No-tillage Crop Production in the Tropics

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Contents

Foreword

There is an urgent need to understand the food production systems of the tropics especially as the initial attempts at wholesale transfer of crop production technologies from the temperate region have led to repeated failures.

The search for alternatives to conventional crop production practices has generated interest in no-tillage crop production. Eliminating (or reducing) tillage holds the promise of conserving tropical soils, reducing rapid loss of organic matter, and making possible the intensive use of tropical soils on a sustained yield basis.

While knowledge of no-tillage crop production practices in temperate regions has grown, data for this production system, as applied to the tropics, has been spotty. Further, there has been little development of viable packages of inputs that could be handed over to tropical farmers.

To address this knowledge gap and better define the problems of no-tillage in the tropics, a symposium was organized jointly by the West African Weed Science Society and the International Weed Science Society, and held during August 1981 at the West African Rice Development Association center in Monrovia, Liberia.

The purpose of this symposium was to examine problems of no-tillage crop production in both temperate and tropical agriculture and then assess experiences gained from both systems with a view toward modifying inputs to make no-tillage a workable system in the tropics. Scientists were invited to the symposium from Europe, the Americas, and Africa to present papers on various aspects of crop production in no-tillage systems. The papers presented appear on the following pages in the hope that the information they contain will advance the cause of no-tillage crop production in the tropics. ■

Acknowledgements

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Thanks, in particular, go to IWSS secretary treasurer L.C. Burrill for encouragement and patience, and to IPPC director S.F. Miller for recognizing the need to publish no-tillage information for the tropics.

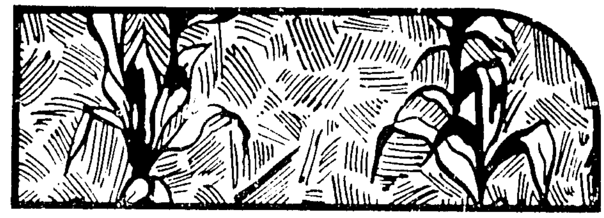
The West African Weed Science Society (WAWSS) acknowledges, with thanks, the financial support by those organisations that made it possible to bring speakers from various parts of the world to Monrovia. The WAWSS also takes this opportunity to thank Ciba-Geigy, Shell International, American Cyanamid, and Monsanto Chemical Company for the financial support that allowed the Society to host both the symposium and a biennial weed science conference at the same venue. The U.S. Agency for International Development was also most supportive.

A hearty thanks to IPPC's Mary Welsch for breaking in the Center's new word processor while capably preparing the final manuscript.

In editing the papers, we attempted to standardize terminologies and shorten many papers to reduce cost, but hopefully without distracting from the authors' line of thought. We thank the authors for promptly reviewing the edited copies; however, we remain responsible for any shortcomings arising from the editing. ■

• I. Okezie Akobundu
• A.E. Deutsch
February 1983

Section I
An overview of no-tillage crop production



NO-TILLAGE CROP PRODUCTION IN TEMPERATE AGRICULTURE

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INTRODUCTION

In temperate regions, limited tillage and no-tillage have gained favor as techniques to reduce erosion and increase production efficiency. This trend has spanned a long period and resulted in a proliferation of names describing tillage systems.

Conservation tillage, a general term, was developed to encompass many tillage systems that conserve soil and water. Wittmus, et al., (1973) say, "Conservation tillage includes tillage systems that create as good an environment as possible for the growing crop and that optimize conservation of our soil and water resources, consistent with sound economic practices. Conservation tillage is synonymous with maximum or optimum retention of residues on the soil surface and the utilization of herbicides to control weeds where tillage is not or cannot be performed."

Minimum, reduced, or limited tillage are defined by Crosson (1981) as systems in which moldboard plows are not used, enough residue is left on the soil surface to significantly reduce erosion, and weed control is accomplished primarily with herbicides. No-tillage systems are an extreme form of conservation tillage; Young (1973) defines them as "placing the crop seed or seed transplant into the soil by a device that opens a trench or slot through the sod or previous crop residue only sufficiently wide or deep to receive the seed or transplant roots and to provide satisfactory seed or root coverage. No soil manipulation is required. Weeds are controlled by herbicides, crop rotation, and plant competition."

Other names that imply no-tillage or preparation of a very narrow seedbed are no-till, till-plant, chisel plant, rotary strip tillage, and zero tillage.

HISTORY OF NO-TILLAGE

A. United States of America

The possibility of eliminating tillage and cultivation from crop production evolved with the introduction of herbicides. In the United States (U.S.), crop production without tillage was first evaluated in (the state of) California orchards in 1944 (Lombard, 1944). In 1949, another report discussed chemicals and equipment needed to eliminate tillage in orchards (Johnston and Sullivan, 1949). Over a 4-year period, chemical weed control with oil proved cheaper than cultural methods. Soil physical condition and water penetration were improved; consequently, soil erosion was reduced by the use of this system.

Early attempts to use herbicides in pasture renovation began in 1949 (Sprague, et al., 1962; Davidson and Barrons, 1954) leading to an integrated program of pasture renovation involving herbicides, tillage equipment, and special planters.

Early attempts to eliminate cropland tillage with herbicides occurred in the western U.S. The practice, chemical fallow, was viewed as an additional opportunity beyond stubble mulching to conserve soil moisture and reduce erosion. The first experiments, initiated at Havre, in the state of Montana, in 1948 by Baker, et al, (1956), found grain yields with chemical fallow comparable to yields with conventional tillage, provided weeds were controlled.

About 1960, when atrazine and propazine became available as herbicides for sorghum (*Sorghum bicolor* L. Moench), chemical fallow became practical in the Great Plains. A common cropping sequence that emerged was wheat (*Triticum aestivum* L.)-sorghum-fallow in which two crops are harvested in 3 years. Atrazine applied to wheat stubble at 3.3 kg/ha controlled weeds until sorghum was planted the following June. At Hays, in the state of Kansas, sorghum yield markedly increased using chemical fallow compared to regular sweep tillage (Phillips, 1964). However, after a few years, the weed population shifted from broadleaf species susceptible to atrazine to *Cenchrus pauciflorus* Benth (field sandbur) which was resistant. Yields decreased unless some tillage took place at critical times to control *C. pauciflorus*; when practiced, normal tillage yielded 2300 kg/ha and limited or reduced tillage 3720 kg/ha (Phillips, 1969). In a drier region of the Great Plains, near Amarillo, in the state of Texas, similar studies were conducted. Propazine applied to wheat stubble controlled weeds, but neither soil moisture storage nor sorghum yield increased (Wiese, *et al.*, 1967).

In the late 1950's, no-tillage research was initiated in the states of Ohio (Triplett, 1966), Virginia (Moody, *et al.*, 1965), North Carolina (Klingman and Spain, 1965), and Kentucky. Most of this early work was directed toward establishing corn (*Zea mays* L.) and other crops in sod or cover crop. The best herbicides for killing sod or cover corps were combinations of paraquat with atrazine, simazine, or 2,4-D. Recently, glyphosate has been used for preplant weed control.

In the last few years, soybeans (*Glycine max* Merr.) have been double-cropped without tillage or cultivation following small grain harvest. Weed control has been accomplished using a combination of paraquat for killing existing vegetation and linuron or alachlor for preemergence weed control in the crop (Kincade, 1972). Metribuzin and metolachlor are new herbicides used in no-tillage soybeans.

B. Other Parts of the World

Since the early 1960's in Europe, no-tillage systems have been developed for establishing wheat, barley (*Hordeum vulgare* L.), and other crops using paraquat. The original research for these systems was conducted in the United Kingdom by the manufacturer of paraquat (Allen, 1975). Additional field research was conducted with various crops in Holland (Lumkes and te Velde, 1974), Czechoslovakia (Rod and Pesek, 1974), Germany (Bachthaler, 1974), France (Damour, *et al.*, 1973), and Yugoslavia (Kosovac, 1972).

Adoption of no-tillage for small grains in the U.K. was motivated by the need to plant winter wheat shortly after summer crop harvest. No-tillage sped up operations and conserved fuel, time, and labor. The system is called direct drilling.

Early limited and no-tillage research with grain crops in Australia and Japan involved rice (Oryza sativa L.). In Australia, after heavy grazing of pasture by sheep, rice was (aerially or sod) seeded into undisturbed pasture (Boerema and McDonald, 1967). Later, the system was improved by applying paraquat or diquat to desiccate the pasture (Rowell and Barrett, 1975).

In Japan, rice traditionally has been planted in the spring after tillage during the winter. Using paraquat to kill weeds was an innovation reported by Brown and Quantrill (1973).

The earliest work of pasture renovation in New Zealand involved spraying a 20 mm band of paraquat in front of drill disks prior to seeding a perennial herbage seed mixture or an annual forage crop (Blackmore, 1962).

Other work on pastures was conducted in England (Allen, 1967), Netherlands (Hoogerkamp, 1970), Hungary (Pusztai and Kovacs, 1967), and Germany (Skirde, 1966). These researchers utilized both dalapon and paraquat in their studies. Douglas (1965) summarized this early research.

PRESENT STATUS OF NO-TILLAGE

A. United States of America

1. Publications.

In the last 10 years, four excellent limited tillage information sources have been published: No-Tillage Farming (Phillips and Young, 1973); Proceed ings of the National Conference on Tillage held in March 1973, at Des Moines, Iowa, published by the Soil Conservation Society of America, Ankeny, Iowa; the January-February 1977 issue of the Journal of Soil and Water Conservation published in Ankeny, Iowa; and, Conservation Tillage and Conventional Tillage: A Comparative Assessment (Crosson, 1981).

Limited or no-tillage has gained adoption in temperate areas of the world where it has demonstrated advantages to growers. A look at various regions in the U.S. (Figure 1), and other areas of the world, will provide insight into acceptance of limited or no-tillage.

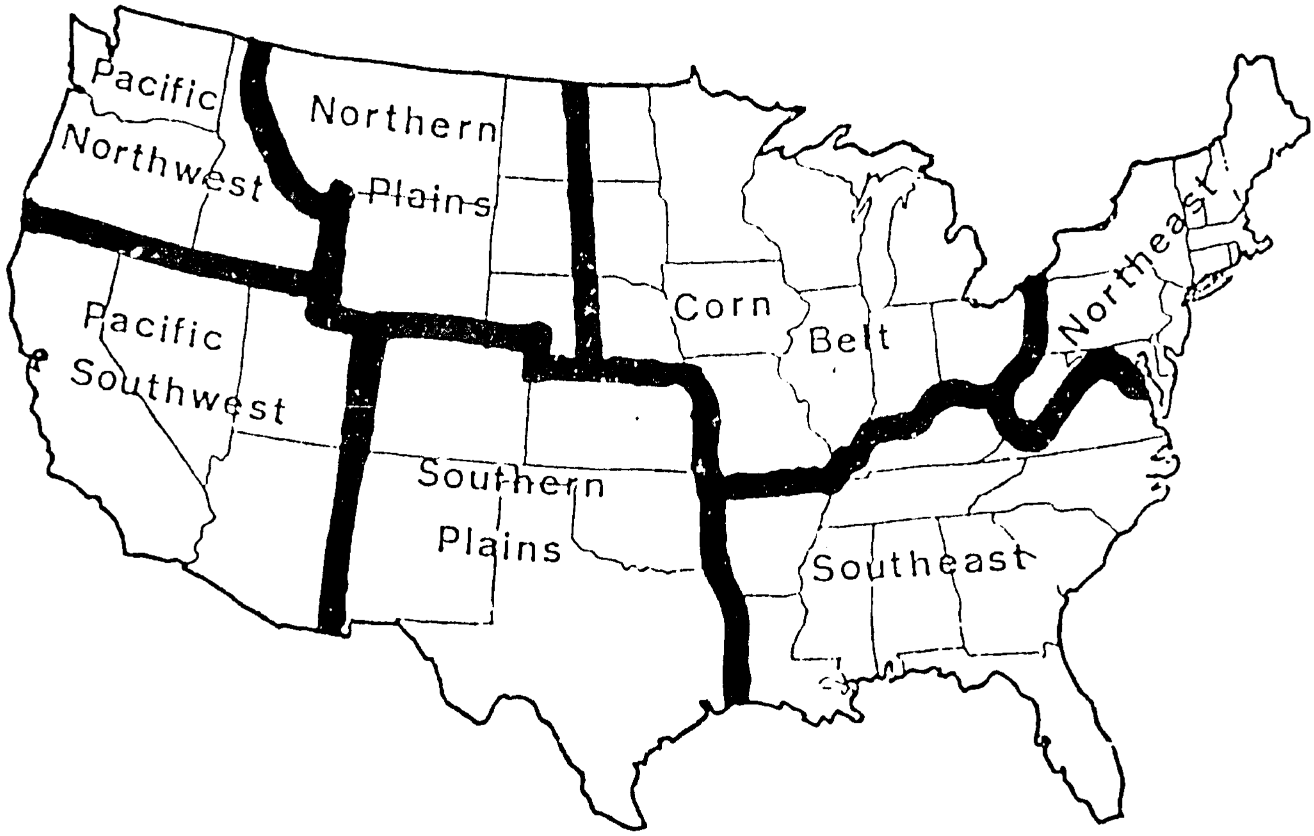

Figure 1. Geographical regions of the United States used to discuss limited tillage.

