, agriculture has relied upon the moldboard plow and disk harrow to prepare soil to produce food. Without the moldboard plow and disk it would not have been possible to control weeds and to obtain the yields necessary to provide favorable economic returns from agriculture. Weeds are strong competitors with food crops for water and plant nutrients, and it was not until plant growth regulators were introduced in the late 1940's that attention was turned to no-tillage agriculture. From plant growth regulators selective herbicides were developed, and these increased the feasibility of growing many different crops without tilling the soil (*1-3*).

In this article, we define conventional tillage as moldboard plowing followed by disking one or more times. By this method one obtains a loose, friable seedbed in the surface 10 centimeters of soil. We define the no-tillage system (*4*) as one in which the crop is planted either entirely without tillage or with just sufficient tillage to allow placement and coverage of the seed with soil to allow it to germinate and emerge. Usually no further cultivation is done before harvesting. Weeds and other competing vegetation are controlled by chemical herbicides. Soil amendments, such as lime and fertilizer, are applied to the soil surface.

In pasture management, chemicals are used as a substitute for tillage, herbicides being used to restrict growth and competition of undesirable plants during the establishment of the newly seeded crop or to supress growth of grasses and allow establishment of legumes. Row crop production with the no-tillage system is almost always carried out by planting the crop into soil covered by a chemically killed grass sod or with dead plant residues of a previous crop. For example, in continuous no-tillage corn (*Zea mays*) production, the soil surface at the time of planting is covered with corn stalk residues of the previous corn crop. In double-cropped soybeans, the soil at the time of planting is covered with residues of a recently harvested small-grain crop such as barley or wheat.

The land area used for row crops and forage crops grown by the no-tillage system has increased rapidly during the past 15 years. In 1974, the U.S. Department of Agriculture (*5*) estimated that the amount of cropland in the United States under no-tillage cultivation was 2.23 million hectares, and that 62 million hectares or 45 percent of the total U.S. cropland (*6*) will be under the no-tillage system by 2000. An estimated 65 percent of the seven major annual crops (corn, soybeans, sorghum, wheat, oats, barley, and rye) will be grown by the no-tillage system by the year 2000 and 78 percent by the year 2010 (*5*). In Kentucky there were 44,000, 160,400, and 220,000 ha of no-tillage corn and soybeans grown in 1969, 1972, and 1978, respectively.

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We estimate that at least 65 percent of the corn and soybeans in the Southern corn belt will be grown with the no-tillage system by the year 2000.

The major advantages of the no-tillage cropping system are as follows. (i) Soil erosion caused by wind and water is reduced. (ii) The acreage of land that can be safely used for row crops is increased because such crops can be grown on sloping land that would be subject to soil erosion by water under the conventional tillage system. (iii) Energy requirements are reduced. (iv) The timing of planting and harvesting can be improved. Row crops on well-drained soils may be planted and harvested under a wider range of soil moisture contents with the no-tillage system than with conventional tillage. (v) Soil water is used more efficiently by plants because of decreased water evaporation from the soil and increased water infiltration into the soil. (vi) The investment in machinery is reduced.

Summary. The no-tillage cropping system, a combination of ancient and modern agricultural practices, has been rapidly increasing in use. By the year 2000, as much as 65 percent of the acreage of crops grown in the United States may be grown by the no-tillage practice. Soil erosion, the major source of pollutants in rural streams, is virtually eliminated when no-tillage agriculture is practiced. The no-tillage system reduces the energy input into corn and soybean production by 7 and 18 percent, respectively, when compared to the conventional tillage system of moldboard plowing followed by disking. In addition, crop yields are as high as or higher than those obtained with traditional tillage practices on large areas of agricultural land.

There are several disadvantages in the no-tillage system. (i) The populations of insects and disease-producing organisms and resulting crop damage may be higher than in the conventional tillage system because of a more favorable habitat. The number of rodents may also be increased, but these can be controlled with rodenticides. (ii) Greater management ability is required for success, since there are fewer alternatives for correcting management errors than in conventional tillage systems. (iii) Because a mulch is usually applied to the soil surface in the no-tillage system, soil temperature may be decreased by as much as 6°C at a depth of 2.5 cm in the spring (*7*) or until the plant canopy shades an appreciable proportion of the land area. This lower temperature is a disadvantage when it delays spring planting in areas such as the central and northern United States, or where the soil temperature in the no-tilled soil is below the optimum temperature required for maximum plant growth. In the tropics, however, the lower soil temperature can be advantageous because the soil temperatures are frequently above the optimum required for maximum plant growth.

A reduction in tillage generally requires an increase in the use of pesticides. About 50 percent more pesticides are used for corn production by the no-tillage method than by conventional tillage. Most pesticides used in the no-tillage production of corn and soybeans do not move appreciably in the environment except by soil erosion. Because soil erosion is greatly decreased by no-tillage agriculture in comparison to conventional tillage, one would expect less movement of pesticides from the field. Triplett *et al.* (*8*) found that the transport of herbicides (atrazine and simazine) in runoff water was no greater from no-tilled fields than from conventionally tilled fields. Some pesticides are degraded to harmless components in the soil in a shorter period of time under no-tillage than under conventional tillage (*9*). Thus, although more pesticides are used for the no-tillage system, it appears that the potential for pollution is no greater, and may be less, than for conventional tillage (*8, 9*).

Farmers in many areas of the world are finding that the advantages of the no-tillage system far outweigh the disadvantages. In this time of modern technology it is paradoxical that the no-tillage system combines the use of modern chemicals (selective herbicides) with the most ancient method of introducing seed into soil. Farmers in the mid-Atlantic and the southeastern United States are finding that one or more of the advantages listed above are increasing the net profit of their farming operations as well as conserving their most basic natural resource, soil.

Soil Erosion

Many studies indicate that no-tillage agriculture reduces soil erosion to almost zero. McGregor *et al.* (*10*) found that on a highly erodible soil in Mississippi erosion was reduced from 17.5 metric tons per hectare to about 1.8 tons per hectare when the no-tillage system was used; Triplett *et al.* (*8*) found that the no-tillage system reduced soil erosion by as much as 50-fold. Harrold and Edwards (*11*) in Ohio compared soil erosion and runoff on watersheds with poor management practices, improved management practices, and no-tillage practices during a severe rainstorm in which 17.5 cm of rain fell in 7 hours. Corn was being grown in all three watersheds. Soil erosion losses for this one rainstorm were 51,477, 7,307, and 72 kilograms of soil per hectare for the watersheds with poor management practices, improved management practices, and no-tillage practices, respectively. The corresponding amounts of runoff were 11.0, 5.8, and 6.2 cm, respectively; and the slopes of the land for the three watersheds were 6.6, 5.8, and 20.7 percent, respectively. Such a severe rainstorm is likely to occur only once in 100 years, however. Harrold *et al.* (*12*) measured soil erosion losses during 5 years of more normal rainfall. Their results from 5 years of continuous no-tillage corn production showed that erosion losses on a 9 percent slope during the growing season decreased from 1761 kg/ha on conventionally tilled watersheds to 27 kg/ha on no-tilled watersheds. In some years, no soil was lost from either conventional or no-tillage systems. However, in 1964, soil loss from the conventional tillage watershed was 6477 kg/ha whereas only 134 kg/ha was lost from the no-tillage watershed. Average corn (grain) yields during the 5-year period were 7091 and 7909 kg/ha for the conventional and no-tillage watersheds, respectively.

Langdale *et al.* (*13*) in Georgia found that on land with a 6 percent slope, the no-tillage system reduced soil loss from about 40 tons to about 0.2 ton per hectare when simulated rain was added at a rate of 6.4 cm/hour for a period of 2 hours. Studies of a tropical soil in Nigeria showed that plots with slopes of 10 to 15 percent lost 7.3 tons of soil per hectare by erosion during a rainstorm of 4.2 cm if they had been plowed and only 0.001 ton if they were under the no-tillage system (*14*). In many regions wind erosion is a problem. A comparison of wind erosion losses by Schmidt and Triplett (*15*) showed that, per hectare, a conventionally planted field of corn lost 291 tons of soil whereas a no-tillage cornfield lost 4.5 tons during one severe windstorm.