2. Northeast Region.

The Northeast comprises 13 states, with West Virginia, Maryland, and Delaware forming the southern boundary of the region (Bennett, 1977). Adequate precipitation occurs for most crops. Pronounced geographic features include the Coastal Plain, and the Appalachian Mountains with steep, erosion prone slopes. Shallow soils make vegetative cover difficult to maintain; a significant portion of land is utilized for pasturing livestock. Level to rolling topography characterizes the Coastal Plain. The region's growing season is short to intermediate, but long enough for major crops.

Corn, for dairy cattle feed, widely relies on no-tillage. The concept of planting corn in sod, or a winter cover crop, emerged in 1954 (for this region) (Davidson and Barrons, 1954). Today, no-tillage corn is planted continuously in small grain cover crops or in grass sod that has been killed or retarded with herbicides. Agropyron repens (L.) Beauv. (quackgrass), sod in meadows or weedy fields can be controlled with 4.4 kg/ha atrazine applied in a no-tillage system for 2 years. Occasionally corn is no-till planted in legume cover that was killed with atrazine.

Another popular practice on the Coastal Plain involves double cropping soybeans following barley or wheat harvest. Small grain stubble prevents erosion and conserves soil moisture, and herbicides control weeds.

For steeply sloping pasture, renovation without tillage has become very popular. Paraquat controls Poa spp. (bluegrass) in native pastures; alfalfa (Medicago sativa L.), bromegrass (Bromus sp), red clover (Trifolium pratense L), and white clover (Trifolium repens L.) can be seeded directly into the dead sod.

Although not adopted widely, no-till planting of horticultural crops in this region has merit. Recent research suggests potatoes (Solanum tuberosum L.) can be produced by killing a rye (Secale cereale L.) cover crop with paraquat and planting in the remaining mulch. Tomatoes (Lycopersicon esculentum Mill) can be grown similarly producing yields usually higher than with conventional tillage; up to 60,000 kg/ha of tomatoes and 30,000 kg/ha of potatoes have been produced in research plots (Bennett, et al., 1975).

3. Southeast.

This region, conservation-minded people believe, will benefit from no-tillage more than any other in the U.S. Characteristics of a long growing season, soil that does not freeze, and adequate but unevenly distributed rainfall leads to potential winter erosion and cropping season moisture stress. These circumstances have caused no-till planting to spread rapidly in the region. Row crops can be grown on slopes previously considered unsuitable for conventional tillage. Because of the long growing season, double cropping with no-tillage systems is very popular. In 1976, the states of Kentucky and Virginia had 206,000 ha of no-till planted soybeans, nearly 80% of which was double cropped after wheat or barley. Nearly a quarter of the corn in Kentucky and Virginia utilizes no-till. Most corn is grown continuously with a small portion double cropped (Shear and Moschler, 1969; Smith and Lillard, 1976).

4. Corn Belt.

The most productive and naturally fertile soils in the U.S. occur in the Corn Belt states of Ohio, Indiana, Illinois, Missouri, Iowa, Minnesota, Wisconsin, Michigan, and the eastern half of North Dakota, South Dakota, and Nebraska (Griffith, et al., 1977; Amemiya, 1977). Rain falls mainly during summer, varying from 50 cm in the west to 100 cm along the region's eastern and southern fringes. Due to intensive agriculture, erosion ranks as a more serious problem than in any other U.S. region. The corn and soybeans grown on 75% of the cropland usually are not rotated.

Traditionally, Corn Belt farmers moldboard plowed in the fall and prepared a seedbed with several diskings or field cultivations in the spring. Since the mid-1960's, the number of secondary tillage operations gradually decreased. More recently, acreage of moldboard plowing has given way to chisel plowing. Only 2% of the corn and soybean acreage in the region is no-till planted.

In Nebraska, minimum tillage using a till-planter--consisting of a 25 cm to 35 cm sweep that clears a path through stubble of the previous crop for planting units--has increased (Wittmus, et al., 1964). The concept of no-tillage corn in the Corn Belt was developed in Ohio (Triplett, 1966).

Because soil remains cool during early spring, systems that leave mulch on the soil surface depress temperatures compared to conventional tillage systems. Reduced soil temperature slows growth in the spring; later in the season, soil mulch increases soil moisture and counteracts early temperature stress. Differences between corn yields using conventional, minimum, or no-tillage tend to be minimal.

Research in Ohio indicates that no-tillage reduced yields of corn grown on poorly drained soils. Mulch cover retains more moisture during the early spring than is desirable. The wet soil warms slowly so that, during cool, wet years, corn grows poorly enough to depress yields.

5. Northern Great Plains.

Annual precipitation ranges from 250 mm in the west to 500 mm in the east with 75% falling during the April-through-September growing season. Spring wheat is grown in the northern part of the region and winter wheat in the south. In the drier western district, growers alternate with fallow to accumulate soil moisture. Water storage efficiency during fallow ranges from 16 to 20% with conventional tillage. Sorghum is the most common row crop.

Erosion, caused by both wind and water, constitutes a major problem during fallow if crop residue cover is not maintained on the soil surface. To control erosion, stubble mulch tillage research began in 1937 (Duley and Russell, 1939, 1942); the effort resulted in design of the sweep plow. The sweeps undercut weeds and leave crop residue and dead weeds on the soil surface to control erosion. In arid areas, soil above the sweep dries out and weeds die, but in humid zones weeds reestablish in wet soil.

Controlling weeds with herbicides during fallow periods has been called chemical fallow. A new term, "ecofallow," emerged recently in Nebraska (Fenster, et al., 1973). In an alternate crop-fallow rotation, wheat yielded 2690 kg/ha using conventional tillage, 2890 kg/ha using sweeps during fallow, and 3830 kg/ha with no-till fallow (Wicks and Smika, 1973). The yield increase was attributed to retention of more soil moisture storage during fallow periods.

6. Southern Great Plains.

Again, wind and water erosion are serious problems. Rainfall varies from less than 250 mm in the west to over 1500 mm on the eastern edge near the Gulf Coast. Wells in the west irrigate 3 million ha. The most widely grown crops include winter wheat, sorghum, and cotton (*Gossypium hirsutum* L.) Rice is grown in the southeast. Citrus and vegetables can be found in the southern tip of the state of Texas. Wheat yields average 650 kg/ha in the west increasing to 3500 kg/ha in the east.

No-tillage research has centered in the western part of the region. At Bushland, Texas, additional soil moisture, stored with sweep tillage, increased wheat yields 107 and 135 kg/ha in continuous wheat and wheat-fallow cropping sequences.

Research with chemical fallow started in the Texas Panhandle in 1955. Prior to 1960, moisture storage and yields were not as high using herbicides to control weeds and volunteer crops as with sweep tillage (Wiese, et al., 1960). After 1960, weed control and soil moisture storage during fallow (with atrazine) became comparable to that obtained with sweep tillage, and yields remained equivalent (Wiese, et al., 1967).

Other research has shown that surface mulches of 5,000 kg/ha are necessary to markedly increase soil moisture storage over that obtained with clean tillage. In the 450 mm rainfall belt, where this research was conducted, dryland crops frequently produce less than 2,000 kg/ha of straw. High crop residue levels can be obtained only with irrigation. In the 11-month fallow between harvest of irrigated wheat and planting sorghum, soil moisture storage with disk tillage was 70 mm, or 20% of precipitation. Where atrazine and 2,4-D were used to control weeds during the fallow, the soil retained 140 mm, or 39%, of precipitation (Unger, et al., 1970). If dryland sorghum or sorghum receiving one or two irrigations follows fallow, the extra soil moisture translates into increased yield, up to 2,000 kg/ha; several experiments at Bushland averaged 1,000 kg/ha increase.

No-tillage in continuous cropping in the Southern Great Plains has not been economically practical for all crops. At Bushland, continuous no-till irrigated wheat yield increased 270 kg/ha annually compared to disk tillage. Weed control between crops was achieved with 2,4-D and paraquat. Production costs increased the same amount as the value of the increased yield. A limited tillage system was most profitable, and increased yield 70 kg/ha, while reducing tillage cost US$7 per ha.

A satisfactory no-tillage system has not been developed for furrow irrigated continuous grain sorghum in the Southern Plains. Crop residue (with no-tillage) in furrows slows irrigation water advance, causing deeper water penetration than with clean tillage. However, a high volunteer population of sorghum usually germinates after planting. This caused forage yield to be high, and grain yield to be lower than with conventional tillage. A recent experiment by Allen, et al. (1980) shows that the cost of producing continuous sorghum can be greatly reduced with limited tillage.

Double cropping grain sorghum after winter wheat harvest has been very successful. In a 5-year experiment, grain yields were increased 560 kg/ha using a no-till system. Weeds and volunteer wheat were controlled using atrazine in an oil-water emulsion spray carrier applied when sorghum was 15 cm tall.

In the state of Oklahoma, efforts to grow continuous no-till wheat have failed because chemical methods of controlling *Bromus secalinus* L. (cheat) were not available until 1980. Moldboard plowing provides optimum *B.*

secalinus control and highest wheat yields. Now, several new no-tillage systems are being evaluated. In the lower Rio Grande Valley of Texas, citrus orchards are maintained weed-free without cultivation or tillage (Leyden, 1965). The bare soil was warmer, freeze damage decreased, and yields improved with this type of chemical fallow. However, this practice is only feasible for leveled orchards not subject to water erosion. There have been attempts to grow cotton in no-tillage systems, (Wiese, et al., 1967), but suitable herbicides for this purpose have not been discovered.

Although research results have shown certain limited and no-tillage systems to be profitable as well as outstanding conservation practices, widespread adoption by farmers in the Southern Great Plains has not occurred, though higher fuel costs have caused increased adoption in the last 2 years.

7. Pacific Northwest.

The Pacific Northwest is a diversified crop production area containing some of the U.S.'s most productive wheatland. Most of the region is dryland, but some areas are irrigated from the Columbia and Snake Rivers. Winter wheat is the major crop, both dryland and irrigated. Topography in the wheat zone varies from nearly level to steep slopes. Up to 80% of the dry farming cropland has slopes from 8 to 30% with some slopes exceeding 50%. Rainfall varies from 200 to 1000 mm. In areas receiving less than 300 mm of rain, wheat is cropped every other year.

In the Pacific Northwest, up to 75% of the annual precipitation falls during winter in contrast to rainfall patterns in the rest of the U.S. Of this amount, 50 to 75% is stored in the soil during the first winter after wheat harvest. However, erosion losses have exceeded 300 tons of soil per ha. In areas that receive 40 mm of rain or less, wind erosion can be serious during the summer. Erosion has been severe on steep slopes; the constant movement of soil down steep slopes with plows has formed banks of soil 3 m high at the edge of fields. Serious rill erosion occurs in the winter when snow melts and water runs across frozen soil. Stubble mulching is the most common conservation practice under dry conditions during the fallow period. With 5,000 kg/ha of straw on the soil surface after wheat harvest, soil moisture storage is greatly increased and erosion reduced.

No-till planting has been evaluated for over 20 years, but has not been adopted by those farmers who felt that the change might reduce yields. In

1975, winter wheat and barley were seeded directly into stubble near Pullman in the state of Washington on 3,200 ha. The practice nearly eliminated erosion.

8. Pacific Southwest.

The region, a major agricultural production center worldwide, displays a broad range of crops and farming practices. While some land is dryland, great segments of the state of Arizona and California are irrigated. Because high revenue crops are grown in rotation, no-tillage has not become very popular. No-tillage has been used in citrus orchards for many years (Lombard, 1944).

B. Other Parts of the World

Wheat produced in the United Kingdom, to a great extent, involves direct drilling (Elliot, 1974; Cannell, et al., 1977). Fields are burned in order to prevent toxic chemicals from degrading straw and reducing stand and yield in the subsequent crop. This toxicity problem is not as severe in less humid areas. Similar systems are in various stages of development in Europe.

No-tillage systems are being developed in Australia and New Zealand. In Western Australia, where rainfall comes almost exclusively in the winter, a "spray seed" system has proven successful (Malcolm, 1971). Weeds that emerge in the summer are grazed. These weeds, and others that emerge after early fall rains, are killed with one application of paraquat prior to drilling into unplowed soil. Seeding equipment in both the U.K. and Western Australia carries heavy weight in order to penetrate unplowed soil. In Eastern Australia, where rain falls year round, a "spray seed" system is less effective because weeds emerge all year. The problem can be reduced if clover and weeds are grazed heavily and killed with paraquat just before planting. This works only in areas where sufficient rainfall eliminates need for a fallow period to store soil moisture (Collins, 1977).