In general, soil erosion increases as the amount of tillage increases and decreases as amounts of residues or plant cover increase. By far the most acceptable and effective measure for control of wind and water erosion is the maintenance of surface residues (mulches). Certainly, no-tillage agriculture provides conditions that favor soil conservation.

Water Utilization by Crops

Crop yields from no-tillage agriculture are usually as high as or higher than yields from crops produced by conventional tillage, especially on well to moderately well-drained soils. Except for a few unusual situations, soil water content is almost always higher under the no-tillage system than under conventional tillage (*12*, *16-23*). This is mainly because the presence of a mulch on the surface of the soil significantly reduces water evaporation from the soil when the crop canopy does not cover the soil surface. After a full crop canopy is attained, there is little or no difference in soil water evaporation between the conventional tillage and no-tillage methods. For a 4-year period in central Kentucky the average of a Maury silt loam soil at depths of 0 to 15 cm during the corn growing season was 29.5 percent on a volume basis for the no-tillage system and 24.4 percent for conventional tillage. This difference translates into 0.75 cm more water being present in the surface 15 cm of soil under no tillage than in soil under conventional tillage during the growing season. This difference in soil water content can often mean the difference between a good corn yield and a mediocre one. The average amounts of soil water transpired through a corn crop and the amounts of water lost by evaporation to

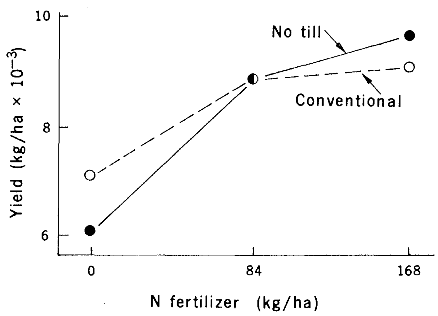

Fig. 1. Response of corn to nitrogen fertilization. The values are the average of eight locations in Kentucky.

the atmosphere because of tillage during 5 months of four growing seasons in central Kentucky are shown in Table 1. The data show that corn grown by the no-tillage system transpired, on the average, 6.5 cm more water than corn grown by the conventional tillage system. Likewise, soil under the no-tillage system lost 15.0 cm less water to the atmosphere by evaporation than did soil under the conventional tillage system. This improved efficiency of water use is important because food crops are not efficient users of water. Corn, for example, transpires a minimum of 500 kg of water for each kilogram of dry matter produced.

Corn Yields

A comparison of corn grain yields from well-drained soils in Kentucky is shown in Table 2. On poorly drained soils, we normally do not obtain as high yields of corn grown by the no-tillage method as we do from conventional tillage. Similar results for well-drained compared to poorly drained soils were obtained in Ohio (*2*). In the northeastern and north central United States, the presence of a mulch consisting of crop residues on the soil surface results in a higher soil water content and lower temperatures in the seed zone at normal planting times. For these reasons, seeding must be delayed to a later than optimum planting date. In addition, nitrate-nitrogen present in the soil may be denitrified and lost from the soil.

Research in Kentucky showed that when nitrogen fertilizer was applied to the soil the corn grain yield on well-drained soils was greater with the no-tillage system than with conventional tillage (see Fig. 1). When no nitrogen fertilizer was applied, corn grain yields were higher with conventional tillage than with the no-tillage system. However, application of 168 kg of nitrogen per hectare resulted in higher yields of corn with the no-tillage system than with conventional tillage; yields were equal when nitrogen was applied at the rate of 84 kg/ha. Results from Maryland were quite similar, as shown in Table 3.

Table 1. Estimated soil water evaporation and transpiration by corn (*Zea mays*) from no-tilled and conventionally tilled crops on Maury silt loam soil during the growing season. The values, in centimeters, are averages for the growing seasons of 1970, 1971, 1972, and 1973.

Month	No tillage		Conventional tillage		Rainfall
	Transpiration	Evaporation	Transpiration	Evaporation	
May	0.0	2.1	0.0	6.3	17.9
June	7.6	1.0	6.4	6.8	9.7
July	12.4	0.3	9.5	2.1	10.1
August	9.2	0.2	7.2	1.4	4.1
September	1.5	0.5	1.1	2.5	9.1
Total	30.7	4.1	24.2	19.1	50.9

Table 2. Average corn grain yields from well-drained soils under the no-tillage and conventional tillage systems.