Kale (Brassica oleracea L.) and fodder rape (Brassica campestris L.) are being sown into forage grasses as a catch crop in the U.K. (Evans, 1973). Research has lead to similar practices in New Zealand (Leonard, 1973).

Renovating pastures with no, or limited, tillage is practiced in the U.K. and New Zealand. One of the more effective practices involves heavily grazing old pasture to reduce crop residue on the soil surface. New seedlings stand a better chance of emergence and survival. The grazed pasturage is killed with paraquat before seeds are planted (Douglas, 1965; Elliot, 1977).

Another innovation: a drill, which treats a 100 mm band with herbicide, also cuts a mini-trench in the center of each sprayed band with two disks and a skimmer that lifts a ribbon of turf and lays it to one side. Seeds are planted in the small trench. Paraquat, dalapon, and glyphosate were evaluated for killing the turf (Squires, 1976).

PROBLEM WEEDS WITH NO-TILLAGE

A. United States of America

Chosing a particular weed control treatment combination tends to favor certain weed species. For example, annual grass weeds are favored by stubble mulch farming in the Great Plains. After sweep plowing, fibrous roots of these weeds reestablish easily in moist soil following rain. Consequently, sweep plowing has been most successful along the western edge of dryland agriculture, where rainfall is infrequent and soil usually dry. In general, perennial weeds are favored by reducing tillage and cultivation. Until the advent of glyphosate, managing perennial weeds in no-tillage systems was exceedingly difficult.

Two weeds, Panicum dichotomiflorum Michx (fall panicum) and Apocynum cannabinum L. (hemp dogbane) became problems in continuous no-tillage corn after 7 years (Triplett, et al., 1972). Herbicides used were ineffective against P. dichotomiflorum, and A. cannabinum is a vigorous perennial weed that spreads rapidly when tillage was not used. Cirsium arvense (L.) scop. (Canada thistle) stands as a problem that was not controlled by spot treatment with 2,4-D.

In another report, perennial weeds, including woody plants were cited as the most troublesome weeds associated with no-tillage production of corn and soybeans on the eastern seaboard (Peters, 1972).

B. Other Parts of World

Prior to the no-tillage method of planting, Bromus sterilis L. (barren brome) grew along roadsides and did not invade fields. Now it has emerged as a new weed problem in direct drilled wheat (Froud-Williams, et al., 1980). Apparently leaving seed on the soil surface encourages germination and establishment of the pest; direct drilling also favors Alopecurus myosuroides Huds (blackgrass).

As in the U.S., no-tillage favors perennial weeds in the U.K. (Cussans, 1975, 1976). Convolvulus arvensis L. (field bindweed), Taraxacum officinale Webber (dandelion), Rumex spp. (docks), Trifolium. repens (clover) and C. arvense are the worst offenders. In Australia, Chondrilla juncea L. (skeleton weed), and Solanium elaeagnifolium Cav. (silverleaf nightshade) are perennial weeds that create problems with no-tillage methods (Wells, 1977).

Rumex spp. and Paspalum paspaloides (water couch), both perennials, cause problems in solid seeded rice in Australia (Boerema and McDonald, 1967). Some of the problem was overcome by using selective herbicides in the pasture phase of the rotation prior to planting rice.

ACCEPTANCE OF LIMITED AND NO-TILLAGE SYSTEMS

A. United States of America

In the last 5 years, the U.S. has witnessed a general trend to less intensive primary tillage on its 150 million ha of cropland. Chisel-disk systems are replacing moldboard plowing throughout the country, a change in tillage that saves 4 to 10 liters of fuel per ha. The U.S. Soil Conservation Service estimated that no-tillage practices increased from 1.7 to 14 million ha during 1963 to 1974 (Allen, et al., 1977). A survey in 1976 indicated that 3.1 million ha were planted without tillage and an additional 22.8 million ha were farmed with reduced tillage. An official government office projected that one-half of U.S. cropland would be managed with reduced tillage by 1990 (Back, 1975). By the year 2010, more than 90% of the crop acreage would be grown with reduced tillage. The same report estimates that no-tillage farming will be used in 50% of U.S. cropland in 2010.

B. Other Parts of the World

Adoption of direct drilling in the U.K. steadily increased since the early 1960's and, by 1974, was used on 35,000 ha of fall sown cereals and 5,000 ha of spring cereals. By 1977, this had increased to 61,000 and 6,000 ha for the two crop categories.

In Western Australia, 60,000 ha of wheat were sown with the "spray seed" method in 1978; in South Australia, about 25,000 ha were sown with the method.

Outside the U.S., there is very little production of corn with no-tillage systems. About 25,000 ha are grown in a pasture forage corn rotation in New Zealand (O'Connor and Mackay, 1977).

CONCLUSIONS

Limited, or no-tillage farming has been adopted in temperate regions when herbicides become available to control weeds both between (and in) crops as well as, or better than, conventional methods of crop culture. Without effective herbicides, no-tillage is impractical because crop yield suffers. Secondly, available planters have to be capable of seeding into untilled ground. Thirdly, mulch on the soil surface must not be detrimental to crop establishment and growth, a problem in poorly drained or naturally cold soils. In some areas, wheat straw can reduce germination and growth of newly planted wheat. No-tillage is becoming economically feasible in many areas because the costs of labor, fuel, and machinery have risen faster than the cost of herbicides. In many cases, limited or no-tillage increases yield because of increased soil water conservation. No-tillage is being adopted rapidly in sloping areas subject to severe erosion. In fact, no-tillage enables farmers to crop areas previously usable only for pasture.

Conversely, no-tillage is not practical if herbicides do not control weeds in a particular field, such as perennial species and small bushes. Cold and wet soils can become even colder under a mulch. Finally, farmers are reluctant to adopt changed technology, especially during periods of small profit margins and high interest rates.

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TECHNOLOGY TRANSFER IN NO-TILLAGE CROP PRODUCTION

IN THIRD WORLD AGRICULTURE

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INTRODUCTION

Heavy tillage of soil is quite recent in the long history of agriculture. The earliest systems of crop production were essentially no-tillage (Phillips, et al., 1980) and, in many less developed countries, minimum tillage is widely practiced today.

Tillage was introduced into farming systems for weed control, seedbed preparation, and for some supposed value of loosening the soil. Many experiments in the United States, starting in the 1880's and continuing to the present, have shown that the main value of cultivation of the soil after planting is for weed control (Sturtevant, 1884; Thompson, 1927; Robinson, 1964). More recent work on complete no-tillage including no land preparation has shown that crop yields can be achieved that are at least equal to those from conventional tillage, and that there are many advantages for this system (Allen, et al., 1975; Unger and McCalla, 1975; Shenk and Locatelli, 1980; Gingrich, et al., 1981; Lal, 1981).

The large number of herbicides available now makes possible the practice of no-tillage on many crops in extensive areas of the world. Notably, no-tillage is increasing rapidly in the countries considered to have a high level of agricultural technology. But what is the situation in less developed countries? To quote Shenk and Locatelli (1980): "Ironically, pressure to increase productivity or economic efficiency is resulting in widespread acceptance of reduced tillage systems in countries with highly developed agricultural technology, while in many countries with less developed technology, where reduced tillage has been practiced for centuries, the adoption of highly mechanized technology is frequently being advocated."

It should become clear that, with help from herbicides, small farmers in the tropics can have the most advanced crop production systems paralleling those practiced by large farmers in developed countries. Minimum changes are needed and at relatively small cash cost. Certainly, the introduction of expensive tillage equipment and large tractors is a big step backward.

Before discussing the systems and technology involved, the possible advantages and disadvantages of no-tillage should be stated:

Possible Advantages of No-tillage

(1) can be used on hilly, rocky, rough land where animal or tractor tillage is difficult or impossible;

(2) reduces the fuel, animal and human energy required in crop production (Allen, et al., 1980; Nalewaja, 1980).

(3) requires smaller, less expensive equipment (Phillips, et al., 1980);

(4) greatly reduces both water and wind erosion of the soil (Mannering, 1979; Lal, 1981);

(5) conserves soil moisture (Lal, 1981; Gingrich, et al., 1981);

(6) conserves soil organic matter (Lal, 1981);

(7) may improve soil structure (Johnston and Sullivan, 1949; Lal, 1981);

(8) leaves mulch on the soil surface which reduces weed germination, avoids stimulating germination of weeds seeds through burning, and does not bring new weed seeds to the surface;

(9) lowers soil temperature and reduces daily fluctuations which favor the growth of many crops in hot climates (Lal, 1981);

(10) saves time and moisture in critical planting periods by reducing "turn around time" between harvest of one crop and planting of the next one (Allen, et al., 1975; Gingrich, et al., 1981);

(11) allows for optimum spacing between plants to obtain maximum yields (Bleasdale, 1963);

(12) eliminates injury to crop plant roots caused by between-row mechanical tillage and hand weeding (William and Warren, 1975; Hamdoun and El Tegani, 1977);

(13) reduces incidence of certain soil-borne diseases due to lack of spreading by equipment and injury to plants which favors infection (Green, 1980[1/]; Norris, 1981);

(14) may reduce certain insect problems (Edwards, 1979; Shenk and Saunders, 1981).

Possible Disadvantages of No-tillage

(1) may increase some insect, disease, and other pest problems (Unger, et al, 1977; Edwards, 1979; Unger and McCalla, 1979);

(2) can cause perennial weed population increase unless the system used effectively controls them (Triplett and Lytle, 1972);

(3) may cause more water to be lost by runoff if little or no surface mulch is present (Robinson, 1964).

REQUIREMENTS FOR A NO-TILLAGE SYSTEM

The systems used in no-tillage will vary greatly with the crop, climate, soil, topography, and economic situation. However, there are certain general requirements which include: 1) weed control without stirring the soil; 2) a surface mulch of crop residues and/or added mulch; 3) a system for planting through the mulch with a minimum of soil disturbance; 4) appropriate fertilizer program; and, 5) control of insects, diseases, and other pests. Harvesting and storage of the crop usually do not vary greatly from present methods found with conventional tillage systems.

A. Weed control

More than any other aspect, effective weed control, practiced with little or no soil disturbance, is the key to a modern no-tillage system. Prior to planting, existing vegetation must be killed. This can be accomplished entirely with herbicides, or by slashing with a machete or similar

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1/ R.J. Green. 1980. Personal communication.

tool, followed by a herbicide treatment. Mulch on the surface contributes significantly toward controlling weeds. Those not controlled by the mulch can be killed by directed applications of herbicides, either between the crop plants or, for tall weeds, above the crop. Products that are especially valuable for small farmers using no-tillage systems are contact herbicides such as paraquat and translocated herbicides such as glyphosate. These two materials essentially have no soil activity; thus, calibration of application equipment is not critical. Many new selective, translocated, postemergence grass herbicides are being developed and these should be of great value in no-tillage.

Preemergence residual herbicides, widely used on large farms for no-tillage, are not as well adapted for small farms in developing countries. The need to calibrate accurately to avoid crop injury is a real problem. For flooded rice in Japan, this application problem largely has been overcome by using granular formulations. Unfortunately, these formulations are not available in most less developed countries. Another solution involves the government or private contractors applying preemergence herbicides as a paid service to the farmers, a method being used with success for irrigated cotton in the Sudan. To be used by small farmers, residual herbicides should provide a sufficient safety margin to the crop being treated and avoid danger to subsequent crops in the rotation.

Equipment required for herbicide application can be simple and low cost. Backpack sprayers are widely used by small farmers throughout the world. For directed sprays between crop rows, these can be improved by the addition of a shield around the nozzle. Granular applicators also are inexpensive and easy to operate.

There have been exciting recent developments in application equipment. The types most adaptable to small, as well as large, farms are the so-called "wiper applicators." A concentrated herbicide solution is wiped on the weeds with either hand-held or tractor-mounted equipment. The applicators can be simple, even home-made. For example, a bamboo pole wrapped with burlap and kept moist with the herbicide can be carried just above the crop to contact tall weeds. Narrow width applicators can be used between crop plants.

Herbicides that have been applied successfully with wiper equipment include glyphosate and 2,4-D. These are translocated materials, so only part of the plant needs to be contacted to kill all of it. Other translocated herbicides, such as the new experimental selective grass killers, should be effective when applied with wipers. This method of application has distinc advantages over spraying: equipment cost is very low, spray drift is elimi nated, the quantity of herbicide used is reduced since none is wasted on ba soil, and the amount of water required is small.

B. Mulch

A surface mulch is an essential component for a viable no-tillage system. Often crop and weed residues provide sufficient material. If not, surplus materials, such as rice straw, may be applied. The mulch serves to protect the soil from wind and water erosion, reduce water loss during heav rains, reduce evaporation from the soil surface, and suppress weeds. While mulch is essential to the system, it also can create problems during crop planting.