Soil type	Number of years tested	Grain yields (kg/ha)	
		No tillage	Conventional tillage
Maury silt loam	8	9,136	8,932
Crider silt loam	5	9,886	8,318
Tilsit silt loam	5	7,705	7,705
Allegheny silt loam	3	10,977	10,909

Efficiency of Fertilizer Use in No-Tillage Agriculture

Under the conventional tillage system, fertilizer and lime are mixed with the "plow layer" of the soil, which usually extends from the surface to about 20 cm. Because there is little soil disturbance under the no-tillage system, it is necessary to apply fertilizers to the soil surface instead of mixing them with the soil.

Experiments show that there is little or no difference in potassium availability whether the fertilizer is applied to the soil surface or mixed in. In the case of phosphorus, surface application has a slight advantage over either band placement or mixture of the fertilizer with the soil. There appear to be two reasons for this. First, with the no-tillage system the soil just under the surface mulch remains wetter than any other portion of the soil during much of the growing season. Increased water in the soil improves the diffusion rate of phosphorus to the roots, which proliferate in this zone. Second, application of phosphorus fertilizer to the soil surface effectively achieves the same results as "banding" the phosphorus in the soil. That is, rather limited soil contact with the phosphorus fertilizer results in higher phosphorus solubility. Studies with fertilizers labeled with phosphorus-32 show that more

Table 3. Efficiency of different increments of nitrogen fertilizer, expressed as kilograms of grain per kilogram of nitrogen, on corn grown on well-drained soils in Kentucky and Maryland.

Nitrogen fertilization per hectare	Yield of corn grain (kilograms per kilogram of nitrogen	
	No tillage	Conventional tillage
	Kentucky	
First 85 kg	35.4	22.2
Second 85 kg	9.6	3.0
	*Maryland**	
First 90 kg	32.4	14.4
Second 45 kg	34.8	3.0
Third 45 kg	0.0	0.0

*See (*28*).

phosphorus is available to plants when fertilizer is surface-applied.

When nitrogen fertilizer was applied to the soil surface on well-drained soils in Kentucky and Maryland, the amount of corn grain obtained per kilogram of nitrogen was much greater for the no-tillage system than for conventional tillage (see Table 3). However, when no nitrogen fertilizer is applied the yields of corn with the no-tillage system are lower than with conventional tillage (Fig. 1). Some experiments indicate that it is only at the higher rates of nitrogen application that both nitrogen use efficiency and corn yields favor no tillage; this is believed to be because of the higher water content of the soil. However, recent experiments in Kentucky show that when nitrogen fertilization is delayed until 30 days after planting, yields of crops under the no-tillage and conventional system are equal.

In the case of nitrogen fertilizers, there are three possible problems associated with nondisturbance of the soil. The first is that, because of accumulation of organic matter at the soil surface, denitrification can occur when the soil contains an excess of water. This is one of the reasons why no-tillage agriculture is not so successful on poorly drained soils as it is on well-drained land. The second problem is that leaching of nitrate occurs more readily under the no-tillage system both because there is less evaporation of water and because the channels through which water and nitrate can move are undisturbed, promoting deeper penetration into the soil. A third problem is that the native soil nitrogen has a lower mineralization rate in undisturbed compared with disturbed soils. The overall effect of these problems is that more nitrogen may be required for optimum yields of some crops grown under the no-tillage system. In Kentucky, we recommend that, per hectare, 28 kg more nitrogen fertilizer be applied for the production of corn under the no-tillage system than under conventional tillage. Recent experiments in Kentucky show that when nitrogen fertilization was delayed until 30 days after planting, yields of corn at all nitrogen fertilization rates were as great or greater under no tillage than under conventional tillage. In Virginia, 20 percent more nitrogen, phosphorus, and potassium fertilizers are recommended for no-tillage corn to support the 20 percent higher yields expected from this system (*24*).

Lime placement on the soil surface is effective because under the no-tillage system the soil surface is the zone most likely to become acid. This is because of the nitrification that leaves residual acidity at the point of fertilizer placement and the lack of soil mixing that would dilute the effects of such acidity. Thus, lime applied to the soil surface contacts the acidity directly and no mixing is necessary. Work in both Virginia and Kentucky has demonstrated the effectiveness of this method in sustaining crop yields.