C. Planting

On highly mechanized farms in temperate regions, special planters have been designed to cut through the mulch to place seeds in the soil. On small farms in the tropics, tools already in use, such as a sharp stick, small hoe or jab planter, effectively plant through most mulches.

D. Fertilizer

The fertilizer most appropriate to use fits the specific crop, climate, soil, and economic situation. Nitrogen requirement under no-tillage may increase somewhat. Application to the surface is usually satisfactory since the roots in this zone are not destroyed by cultivation.

E. Pests Other Than Weeds

Some pest problems may increase, some may decrease, and others remain unchanged when comparing no-tillage to other tillage systems. However, pests must be controlled for maximum production regardless of the tillage system. The difference is that the farmer needs to be alert to changes in the pest problems. The methods of control, equipment and materials will be similar to those used in conventional systems. Resistant cultivars and appropriate pesticides will be the most common control methods.

CONCLUSIONS

A no-tillage crop production system obviously requires several changes from conventional tillage. Fortunately, many small farms in less developed countries already practice minimum tillage. With the help of modern herbicides and the latest application equipment, the advantages of no-tillage systems used in developed countries can be realized. Cash outlays can be low; only small changes need to be made in present production practices. No-tillage appears to be essential for the maintenance of soil structure and productivity in many tropical soils. Research and demonstration trials should be encouraged. The long-term gains from widespread conversion to no-tillage could be greater than from any other innovation in third world agricultural production.

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NO-TILLAGE WEED CONTROL IN THE TROPICS

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INTRODUCTION

Weed control is one of the most expensive aspects of crop production. Many tillage practices and pieces of equipment have been developed over the years essentially to control weeds in various crops, especially row crops, resulting in varying degrees of weed control and soil compaction. Reasons commonly given to justify tillage include a need to: improve soil structure, bury crop residue, and kill weeds. Man has cultivated the land for nearly 8,000 years (Alder, et al., 1976) in pursuit of these objectives and to the point where the detrimental effects of tillage on soil physical properties can no longer be ignored.

Concern over damage to soil structure resulting from various conventional tillage operations has led to interests in other tillage techniques such as minimum tillage, mulch tillage, and no-tillage. These tillage techniques have been listed in decreasing order with respect to the extent to which the soil is disturbed in the course of preparing the land and planting the desired crops. Chemical no-tillage practice differs from conventional and other tillage techniques in that crop seeds are planted directly into chemically killed stubble or sod with no more soil disturbance than is necessary to insert the seed into the soil. This type of no-tillage technique can be distinguished from the no-tillage traditionally practiced by smallholder farmers of the tropics who usually solve the problem of preplant fallow vegetation by a slash-and-burn technique, and dibble their crop seeds into the soil without tillage. The absence of a crop residue mulch predisposes the smallholder farmer's field to some erosion albeit at a lower magnitude than is experienced when conventional tillage is practiced.

NO-TILL CROP PRODUCTION IN THE TROPICS

Smallholder tropical farmers recognized the fragile nature of tropical soils decades ago and contained the problem by combining the bush fallow system of agriculture with small farm sizes and use of light tools that enabled them to either dibble in seeds, or make small mounds for root crops without the need to disturb the entire top soil. The long fallow period reduced dependence on chemical fertilizer, herbicides, and insecticides. However, high human population densities, changing social values, and sheer economic consideration have, in recent years, increased cropping intensity, created a need for increased farm size, and placed emphasis on more efficient labor-saving crop production methods.

Intensive cultivation of tropical soils has been shown to cause irreversible deterioration in soil structure (Nye and Greenland, 1960; Pereira and Jones, 1954; Pereira, et al., 1958). On the other hand, several studies have shown that, with no-tillage techniques, more intensive cropping is possible in the tropics, especially if the no-tillage practices include the use of crop residues (Couper, et al., 1979; Juo and Lal, 1977; Macartney, et al., 1971). The advantages of no-tillage crop production in the tropics include a reduction in soil surface temperature, suppression of annual grass weeds, increased water infiltration rate, reduced erosion hazard, maintenance of soil structure, provision of organic matter, and a more favorable environment for biological activity in the soil (Akobundu, 1977; Jones, et al., 1968; Juo and Lal, 1977; Lal, 1974; 1975; 1976; Rockwood and Lal, 1974; Verinumbe, 1981). Most of these advantages can be derived if a crop residue mulch is provided through the use of preplant herbicides. It is through proper kill of the preplant vegetation that a plant residue can be established to protect the soil from erosion as well as to smother weed seedlings.

PROBLEM OF NO-TILL WEED CONTROL

A primary consideration in no-tillage crop production is weed control. In the tropics where weed growth is more rapid and technology less developed, weed management towers above other considerations related to economic production of basic food crops. Weed management problems in no-tillage crop production range from control of fallow vegetation, through management of the fallow vegetation residue, to choice of appropriate herbicides for specific crops. These problems are examined in relation to the major ecologies in which crop production is important in the tropics.

A. Preplant Vegetation Management

With few virgin forests left in the densely populated parts of the tropics, most crop production activities center around the short duration bush fallows (2-4 year fallows). In the humid and subhumid regions, this fallow is a mixed vegetation of fast growing perennial broadleaves such as *Alchornea* spp., *Combretum* spp., *Fiscus* spp., *Hippocratea pallens*, *Newbouldia laevis*, *Dioscorea* spp., *Albizia* spp., *Eupatorium odoratum*, and some members of the Acanthacea family. The perennial grasses commonly encountered in short term fallows in the tropical forest and derived savanna regions are *Panicum maximum* (guineagrass), *Ctenium newtonii*, *Pennisetum purpureum*, *Andropogon tectorum*, *Loudetia arundinacea*, and *Imperata cylindrica*. In the savanna region, tussocky perennial grasses such as *Andropogon*, *Hyparrhenia* and *Pennisetum* spp. predominate. These species possess a remarkable ability for regrowth after the dead top growth is incinerated. A new flush of vegetative growth usually appears before the onset of rains. Other grasses include *Digitaria scalarum*, *Cymbopogon* and *Sporobolus* spp. The species richness of the different grasses varies with relief and microclimatic conditions.

Because the savanna is prone to fire during the dry season, perennial broadleaves tend to be those species that are able to resume growth after the dry season flash fires. Common among these are *Daniellia oliveri*, *Butyrospermum parkii*, *Terminalia glaucescens*, *Lophira lanceolata*, *Isoberlinia* spp. and *Acacia* spp. According to Keay (1959), these species produce new vegetative shoots after forest fires and before onset of rains. These perennials have a well-established root system that enables them to grow vigorously, often more vigorously than the planted crop. While competition for nutrients may not be as pronounced as with annual weeds, the perennials may shade the crop, provide shelter for animal pests, and interfere with harvest operations.

Various fallow vegetation management practices have been tried. Slashing these perennials prior to cropping only sets them back, but does not prevent them from regrowing from basal stumps. The regrowth interferes with crop harvesting operations, an effect more severe in low growing crops such as cowpea (Vigna catjang Walp.) and soybean (Glycine max. Merr.) than in maize (Zea mays L.). Although paraquat has been successfully used for preplant vegetation control in no-tillage farming in temperate regions (Allen, 1974; Bachthaler, 1974; Triplett, 1966) this herbicide cannot be used exclusively as a preplant herbicide in the tropics because it is not effective against perennial weeds. Although glyphosate is effective against a wide range of tropical weeds (annuals and perennials), its high cost makes its use in a no-tillage package uneconomical for the production of most field crops. In addition, there are a few perennial weeds that are not controlled by glyphosate. These include Talinum triangulare, Ficus exasparata, and Hippocratea pallens. The control of Eupatorium odoratum with glyphosate is poor and often erratic.

In order for no-tillage weed control to be widely adopted and practiced in the tropics, herbicides that can effectively kill the mixed vegetation found in tropical fallow lands must be identified. These herbicides should be cheap, leave no residue that will interfere with the establishment of the crop plant, and provide a quick 'knock-down' effect of the fallow vegetation. When a preplant herbicide fails to completely kill the target fallow species within 3 weeks after application, annual weeds will invariably reinfest the field making it necessary for the farmer to apply paraquat prior to planting his crop to obtain the weedfree environment for germination and early seedling growth required by all food crops.

Herbicides such as 2,4-D, dicamba, picloram, amitrole and dalapon have been screened recently at the International Institute of Tropical Agriculture (IITA) for possible use in no-tillage preplant vegetation control. To date, no product has been found that is free from residue carry-over effect on the crop as well as capable of acceptable perennial weed control. An ideal herbicide for no-tillage preplant vegetation control in the tropics is one which has systemic action, little or no soil activity, quick 'knock-down' effect (phytotoxicity occurring within 2 weeks of application), low cost, an a broad spectrum of activity against both perennial broadleaves and grasses (non-selective). It is unlikely that these attributes will be found in any one herbicide.

A need exists, therefore, to consider herbicide mixtures or, where antagonism in action occurs, sequential herbicide application. Such a proposition appears logical for glyphosate and 2,4-D. Greater phytotoxicity in Eupatorium odoratum treated with 2,4-D alone at 1.0 kg/ha has been observed than when the weed is treated with a tank mixture of 2,4-D + glyphosate (1.0 2.0 kg a.i./ha). Similar observations on the antagonistic effects of 2,4-D on glyphosate have been reported by O'Donovan and O'Sullivar (1982).

B. Residue Management

Whether surface mulch *per se*, is a requirement for the success of no-tillage crop production, especially in the short run, is not clear presently. But the importance of crop residue in reducing soil erosion, preventing direct impact of rain drops on the soil surface, restoring organic matter to soil, reducing surface soil temperature, and smothering weeds is well known (Baeumer and Bakermans, 1973; Bennett, 1977; Jones, *et al.*, 1968; Juo and Lal, 1977; Kannegieter, 1969; Lal, 1975; 1980; Meyer, *et al.*, 1970). In the tropics, crop residue levels vary from excess residue in the humid tropics, to near absence of crop residue in parts of the savanna and most of the semi-arid tropics. A number of factors that account for the scarcity of crop residue mulch in the savanna and semi-arid regions include excessive grazing, forest fire, sparse vegetation, and limited moisture.

While the presence of a crop residue mulch has several advantages in no-tillage crop production, excess plant residue has many disadvantages. It is difficult to plant crop seeds when the plant residue is too extensive. Excess plant residue smothers crop seedlings and also provides shelter for animal pests. In addition, studies have shown that crop residue mulch may intercept herbicides and reduce the efficacy of preemergence herbicides (Addy, 1981; Erbach and Lovely, 1975). In a greenhouse study, Addy (1981) reported that maize stover mulch in excess of 5 t/ha (oven-dry weight basis) was found to intercept over 66% of the metolachlor that was applied broadcast on the soil surface.

Smallholder farmers have traditionally solved the problem of excess plant residue by burning the dry residues. This action is a low cost method for getting rid of excess vegetation and also destroying weed seeds and animal pests. In the Ultisols, such burning is known to increase soil pH and reduce the need for liming. Modern no-tillage crop production involving use of herbicides for preplant vegetation control is yet to find a solution to the problem of excess plant residue. Such a solution should identify the optimum residue level necessary to achieve most of the benefits of crop residue mulch without the adverse effects of this mulch.

In the savanna and semi-arid tropics where plant residue for mulch is very limited, studies show that the sparse surface mulch available is not as effective as cultivation in conserving moisture in the poorly structured soils (Nicou and Chopart, 1979). However, surface mulch could play a role in reducing erosion. Some crops such as millet (Panicum miliaceum Linn.), maize, and sorghum are more effective than others (e.g., cowpea) in generating plant residues. In other parts of the semi-arid tropics, the increasing demand for crop residues such as groundnut (Arachis hypogaea Linn.) stubbles for animal feed casts doubt on the prospects of crop residue mulch for erosion control in this region.

C. Herbicides for No-tillage Crop Production

While no-tillage crop production in temperate agriculture generally involves planting a crop either in the stubble of a previous crop or in a sod, no-tillage in tropical agriculture invariably involves planting a crop in a bush fallow. Consequently, herbicide requirements for preplant vegetation control are different for the two regions. For several years, paraquat has met most of the weed control needs of the temperate no-till farmer. By contrast, the tropical fallow vegetation predominated by perennial broadleaves and grasses requires a systemic herbicide that has a broad spectrum of action and that will not persist so long as to injure the farmer's crops. This type of herbicide is not generally available in the tropics. Further, a herbicide should not readily leach through the soil profile and contaminate underground water. This consideration is important because most inland waters in the tropics are potable water.