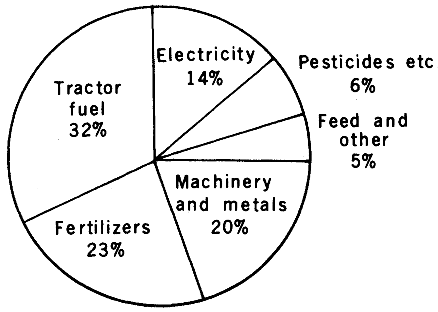

Fig. 2. Energy used in U.S. agriculture. The values given are percentages of total energy used in agriculture. [Courtesy of American Chemical Society (*32*)]

Effect of Tillage on Energy Use

The input of pesticides, fertilizers, fuels, and machinery has increased to the point that agriculture is a very energy-dependent industry. The total U.S. energy demand in 1978 was approximately 19.57×10^{15} kilocalories (*25*). Most estimates place agriculture's share of energy used for the production of food at about 3 percent of the total U.S. energy demand. Of this estimated 0.59×10^{15}

Table 4. Comparison of energy consumption for the product of corn by conventional tillage and the no-tillage system.

Management input or operation	Reference	Energy requirement per unit of input (kcal $\times 10^3$)	Assumption	Energy required per hectare (kcal $\times 10^3$)	
				Conventional tillage	No tillage
Machinery, manufacturing, and repair	(*29*)	20.5/kg	11.6 kg/ha for conventional tillage; 9.5 kg/ha for no tillage (based on 240-ha farm)	237	195
Fertilizer	(*29*)				
Nitrogen		13.9/kg (as N)	140 kg/ha	1946	1946
Phosphorus		1.8/kg (as P_2O_5)	70 kg/ha	126	126
Potassium		1.1/kg (as K_2O)	70 kg/ha	77	77
Seed	(*30*)	4.0/kg	15.9 kg/ha for conventional 18.2 kg/ha for no tillage	64	73
Herbicides and insecticides	(*29*)	24.2/kg of active ingredients	2.3 kg active ingredient for conventional; 3.4 kg active ingredient for no tillage	56	82
Plow (moldboard)	(*30*)	235/ha		235	
Disk	(*30*)	82/ha	One time	82	
Plant	(*30*)	83/ha	75-cm rows	83	83
Apply herbicides	(*31*)	17/ha		17	17
Broadcast fertilizer	(*30*)	18/ha		18	18
Harvest (cornpicker)	(*30*)	128/ha	75-cm rows	128	128
Dry grain	(*29*)	0.15/kg	23 to 15 percent moisture (9000 kg/ha yield)	1350	1350
Transport grain	(*29*)	0.033/kg (3 km distance)	9000 kg/ha yield	297	297
Total				4716	4392

Table 5. Comparison of energy efficiency of nitrogen fertilizer for the no-tillage and conventional tillage systems of corn production in Kentucky.

Output and input	Energy required per hectare (kcal × 10^3)	
	No tillage	Conventional tillage
	First 85 kg of nitrogen fertilizer per hectare	
Yield output*	11,171	5,077
Production input†	1,756	1,457
Gain (+) or loss (−)	+9,415	+3,620
	Second 85 kg of nitrogen fertilizer per hectare	
Yield output ‡	4,786	131
Production input†	1,424	1,196
Gain (+) or loss (−)	3,362	−1,065

*3.73 × 10^3 kcal per kilogram of grain. Based on yield increase due to the first 85 kg of nitrogen fertilizer. †Includes energy required to manufacture the nitrogen fertilizer, application of fertilizer to land, and drying and transporting the grain to market. ‡3.73 × 10^3 kcal per kilogram of grain. Based on yield increase due to the second 85 kg of nitrogen fertilizer.

kcal of energy used annually for food production, about one-third is used in the production phase, and two-thirds is used as input manufacturing (Fig. 2). About 80 percent of the energy used by agriculture is from liquid petroleum fuels and natural gas.

Steinhart and Steinhart (*26*) have described the close connection between farm output and the amount of energy input into the U.S. food system since 1920. Their data indicate, however, that the efficiency ratio for farm output to energy input has declined somewhat in recent years, perhaps emphasizing the need for improved energy efficiency in agriculture.

Conventional tillage requires relatively large amounts of fuel, much of which is used in plowing and disking to prepare a seedbed (Table 4). Since plowing, disking, and some trips over the field with machinery are eliminated with the no-tillage system, a considerable quantity of fuel is saved with this method. However, the requirements for additional herbicides in no-tillage systems offset some of these gains. The elimination of plowing and disking and reduction in machinery manufacture brought about by the no-tillage system results in an annual energy saving equivalent to about 36.6 liters of diesel fuel per hectare. The extra pesticides needed for the no-tillage system offset about 2.65 liters of this saving. Additional seed, which is usually recommended for no-tillage agriculture, offsets another 1 liter per hectare. Thus, the energy saving for the no-tillage production of a hectare of corn is equivalent to about 33 liters of diesel fuel annually compared to conventional tillage. This is about 7 percent less per year for the no-tillage system than for conventional tillage. For soybean production there is about an 18 percent saving of energy in favor of no tillage, 1427 × 10^3 as opposed to 1735 × 10^3 kcal/ha, or about 31.4 liters of diesel fuel equivalent per hectare. Nitrogen fertilizer is not usually used in soybean production since the soybean is a legume. This accounts for the greater percentage saving of energy with no-tillage soybeans compared to no-tillage corn.

The greatest single energy input into corn production is nitrogen fertilizer. In general, 100 to 175 kg of nitrogen fertilizer per hectare are recommended for corn production depending on the type of soil and climatic conditions. In the example shown in Table 4, nitrogen fertilizer represents almost one-half of the energy required. In most soils, nitrogen is the most important fertilizer element for corn production, since it is more likely to be a limiting factor than any other plant nutrient. Table 5 shows that the energy output from increased grain yield for each unit of nitrogen fertilizer applied, when compared to the energy input associated with that unit of nitrogen fertilizer, is much greater for no-tillage agriculture than for conventional tillage. Since the response to nitrogen fertilizer is greater with the no-tillage system (Fig. 1), the energy efficiency values are also greater.

The amount of energy required for various field operations is affected by several factors that are not taken into account in Table 4. Match-up in size between the tractor, equipment, fields, and jobs is an important factor. Size, shape, topography, and type of soil can greatly influence the energy used in field operations. Small or irregularly shaped fields or fields with irregular slopes require more time and energy with respect to equipment use, especially where conventional tillage requires that contour farming be practiced to control soil erosion. The higher the amount of clay in a soil, the higher the quantity of energy required in tillage, especially in those operations involving soil movement such as plowing and disking. These factors favor the no-tillage system over conventional tillage in energy savings, since the no-tillage system requires fewer field operations and practically no soil movement. Less need for use of traditional erosion control practices (contour farming, contour strip-cropping, and terracing) and a much lower loss of plant nutrient supplying capacity in the no-tillage system provide some immediate energy savings. Except for that small amount, the energy savings associated with better erosion control will be largely deferred to future generations. When erosion does occur, large amounts of energy are required to restore the land to productivity (*27*).

The energy saved by using the no-tillage cropping system may seem small when it is expressed on a per-hectare basis, but it is relatively large when viewed on a national scale. If 65 percent is a reasonable estimate for the percentage of corn and soybeans that will be grown under the no-tillage system by the year 2000 (*5*), then on the basis of the estimated 35 million hectares each of corn and soybeans by that year, the potential annual savings of energy will be 14.9 × 10^{12} kcal or 1.5 billion liters of diesel fuel equivalent per year for corn and soybeans alone. Although such savings may have little effect on energy use on a national scale, they may be significant for an individual farmer.