The lack of an appropriate, low cost herbicide for control of the fallow vegetation is a major limitation to large-scale adoption of no-tillage systems in the tropics. While a farmer with fields heavily infested with Imperta cylindrica may be willing to make a once-and-for-all investment to rid his field of this rhizomatous perennial weed by using glyphosate at rates of 2.9-3.6 kg/ha at a current cost of over U.S.$250 per ha, the same farmer will be unwilling to use glyphosate regularly as part of a no-tillage herbicide package because of its high cost. The reason why there are so few alternatives for the tropical no-till farmer can be traced to the fact that very few tropical weeds are included in primary screening of herbicides during early testing of proprietary products. Consequently, herbicide use in tropical agriculture has centered on discovering new uses for products developed, for example, for Avena fatua L. (wild oat) control in small grains, or control of Xanthium pensylvanicum Wallr. (cocklebur) in soybean in temperate agriculture.

D. Animal Pest Problems in No-tillage

Little research has been done to quantify damage by animal pests in no-tillage crop production in the tropics. However, insect, bird, and rodent damage has been observed to be greater in no-tillage maize than in a conventionally tilled crop. The presence of crop residue appears to favor insect damage in maize. Musick (1970) reported poor seedling emergence and increased insect damage of no-till corn. Damage by above-ground insects in no-till crop was confirmed by Gregory (1974).

The problem of pests and their control in no-tillage crop production was recently reviewed by Gregory and Raney (1979). The animal pest problems identified included insects, field mice, birds, and slugs. According to these authors, killing fallow vegetation with herbicides destroys the natural food source of field mice who then turn to crop seedlings for food, causing serious damage. Control measures used in temperate agriculture have emphasized increased use of pesticides--a practice that may not be readily acceptable in the tropics. It is generally accepted, however, that insect management under no-tillage is difficult because of pesticide application problems.

RECENT ADVANCEMENTS IN NO-TILL WEED CONTROL

The widely accepted advantages of no-tillage crop production in the tropics include reduced soil erosion, energy conservation, reduced soil compaction, reduced moisture loss through evaporation, improved moisture regime through increased infiltration, reduced soil temperature, and increased land use. In order to derive these advantages, weeds must be properly and more precisely controlled than in a conventional tillage system. A myriad of weed problems tends to complicate weed control efforts. Perhaps the greatest impediment to effective solution of weed problems in the tropics is a shortage of manpower to deal with the challenge. There are only three institutions known to this author that are deliberately working on weed control in no-tillage crop production in the tropics. These are the International Institute of Tropical Agriculture, Ibadan, Nigeria, the joint International Plant Protection Center/Centro Agronomica Tropical de Investigacion y Ensenanza program in Central America, and the research centers in West Africa coordinated by the Institut de Recherches Agronomiques Tropicales, Montpellier, France.

Although earlier reports by Lal (1980) include cassava (Manihot utilissima Pohl.) among crops that can be grown in no-tillage, more detailed study by Akobundu (1982) shows that both weed control and crop yield are significantly poorer in no-tillage than in conventionally tilled cassava. However, the no-tillage system is applicable to grain legumes and cereals.

Advances in no-tillage weed control have occurred in two distinct directions: (a) chemical; and, (b) biocontrol. In the chemical no-tillage system, effort has centered on identifying suitable herbicides for preplant weed control together with appropriate herbicides for preemergence weed control. The currently used packages for maize and cowpea weed control are listed in Table 1.

For biocontrol, current research centers on manipulating herbacious tropical legumes for weed control in food crops. One aspect of this research has been the use of annual legumes, such as Mucuna utilis (mucuna), which either can be interplanted in maize or used as a fallow crop. The legume dies off during the dry season and maize can be grown without tillage in the mulch left by the mucuna. The mucuna mulch helps smother weeds and thus reduces the rate of herbicide needed. One problem associated with this dead mulch system is the control of volunteer mucuna in the maize. The presence of volunteer mucuna precludes growing a legume crop in this system.

Table 1

NO-TILLAGE WEED CONTROL PACKAGE FOR COWPEA AND MAIZE

preplant herbicides	
annual weeds	perennial weeds
Paraquat 1.0 kg/ha	Glyphosate 2-3 kg/ha
	Glyphosate 1.5 kg/ha fb 2,4-D 0.5-1.5 kg/ha
preemergence herbicides**	
cowpea	maize
1. metolachlor	1. atrazine + metolachlor
2. metolachlor + metobromuron	2. atrazine + pendimethalin
3. metobromuron + pendimethalin	3. atrazine + alachlor
	4. atrazine fb 2,4-D

*fb = followed by.

**Rate of herbicide varies with soil conditions and rainfall.

Another biocontrol approach involves the live mulch system. In this no-tillage practice crop seeds are directly planted into a living perennial legume mulch without tillage and without need for either preplant or preemergence herbicide. Maize production in this system has been described earlier by Akobundu (1980). A comparison of crop production in conventional tillage, no-tillage, and a live mulch system under continuous cropping conditions shows that maize yield was greater in the live mulch and no-tillage systems than in conventional tillage under continuous cropping (Figure 1). High maize yield was obtained in the no-till crop through use of high rates of nitrogen fertilizer, while the live mulch cropping system produced a favorable crop yield at low nitrogen levels. On the other hand, maize yield dropped in the continuously cropped conventional tillage plots in spite of high inputs in nitrogen fertilizer. The return of organic matter to the soil

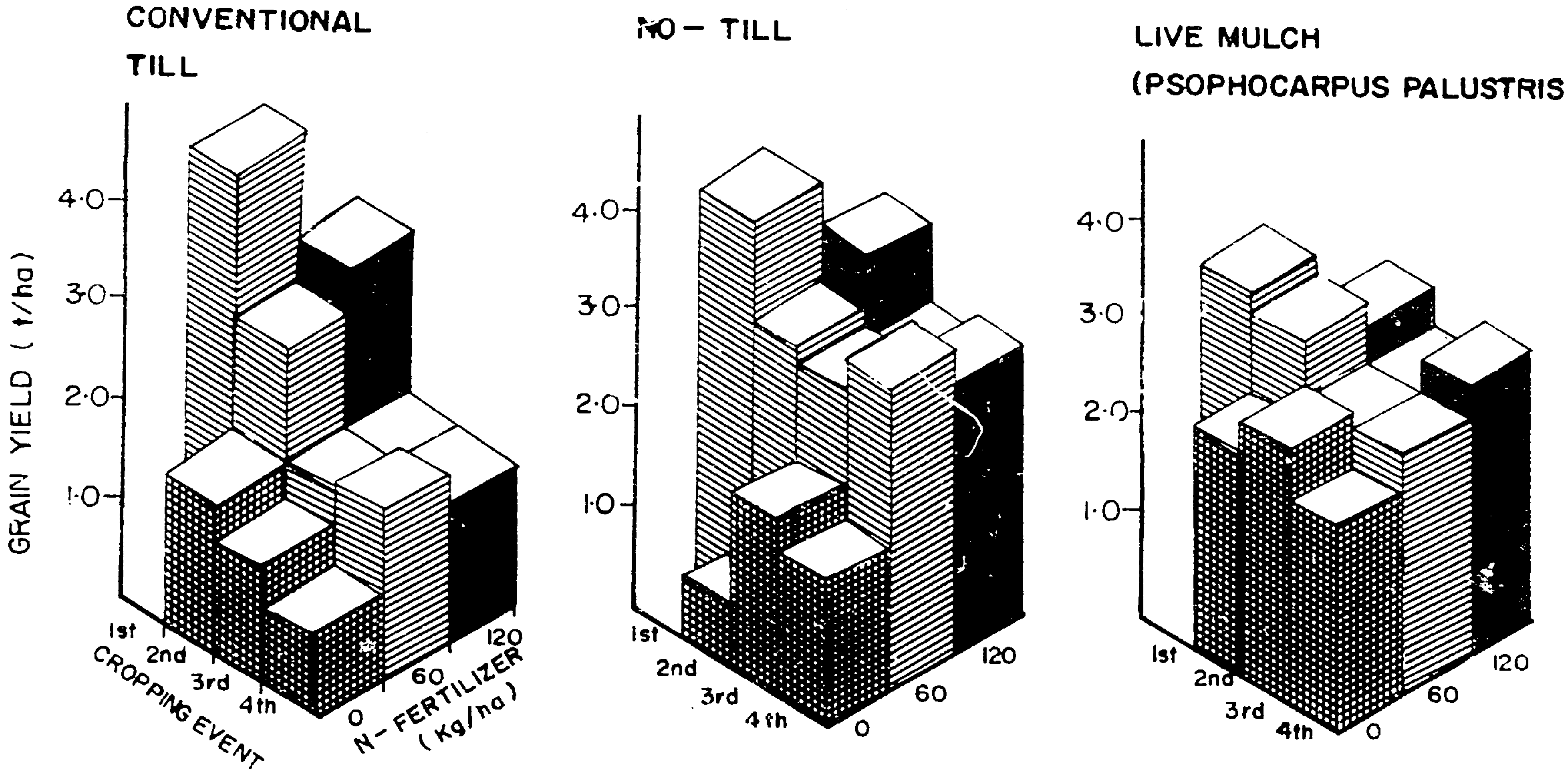

Figure 1. Effect of Land Management, N-Fertilizer, and Cropping Intensity on Maize Yield (I.I.T.A., Ibadan, Nigeria, 1979 and 1980).

in the no-till and live mulch systems is implicated in the soil conditions that favored better crop performance in these systems.

CONCLUSION

No-tillage crop production is evidently necessary if the carrying capacity of arable lands is to be improved in the face of increasing human population. In order to derive the benefits that are associated with no-tillage crop production, proper weed management practices that incorporate weed control and reduction in weed seed population in the soil must be developed and made available to farmers. Although no-tillage has merit, it must be recognized that its successful adoption requires skilled management in order for the no-till benefits to be realized.

Two approaches to no-tillage crop production in the tropics have been suggested. A no-tillage system that depends on herbicides for its implementation, and an alternative system that depends for its success on the use of mulch (living and dead) from herbacious legumes. Effective transfer of these technologies to the farmer requires trained personnel to assist with the transfer in developing countries. It also requires that herbicides, where they are to be used, should be available in consumer useable packages. Ultimately, the success of food production in the tropics requires recognition of these constraints and a demonstrable willingness on the part of researchers and policy makers in government to solve the research, staff, and infrastructural problems that directly and indirectly limit food production.

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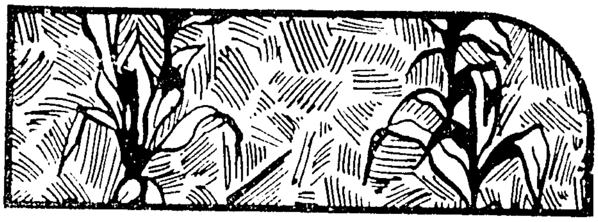
Section II
Vegetation and pest management in no-tillage crop production



VEGETATION MANAGEMENT IN NO-TILL CROP PRODUCTION

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INTRODUCTION

There is nothing unnatural in the concept of no-till crop production, except the use of chemical energy for vegetation management and/or seedbed preparation. The reverse is true of cultivation, which is an artificial concept, expedient to human endeavour, but totally alien to plant establishment within natural communities. The destruction of surface mulch, nature's plant establishment medium, is almost totally responsible for such present ills in tropical agriculture as: expansion of deserts; increasing structureless, compacted soils with zero, or low, biological activity and reduced ability to absorb and retain moisture; and, presence of toxic levels of iron, aluminum and magnesium ions. These adverse effects to plant growth have increased crop production costs and reduced yields.

The tragedy within this chain reaction is that, as nature's soft nurse, vegetation, becomes more and more sparse, surviving species develop stronger mechanisms of survival consequently making their control by conventional methods of crop production more difficult. In the long term, man is answer-

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The views and interpretations expressed in this paper are largely those of the author and must not be attributed to FAO or any other organization.

able for the cataclysmic effects of his own wanton destruction of vegetation, more particularly as the areas suitable for no-till crop production are being rapidly diminished. A complete turn-around in methods of crop production is required, and no-till crop production offers the most suitable alternative at the moment.

VEGETATION

For conventional methods of crop establishment, vegetation, particularly if it contains a high percentage of weed growth, is often considered a nuisance: something to be destroyed as completely and as expeditiously as possible. This approach is totally alien to the role of vegetation in no-till crop production. For no-till crop production, the quantity of vegetation present will dictate the probable success of the concept as well as the manner in which vegetation should be managed.

THE SEEDBED

For oversown or broadcast seed, dead litter protects the germinating seed from the vagaries of climatic conditions. Generally, seed only should be oversown when, for the period of establishment, the availability of moisture exceeds the evapotranspiration rate. Dead litter insulates the soil against temperature fluctuation and, as a direct result, causes less moisture to be lost under higher air temperatures. This factor is important where moisture is likely to be limiting, but also should be recognized for the early or late sowing of crops or the extension of warmer zone crops into cooler zones. Cooler soils may be detrimental to crop seed establishment.