Disease and Insect Problems

Some plant diseases, such as take-all in wheat, occur less frequently in no-tillage crops than in crops grown with conventional tillage, and others, such as early anthracnose in corn, occur less frequently in conventionally tilled crops. Some researchers have been concerned about the possibility of no-tillage systems permitting a buildup of a reservoir of disease organisms on crop debris left on the soil surface as mulch. However, there are certain beneficial aspects related to the practice of no-tillage agriculture that should not be overlooked. Conservation of moisture and reduction in soil compaction are factors that contribute to the production of healthier plants that are able to withstand more disease and insect pressures. Thus the fact that corn and sorghum succumb less frequently to stalk rots under reduced tillage systems is not surprising, because stalk rots occur more frequently in plants subjected to stress. By avoiding many of the stresses of tillage, plants may be able to withstand greater disease pressures. Regardless of the tillage system used, two practices appear to reduce losses due to disease. First is the use of varieties or hybrids that are resistant to disease, particularly in areas where crops are known to be subject to heavy disease pressures; second, and perhaps more important, is the practice of crop rotation, which benefits disease control in nearly all tillage systems.

Depending on the climate, the presence of mulch and crop residues on the surface of the soil can be advantageous with respect to the control of destructive insects. In areas with large numbers of predators, such as in tropical zones, harmful insects are subject to biological control. In areas where such control is not effective and the mulch serves as a habitat for harmful insect populations, these may be adequately controlled by the soil insecticides used in conventional tillage agriculture in the United States. Systemic insecticides provide adequate protection when they are banded in close proximity to the seed.

Multicropping with No-Tillage Techniques

The potential for multicropping may be the most important factor in no-tillage agriculture. All the advantages of the no-tillage system became more important with multicropping. These advantages include (i) reduced labor and costs; (ii) elimination of moisture loss associated with conventional tillage at planting time, ensuring stands of second and third crops under restricted rainfall patterns; (iii) production of more than one crop per year, which increases land use; (iv) further reduction of soil erosion; (v) maintenance of soil structure by elimination of plowing and land preparation; and (vi) time saved in planting the second and third crops when timeliness of planting is very important.

With the no-tillage system, harvesting can be followed immediately by planting of the succeeding crop, thus reducing the time lag between crops. On well-drained soils, no-tillage crops can be planted over a wider range of soil moisture conditions than can conventional tillage crops, and this further reduces the time before the next crop can be planted in the multicropping sequence. The crops used for multicropping may include seed crops such as small grain, maize, soybeans, grain sorghum, sunflower, flax, and others depending on climatic conditions.

The Worldwide Potential of No-Tillage Crop Production

Factors that will govern the use of the no-tillage system throughout the world include (i) the erodible land that is used for crop production; (ii) soil drainage; (iii) climate; (iv) availability and cost of fuel for agriculture; (v) labor supply; (vi) potential for multicropping, which in turn depends on climate and markets; and (vii) development of technology and management skills to the level needed for the adoption of no-tillage agriculture.

Research data obtained on the use of no-tillage and conventional tillage systems in tropical zones parallel those obtained from research in the southern corn belt with respect to yield increase and reduction of erosion. The fragile soils of the tropics may offer greater opportunity for the long-term advantages of the no-tillage system than any other soils in the world.

Recent studies on the applicability of no-tillage techniques for a range of soils and crops in West Africa have been conducted by the International Institute of Tropical Agriculture in Nigeria. Lal (*19*) reported that corn, soybeans, and cowpeas responded favorably under no-tillage conditions and that soil erosion was adequately controlled. Tropical soils are characterized by thin surface layers and have a high erosion potential because they are exposed to heavy rainfall. Thus the kind and amount of tillage play a vital role in controlling erosion in the tropics. According to Lal (*19*), advantages of the no-tillage system in tropical environments include (i) improved soil structure and soil porosity, (ii) effective erosion control, (iii) conservation of soil moisture in the soil surface, (iv) lowering of the daily maximum soil temperature at the soil surface to a level more favorable for plant growth, (v) maintenance for soil organic matter, and (vi) improved water use efficiency.

Results from South America and the Philippines and other parts of Asia also indicate that the no-tillage system will soon become more widely used in many parts of the world. Although the system has been adopted primarily by farmers practicing agriculture on a large scale, it is likely to find favor on small farms. The energy required to prepare soil for planting with the use of hand tools in most cases limits the total area of food crops that a family can grow. It has been demonstrated in Colombia that by careful application of herbicides by means of a small hand pump, maize can be grown satisfactorally without tillage.

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