Most inocula for legumes are sensitive to ultra-violet light and/or higher soil temperatures. Dead litter is helpful in protecting inocula against both agents.

The spatial relationship of the dead litter is important for oversown seed. There is a need for enough bare ground within any plant community to provide sufficient space for oversown seed to establish. Generally, the taller the vegetation, even in natural communities, the higher the percentage of bare ground. The acme of this is row planting in conventional crop production where bare ground may exceed 90% of the total space.

For conventional cultivation, a broad generalization exists; the lower the biological activity within the soil, the longer the period required to adjust the carbon-nitrogen ratio (C/N ratio). In soils with reduced biological activity, vegetation is often removed, by burning or by severe grazing prior to cultivation, to hasten the adjustment of the C/N ratio and lessen the requirement for nitrogen in the crop to be established. This practice, however, does not fully compensate for the residual plant material at, and below, the soil surface. The residual vegetation--after either close grazing, or desiccation by high temperatures under dry conditions--may be in the order of 2000 kg/ha. Thus, the total quantity of residual vegetation, turned under by plowing, at any given site may approximate 50% of the whole.

Distinction also must be made between aerial vegetation and that below the soil surface, the prevailing growth conditions, and the period taken for decomposition when vegetation is turned under. Usually, vegetation grown under harsher conditions, particularly the aerial portions, requires longer to decompose than that grown under favorable conditions. As the biological activity in the soil decreases, greater artificial nitrogen input is required, not only to assist in the adjustment of the C/N ration and lessen nitrogen deficiency in the crops, but also to satisfy the increasing nitrogen levels required by the crops to attain full potential.

In contrast, dead litter left on the soil surface not only acts as a better medium for biological activity than bare, cultivated, over-dry or over-wet, highly compacted soils, but also lowers the quantity of vegetation within the soil for the C/N adjustment. Residual vegetation within the soil, killed by chemical energy, also may decompose more quickly than that controlled by cultivation, allowing a quicker and more precise adjustment of the C/N ratio (Palmer and McKay, 1972). Provided this "chemical fallow" period is equated to prevailing site conditions, less nitrogen needs to be employed and the sown crop may have greater access to that which is applied, provided there is no placement difficulty. The process does not apply to over-wet, highly compacted soils where the excessive return of straw may create nitrification problems.

COMPENSATING FOR ALLELOPATHIC EFFECTS

The damaging effects of allelopathy (plant toxins from living, dead, or decaying vegetation) are likely to be greater under poor growth conditions and/or lower biological activity within the soil than in soils exhibiting favorable growth conditions (Field, 1979). Allelopathic effects appear to be magnified under anaerobic conditions compared to aerobic situations. The latter is more likely to be apparent in no-tillage systems. However, since chemically killed vegetation decomposes more rapidly than slashed, dry plant mass, the requirement to compensate for increased allelopathic effects either may not be necessary or may need consideration for only a shorter period.

CROP PREDATORS

The fact has been clearly established that some insects may be transferred from the foliage of resident vegetation to the coleoptile of crop plants by cultivation for seedbed preparations. No-till, however, can cause slugs, deprived of live vegetation, to quickly relish--virtually overnight--the green growth of crop seedlings as these appear. Bird damage to crop plants also may increase with no-till.

RAIN AND EROSION

Bare soil has little, if any, protection from the energy carried by falling rain. Similarly, structureless, compacted soils lack the ability to absorb raindrop energy. Soil movement may occur as a result, even under pastoral conditions. Soil movement of approximately 1 t/ha has been reported for New Zealand pastures (Matthews, 1972). Dead vegetative litter can cushion and absorb the effects of impact energy and thus limit soil movement.

VEGETATION MANAGEMENT

The quantity of vegetation (dry matter) at any given site may not be able to meet all the requirements of the no-tillage cropping concept. As an example, harvest-created straw is fed to animals and then, any remaining crop residue is further depleted by severe in-situ grazing by goats or sheep. Invariably such practices lead to: slower adjustment of the C/N ratio; rise of allelopathic effects; increased weed establishment; an unfavorable microclimate for crop seed establishment.

Upright vegetation, such as the residue from cereal row crops (plus or minus dead weed growth) is not as ideal as the resulting high bare ground ratio (50% or more) does not suit the concept of no-tillage cropping. Where the "husks" of cereals are returned as mulch to the soil surface, the site conditions may be modified sufficiently to achieve successful results. Maize residue shredded on site not only requires extensive, and likely unavailable, energy, but tends to rapidly decay (in the tropics) thereby failing to provide sufficient weed control during early crop establishment stages.

The residual vegetation resulting from broadcast cereals approximates the ideal cover for crop establishment by the no-tillage method. Small-leaved legumes, established at high densities by broadcasting, form the most satisfactory mulch.

A. Living Mulch

Inter-row living mulch could be either an annual or perennial crop. The crops' usefulness may lie more in its mulching ability than in its intrinsic value. Competition between living mulch plants and other crop plants should be minimized, if not avoided, particularly during establishment of the primary, or non-mulch, crop. Row-planted living mulch plants are more manageable in this respect than broadcast planted mulch.

B. Vegetation Control

If the concept of no-till crop establishment is to become successfully established within the tropical regions, all herbaceous and fibrous vegetation must be regarded as a valuable commodity. Its destruction by burning and physical methods must be arrested. The concept of maintaining sufficient vegetation for a ground cover at all times must be generated. That challenge involves a dramatic switch from physical and sequestered energy to greater use of chemical energy as a subtle ecological and management tool. Such a switch would utilize and value vegetation more highly as a management tool to ensure reduced inputs for crop production, i.e., vegetation management for vegetation production.

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PROVIDING MULCHES FOR NO-TILLAGE CROPPING IN THE TROPICS

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INTRODUCTION

In any agricultural system, optimum yields can be sustained only if the system has the ability to conserve those resources that are either non-renewable or renewed or restored very slowly. The soil, the natural medium for plant growth, stands out among the natural resources which, when lost or degraded, requires many years for replacement or restoration.

When human population in tropical regions was low, only small areas were cleared of forest for very short periods of cropping. Under this system--bush fallow--natural processes had ample time to restore soil fertility. Today, because of the population explosion, more land must be brought into production to meet food demand. Also, these lands must remain under production for longer periods. Unfortunately, conventional tillage techniques used for crop production in the tropics often are not compatible with soil and climate. Consequent soil erosion and degradation results in rapid yield decline.

For the humid and subhumid tropics, where rainfall is high, rain showers heavy, and soils highly erodible, soil erosion is a major hinderance to intensive cropping with sustained yields (Lal, 1975; Kowal, 1972; Fournier, 1967; Kannegieter, 1967, 1969).

Although maintaining a protective soil cover or mulch appears to be the most effective means to reduce or prevent soil erosion or degradation with continuous cropping in the humid tropics (Lal, 1975; Wilson, 1978b), mulching has not yet become a common practice.

Before the advent of no-tillage with chemical land preparation, (Phillips and Young, 1973) mulching was usually accomplished by spreading mulching material over already tilled soil. However, with chemical weed control, plus no-tillage planting techniques, it is now possible to consider recent developments that are potentially feasible for providing mulch for large scale production of tropical staples.

THE BENEFITS OF MULCH

The desirable benefits of mulch are well known, but some are stated here to strengthen the discussion to follow. Generally a mulch can be defined as: any covering placed over the soil surface to modify soil physical properties, create favorable environments for root development and nutrient uptake, and reduce soil erosion and degradation. Mulches also decrease soil moisture evaporation, increase infiltration rate, smother weeds, lower soil temperature, and enrich soils.

Of the benefits listed above, soil moisture conservation has received the most attention; mulching is usually recommended where conditions favor rapid soil moisture evaporation (Rajput and Singh, 1970). Agboola and Udom (1967) observed that soil under 8.8-11 tons of straw mulch had a moisture content of 7.8%, compared with 4.3% in unmulched soil. The high soil moisture content associated with mulch should not be ascribed to evaporation reduction alone; mulch tends to increase water infiltration by reducing the impact of raindrops and preventing surface crusting. Mulching helps retain soil pore spaces creating better infiltration, less runoff, and less erosion (Table 1). Lal (1975) found that accumulated infiltration after 3 hours on a 1% slope was higher for mulched soil than for unmulched. He attributed the higher infiltration under mulch to minimal crusting and high earthworm and micro-organism activity.

In the tropics, where high soil temperatures often hinder seed germination and root development and function, mulches have been found to be effective in reducing soil temperatures (Lal, 1975; IITA, 1972, 1973; Jacks, et al., 1955) and suppressing weeds (Lal, 1975; Agboola and Udom, 1967; Okigbo, 1965).

Table 1

MULCHING RATE EFFECTS

mulch rate (t/ha)	slope % 1	5	10	15	rainfall lost
rainfall runoff	(mm)				(%)*
0	12.0	14.8	10.4	14.8	20
2	1.3	6.2	6.0	5.7	8
4	0.4	1.5	3.6	3.3	3
6	0.0	0.7	1.9	1.8	2
soil loss	(t/ha)				
0	0.48	12.2	27.0	12.3	
2	0.01	3.5	0.8	1.6	
4	0.0	0.7	0.1	0.3	
6	0.0	0.2	0.1	0.1	

* Total rainfall = 64mm
(After Lal, 1975)

The ability of plant residue mulch to improve soil physical properties depends on the soil (Jacks, et al., 1955) and the type of mulch. Upon decomposition, plant residues increase the humus content and thus the cation exchange capacity of the soil. The high organic matter content favors the activities of soil organisms which leads to improved soil physical properties (Lal, 1975; Russell, 1973; Jones, 1971; Ghildyal and Gupta, 1959). Most organic mulches, upon decomposition, also release nutrients beneficial to plant growth (Stewart, et al., 1966; Alexander, 1961; Jacks, et al., 1955; Griffith, 1951).

Many pests and pathogens are suppressed by mulch (Huber and Watson, 1970; Sayre, 1971; Oswald and Lorenz, 1956; Patrick and Toussoun, 1970). However, there are cases where mulches favor development of harmful organisms (Linderman and Gilbert, 1968), and release phytotoxic substance that may be deleterious to some crops (Langdale, 1970; Linderman, 1970).

Crop response to mulch represents the sum total of complex interactions between physical, chemical, and biological factors (Jacks, et al., 1955). In the tropics crop response to mulch is nearly always positive (Lal, 1975, Wilson, 1978a; Okigbo, 1965, 1972; Griffith, 1951).

NO-TILLAGE

According to Phillips and Young (1973) no-tillage is a system of crop establishment in which seeds are introduced into untilled soil with minimum soil disturbance. Usually seed is planted in a hole or narrow slit of adequate width or depth for good coverage and soil contact. A mulch of plant residue retained on the soil surface appears to be essential to the technique. Herbicides are used to destroy the pre-plant vegetation and control weeds during cropping.

On many soil types, tillage is necessary only for weed control, but not crop establishment (Russell, 1941; Faulkner, 1943). In North-America, no-tillage has become very popular; development of special no-till equipment has led to large scale commercial no-till grain production (Bennett, 1977).

No-tillage is by no means new to the tropics. In fact, it is the major crop establishment method in many indigenous bush fallow, slash and burn systems. After burning, seeds are planted with minimum soil disturbance. However, traditional no-till practice differs from chemical no-tillage in that burning off plant residue leaves the soil exposed and vulnerable to erosion. Attempts being made to develop herbicide based no-tillage systems for the tropics involve developing techniques for retaining a protective mulch and thus reducing soil erosion.

PROVIDING THE MULCH

With conventional tillage, mulch was associated with the introduction of material from some source outside the field. This involved transporting and handling large quantities of materials, a time-consuming practice so expensive that it was limited to use only on high value crops. In a no-tillage system, transportation of plant residue for mulching is unnecessary provided that plant residue can be obtained either from a previous crop or fallow vegetation. The major problem, therefore, is to ensure that a suitable mulch is available in a weed-free situation on the soil surface at planting. The methods presently being tested for providing no-tillage mulch in the tropics can be classified as follows.

A. Crop Residue

Cereal straw and stalks are the most commonly used crop residue for no-tillage mulch. Where these crops are combine harvested, the stubble plus the chaff forms the mulch (Phillips and Young, 1973). In the tropics, the most likely crops for leaving suitable residue for mulch tillage are rice, sorghum, millets, and maize. So far, only maize has been tested extensively in no-tillage systems in the tropics to produce residue used for mulch (IITA, 1972, 1975, 1978, 1979).

In a study covering a 10-year period, maize yield from no-tillage plots--using retained maize residue as mulch--consistently produced equal or better yields than conventionally tilled maize; both systems relied on hand-operated equipment. Termites could be a serious problem for the no-tillage system by destroying the crop residue and leaving the soil relatively bare. Organic residue decomposition is fairly rapid in the tropics. Consequently, a large proportion of residue may decompose prior to planting if the interval between one crop and the next is fairly long.

B. In-situ Mulch

In situations where crop residues do not persist long enough to provide mulch for the next crop, attempts must be made to establish plants that, when killed, will provide the necessary residue. Lal (1975) suggested that lush weed growth killed with chemical could provide suitable mulch. However, this system has many disadvantages. The weeds are not uniform and some sections may decompose too quickly leaving bare patches. Weeds are likely to carry seeds which will germinate later and become a problem. Kannegieter (1967, 1969) observed that when Pueraria phaseoloides, a popular tropical cover crop, was killed with herbicide, it left a uniform mulch through which maize could be planted. The maize yield was similar to maize planted in conventionally tilled land, but there was no erosion with the mulch. Research at the International Institute of Tropical Agriculture (IITA) has shown that many other tropical cover crop legumes and grasses left a uniform mulch when killed with herbicide. Even during establishment the mulch encouraged earthworm activity (Table 2). The performance of maize, cowpea, and pigeon pea grown with no-tillage and in-situ mulch from three grasses and four legumes was usually as good or better than that established with conventional tillage (Table 3). Invariably the grasses were more difficult to establish and to kill, and thus research emphasis shifted to the legumes.

Table 2

EARTHWORM ACTIVITY UNDER DIFFERENT COVER CROPS

cover crops	weeks after planting					
	2-4		4-7		7-10	
	maize	cowpeas	maize	cowpeas	maize	cowpeas
	casts/m²/week					
Panicum	1680	1708	75	35	157	27
Setaria	1531	1477	109	64	192	56
Brachiaria	1879	1454	431	253	340	122
Melinis	1257	1280	463	343	419	153
Centrosema	1340	956	100	59	131	33
Pueraria	1233	1139	101	96	45	29
Glycine	1131	833	25	33	59	13
Stylosanthes	1011	976	227	38	189	9
control (no residue)	37	23	8	0	36	0
LSD (0.05)	1200	1066	165	81	193	20

(After Lal, et al., 1978)

Table 3

CROP YIELD AND COVER CROP RESIDUE

cover crop	crop yield maize	cowpea	pigeon pea
	(t/ha)		
Panicum	3.36	0.67	1.06
Setaria	4.36	0.66	0.90
Brachiaria	5.02	0.61	1.42
Melinis	3.96	0.77	1.35
Centrosema	4.34	0.71	1.40
Pueraria	3.38	0.71	1.23
Glycine	3.39	0.72	0.90
Stylosanthes	5.73	0.72	1.25
control	4.08	0.23	1.10
LSD (0.05)	1.06	0.50	0.25

Criteria for plants potentially useful for in-situ mulch are:

(1) be easy to establish, especially with no-tillage planting;

(2) have rapid early growth and be competitive enough to overcome weeds;

(3) be adapted to the climatic region and able to survive stresses (e.g., drought) normal to the region;

(4) be able to produce seeds or other reproductive structure under the local climate;

(5) be free from pests or diseases harmful to other crops in the rotation;

(6) be easily killed with known herbicides that are compatible with crops in the rotation;

(7) be capable of producing a uniform mulch which will persist long enough to keep the soil covered until the crop canopy closes;

(8) not become a weed in fields in which it was used;

(9) produce a residue layer thin enough to allow both planting with available no-tillage equipment, and seedling establishment;

(10) have a dormant seed that can reestablish a cover following the crop; and,

(11) be able to grow on soils low in the major nutrients while possible improving the nutrient, as well as physical, status of that soil.

Table 4

COVER CROP ESTABLISHMENT

legume	establishment one year after planting: conventional tillage	establishment one year after planting: no-tillage
	ratings	ratings
Centrosema pubescens	3.0	3.7
Pueraria phaseoloides	4.0	4.3
Psophocarpus palustris	3.3	3.3
Stylosanthes guianensis	2.7	4.3

rating values:
0 = no legume; 1 = very, poor, less than 20%
2 = 20 - 50% 3 = 50 - 70%
4 = 70 - 90% 5 = 90 - 100% legume cover

To date most plants that satisfied the preceding criteria were aggressive creeping or climbing legumes (Wilson, 1978a). Tests with four popular cover crops showed that no-tillage planting was slightly superior to conventional tillage planting (Table 4). Techniques have been developed to establish a cover crop for in-situ mulch in association with other crops (IITA, 1978). Pueraria phaseoloides, Psophocarpus palustris and Mucuna utilis have been successfully established with maize. Establishment of cover crops between arable crops should be attractive to peasants who are unlikely to plant and tend cover crops from which there are no direct returns.

Wilson and Caveness (1980) investigated the effects of certain leguminous cover crops as suppressors of plant parasitic nematodes. While Centrosema pubescens and Stylosanthes guianensis were effective suppressors of the three types of nematodes observed, P. palustris suppressed the spiral nematode, but increased the prevalence of rootknot nematodes (Table 5).

Table 5

COVER CROP EFFECT ON NEMATODES

species	nematode types: Meloidogyne spp.	Helicotylenchus spp.	Pratylenchus spp.
population: suppression = +, build-up = -			
Centrosema pubescens	+	+	+
Pueraria phaseoloides	+	+	+
Indigofera sublata	+	-	-
Stylosanthes guianensis	+	+	+
Crotalaria juncea	+	-	-
Psophocarpus palustris	-	+	+

Wilson (1978b) found that tomatoes grown with in-situ mulch from P. phaseoloides responded to fertilizer, but the response was less than where the mulch was removed. No-tillage maize grown in a cover crop residue tends to show marked nitrogen deficiency symptoms when nitrogen is not added. The nitrogen requirement, however, is less than maize grown with conventional tillage[1/]. Thus, even, where legumes and their associated symbiotic Rhizobium bacteria have added to the nitrogen level in the environment, such

1/ Wilson and Akapa, unpublished data.

nitrogen is not readily available to crops while tied up in the mulch. A large part of the nitrogen in the mulch could also be lost through volatilization.

Residue from some cover crops sometimes exceeds the mass that available no-till equipment can penetrate. For example, no-till maize planters that were effective with 5 t/ha, dry weight, of residue form Mucuna utilis were ineffective with 10 t/ha residue from Pueraria phaseoloides. Table 6 indicates that mulch obtainable from some legumes used for in-situ mulch for no-tillage cropping is too great for available no-tillage equipment. Where the in-situ mulch is uniform and thick, pre-plant herbicide application is usually unnecessary as the mulch itself suppresses weeds.

Table 6

CREEPING COVER MULCH ACCUMULATION

legume	weight after one year: fresh	dry
	(t/ha)	
Psophocarpus palustris	35	11
Glycine wightii	12	6
Centrosema pubescens	21	13
Pueraria phaseoloides	17	10

C. Live Mulch

Live mulch is similar to in-situ mulch except that the cover crop is not killed. At the time of crop establishment, growth of the cover crop is halted by a chemical growth retardant which keeps the plants dormant for a period sufficient to minimize competition between crop and mulch. By the end of cropping, the cover crops are actively growing and capable of smothering weeds (IITA, 1979; Akobundu, 1980). Live mulch cover crops need the same attributes as in-situ mulch cover crops except that they must be sensitive to the growth retardant used.

In the humid tropics where trees and woody shrubs dominate the climax vegetation, herbaceous fallows are often difficult to maintain. The same is also true in semi-arid regions where shallow-rooting herbaceous plants are likely to succumb to moisture stress during a long dry season. To overcome these difficulties, Wilson and Kang (1980) developed alley cropping; crops are grown in an alley formed by rows of vigorous, fast-growing trees and shrubs (usually legumes). At crop establishment, the trees or shrubs are cut back and the leaves and twigs placed on the soil surface to form a rough mulch. The fallow plants are kept pruned during cropping to reduce competition for light, nutrients, and moisture. All prunings are added to the soil, not only to add mulch, but also to increase the soil nutrient level (Wilson and Kang, 1980; IITA, 1979, 1980). The potential nutrient contribution from tree legume prunings in alley cropping systems deserves consideration (Table 7). In addition, the larger stems and branches can be used as yam stakes or firewood.

Table 7

TREE LEGUMES: MULCH AND NUTRIENT

species	mulch dry weight	nutrient content* N	P	K	maize yield
	(kg/ha)				
Cajanus cajan	4100	151 (3.6)	9 (0.2)	68 (1.6)	3173.4
Tephrosia candida	3067	118 (3.8)	7 (0.2)	49 (1.4)	1912.2
Leucaena leucocephala	2467	105 (4.2)	4 (0.2)	51 (2.0)	2601.6
Gliricidia sepium	2300	84 (3.7)	4 (0.2)	55 (2.5)	2587.3
control	-	-	-	-	2030.3
LSD (0.05)	-	19	2	8	N.S
cov (%)	-	8	13	7	

* Values in parenthesis show % nutrient content.

FUTURE OUTLOOK

The mulching techniques described are relatively new and may require several more years of research before the basic concepts embodied can be refined to meet the requirements of tropical crop production. While the physical aspect of mulch has been emphasized, the potential for contribution by chemicals was not totally forgotten.

Nearly all crops used for supplying mulch are legumes, well known for nitrogen fixation. Henzell and Norris (1962) estimate that most tropical legumes have nitrogen fixation potential of between 73 and 577 kg/ha/year and this potential could be raised with improved legumes and rhizobium symbiotics. If mulching techniques for no-tillage crop production are developed, the contribution of legumes to tropical crop nitrogen needs will increase. The aim is to create an efficient biological system in which nitrogen fixed by legumes and bacteria are transferred to crops through a soil environment adjusted to facilitate maximum absorption of nutrients recycled through the biological system. With these techniques, it may become necessary to reevaluate current thinking concerning soil-plant relationships in the tropics as well as fertilizer recommendations and application techniques. Organic mulch generates high infiltration rates induced by mulch which, in turn, causes leaching losses subsequently increasing demand for highly soluble and mobile mineral nutrients.

Though not used extensively in the experiments cited, grass species have an important role in mulching techniques for the tropics. With some of the newer herbicides that can effectively control grasses, in-situ grass mulch also could become common in tropical savanna where grasses dominate the fallow vegetation. Natural regeneration would eliminate the cost and other problems of establishing in-situ mulch.

While most mulching techniques are transferable to peasants using hand tools, others are not ready for mechanized farming. There is an urgent need for research to develop suitable no-tillage equipment to meet the needs of these tropical systems. Unfortunately, work on large scale implements is almost absent in the tropics and systems developed to improve large scale production may lag behind because of the anticipated slow pace of engineering research in the tropics.

The outlook for tropical agriculture is bright because available soil conservation techniques now make possible the control of erosion, once the scourge of the tropics.

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POTENTIALS FOR NO-TILLAGE CROP PRODUCTION IN SIERRA LEONE

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INTRODUCTION

Farmers in various parts of Sierra Leone employ different tillage techniques depending on the prevailing agro-ecological situation, type of vegetation, soil characteristics, and type of crops grown. These techniques can be grouped under conventional and minimum tillage.

In conventional tillage, the soil is completely dug up, small farmers usually using hand hoes of various types, large-scale farmers utilizing tractors. However, most farmers practice minimum tillage. Upland rice farmers use small hand hoes to scratch the top soil in order to mix rice seed with it. Another form of minimum tillage commonly used in some parts of the country involves planting cassava (*Manihot utilissima* Pohl) on small, widely spaced mounds and leaving the rest of the ground untouched.

The reasons in favor of conventional tillage are well known (Philips and Young, 1973; Van Doren, 1973; Akobundu, 1976; Buckley, 1980). But the extent of their application varies within a region as well as from one region to another. Conventional tillage is intended to provide a clean, weed-free seed bed and a suitable soil texture for plant growth. It is practiced by farmers working with deep top soil and in locations where fallow vegetation can be easily worked into the soil.

Upland rice farmers in Sierra Leone have been forced to use minimum tillage partly because of the gravelly upland soils, and partly because of the high tree density characterized by superficial and spreading root systems. These conditions make deep hoe digging almost impossible. Even using a tractor necessitates a costly manual stumping or bulldozing operation.

No-tillage, by definition, is the planting of crops in previously untilled ground, after the existing fallow vegetation has been killed. Although this method of crop production is not practiced by Sierra Leonean farmers--either due to not knowing anything about it, or not believing that no-tillage can produce the same or even better yields, or not having the resources to embark on no-tillage farming--there are possibilities for modifying present land preparation techniques to improve crop production.

TOWARDS NO-TILLAGE FARMING

The slash-and-burn method is traditional for fallow vegetation management in dryland rice farming. One improvement that could be made would be adjusting the timing of the operation.

When the two operations--cutting and burning--are well-timed, and provided there is enough dry plant residue, the combination effectively leaves a weed-free surface for crop establishment. Rice can then be sown directly by drilling or by dibbling. Experiments have shown that if rice is direct-drilled in such fields, grain yield is as good as in conventionally tilled land (Table 1). Sowing upland rice by drilling is new to the average farmer in Sierra Leone. Since these farmers are already used to the scratching method of seeding, they can be encouraged to plant in rows when the advantages of weeding and harvesting are demonstrated.

Table 1

TILLAGE AND WEEDING EFFECT ON UPLAND RICE

tillage method	weeding method: hand	weeding method: (3) Stam F-34T	(4) tillage means
	kg/ha grain yield in 5-year fallow		
(1) conventional	1,524.0	1,424.6	1,499.3a
(2) no-tillage	1,433.0	1,560.4	1,496.7a
(4) weeding means	1,478.5a	1,517a	1,498.0

(1) hoe digging
(2) hand pulling weeds followed by rice drilling
(3) formulated mixture of propanil and fenoprop
(4) figures followed by the same letter within tillage and weeding means are not significant at P.05.

Source: G.C. Nyoka, 1980, Ph.D. thesis, Njala Univ. Coll., Sierra Leone.

In groundnut growing, plots are prepared in the same way as rice fields, except that they are cleared of shorter duration fallow mainly composed of grasses. The grassy bush is first burned; plants not destroyed by the initial burning are cut at ground level, gathered, and burned in heaps. The field is left bare and clean enough for direct sowing. But the farmers prefer to dig it up thoroughly before sowing. Trials are being planned to test whether or not various no-tillage techniques can produce better yields under these conditions.

Cowpea (*Vigna catjang* Waip.) is usually grown in smaller plots than groundnuts and in the gardens around houses. On farms away from the homestead, cowpea is planted as a second crop in harvested rice fields. The plots are prepared by slashing the rice straw and other vegetation at ground level, gathering the crop residue in heaps, and either burning it or allowing it to rot. The resulting clean ground is dug up and leveled before sowing. Recent trials have indicated that digging up the soil is unnecessary (Table 2). Slashing and using the residue as mulch has resulted in yields equal to those from conventional tillage. The slashing-mulching practice also has shown promise in lowland areas where cowpea is grown as a second crop after rice.

Table 2

MULCH-TILLAGE EFFECT ON COWPEA

treatment	yield (kg/ha)
1. No-tillage: grass cut, evenly spread, dried for 3 days	1323.14ab
2. No-tillage: grass cut, cowpea planted immediately	1470.45ab
3. No-tillage: grass killed using paraquat	1187.78ab
4. Plots plowed, planted, and mulched	1160.63ab
5. Conventional tillage	1021.14bc
6. No-tillage: grass cut, removed from plot	620.19c

Source: modified from, Kamara, C.S., 1980, Tropical Grain Legume Bull. no. 19, p. 10-13.

PROBLEMS OF NO-TILLAGE FARMING

A. Land Clearing

Farming in Sierra Leone occurs in three main ecological zones: dryland (uplands), lowlands, and swamps. In the first zone, direct rainfall is the only source of plant moisture. Lowlands are seasonally flooded areas and normally covered by grass. Swamps are permanently wet or flooded river basins and coastal lowlands. They are composed of either large stretches of grassland or patches of swamp forest.

Before no-tillage can be introduced in any of these ecologies, some form of land clearing--that preserves the top soil--will be necessary. Manual stumping of trees and digging up the tufted and rhizomatous grasses may not be satisfactory because the trees will be cut close to ground level and most of the shrubs ignored. These soon regenerate into luxurious bush regrowth. In lowlands, and especially swamps, problems associated with bush clearing are likely to come from tufted and rhizomatous species such as *Paspalum vaginatum* Linn. f., *Panicum laxum* Sw., *Imperata cylindrica* P. Beauv., and from several sedge and fern species. Furthermore, no-tillage in the lowlands and swamps will require efficient drainage systems to control water. Drainage systems will need to be carefully studied before implementation to ensure that some swamps are not turned into dry valleys.

B. Pests

A shift in weed flora in favor of perennial species has been associated with no-tillage farming. The presence of perennials could pose a serious problem in no-tillage where herbicides are not easily within reach of farmers. Several workers have expressed concern that the presence of crop residue and chemically killed sod on the ground surface may provide shelter for diseases, insects, snails, birds, rodents, and animals (Philips & Young, 1973; Akobundu, 1976).

As for disease control, indigenous farmers have, for ages, controlled or avoided diseases through the shifting cultivation system in which, after abandoning a problem farm, a new, safe area is chosen. Any disease or insects present in the previous farm are left in the fast growing bush. In the absence of efficient control measures, no-tillage may allow insects and diseases to develop and spread and endanger the farmers' crop.

C. Equipment and Chemicals

The basic equipment for no-tillage farming is the planter and the herbicide applicator. In the humid tropics, land clearing equipment is also necessary. Such equipment is not only difficult to find, but also expensive to purchase and maintain at village level.

Although many herbicides have been screened during the past 30 years, very few are available on the local market, mainly because a demand has not been established. Only two, paraquat and a mixture of propanil and fenoprop (selective for rice), are consistently available to the public in Sierra Leone.

Most small farmers in Sierra Leone do not use inorganic fertilizers. They depend on organic matter provided during the fallow period. Recent research reports from the International Institute of Tropical Agriculture (1981) indicate that fertilization is essential in no-tillage farming. The introduction of no-tillage farming will have to include solutions to problems of fertilizer availability, cost, application, and the farmers' attitude toward use of inorganic fertilizer.

Most of Sierra Leone is undulating and the farms now can be seen ranging up to the hill tops in search of well established farm bush. Rainfall is very high with 13-16 rainy days per month, suggesting a high frequency of rainstorms. Therefore, an efficient network of rainfall forecasting is necessary to help the farmers who cannot afford any risks in herbicide and fertilizer application.

CONCLUSION

While no-tillage farming offers benefits, it also has problems, some of which have been cited. Other problems range from unpredictable rainstorms during the growing season to dangers posed by fires. Dry crop residue in no-till systems could be a fire hazard in Sierra Leone where bush fires are a common event.

Very little information about no-tillage farming in any of the three Sierra Leonean ecologic zones is available locally. Extensive plot projects will need to be undertaken to obtain practical data upon which to base no-tillage farming decisions.

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INSECT POPULATION RESPONSES TO VEGETATION MANAGEMENT SYSTEMS IN TROPICAL MAIZE PRODUCTION

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INTRODUCTION

An increase in minimum or no-tillage for crop and pasture production in the U.S.A. from approximately 12 million to 40 million ha during 1972 to 1981 (Lessiter, 1981) suggests that reduced tillage systems provide distinct advantages in many situations. Frequently mentioned advantages are: high yields (Allen, et al., 1977; Blevins, et al., 1971; Moschler, et al., 1972; Phillips, et al., 1980; Phillips and Young, 1973; Van Doren and Allmars, 1978) soil moisture conservation (Blevins, et al., 1971; Moschler, et al., 1972; Shear and Moschler, 1969), reduced energy consumption (Blevins, et al., 1980; Frye, et al., 1981; Phillips, et al., 1980; Wittmus, et al., 1975), and, thus, increased economic efficiency (Phillips and Young, 1973; Shenk and Locatelli, 1978; Wittmus, et al., 1975). However, many investigators caution that insects and diseases frequently pose a greater problem, or are potentially more severe, in no-till systems (Gregory and Raney, 1981; Griffith, et al., 1977; Reicosky, et al., 1977; Stuckey, 1981).

Oregon State University, under contract with the U.S. Agency for International Development, initiated a cooperative weed control research program with the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) in Costa Rica in 1976. This project has concentrated on no-till vegetation management systems for maize (*Zea mays* L.), beans (*Phaseolus vulgaris* Linn.), cassava (*Manihot ultissima* Pohl.) and various combinations of these crops in humid lowland tropics. Interactions between insects and tillage methods were recorded in experiments carried out over a 4-year period in the Atlantic Zone of Costa Rica, an area characterized by 2674 to 4260 mm annual precipitation, and 22.3 to 25.1 C mean annual temperature, with elevation ranging from 250 to 602 m.

Table 1

MAIZE YIELD AND WEED MANAGEMENT

treatments	shelled maize yield 1/ (kg/ha)	plant height (mm)
1. Plowed, preemergence herbicides 2/	2397 b	233 a
2. Plowed, postemergence directed paraquat	2959 a	223 b
3. Slashed at planting, postemergence directed paraquat	2819 a	241 ab
4. Preplant glyphosate (1.3 kg a.e./ha)	3034 a	249 a

cv=13.68%

1/ Yield at 120 days after planting (DAP).

2/ Linuron (1.0 kg/ha) plus metolachlor (2.0 kg/ha).

High infestation of *Rottboellia exaltata* made it necessary to apply paraquat (0.3 kg/ha) 20 and 40 DAP in Treatments 1, 2, and 3, and a single application in Treatment 4, 45 DAP.

Values followed by the same letter do not differ significantly at the 5% level as determined by Duncan's Multiple Range Test.

EXPERIMENT RESULTS

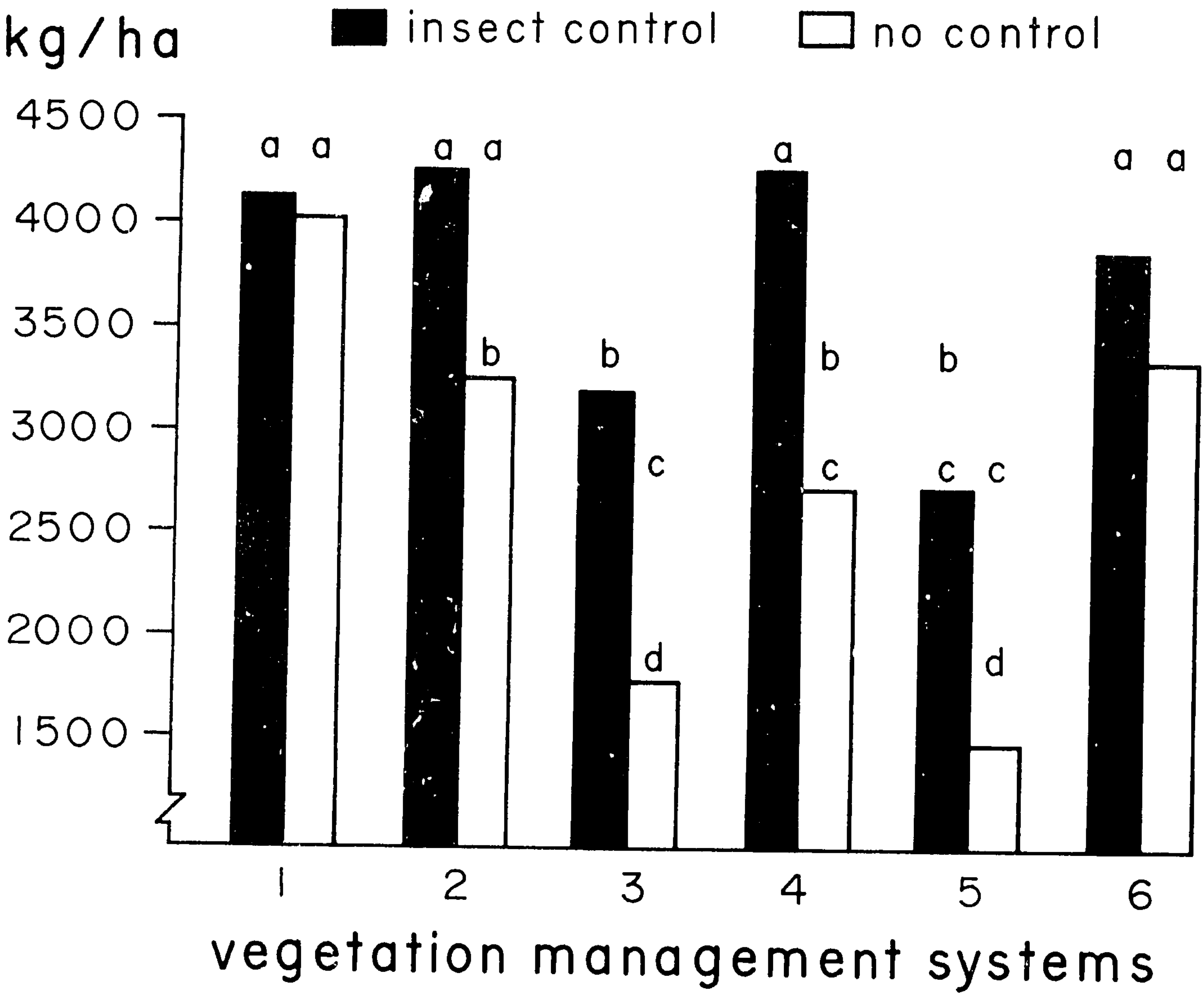
Increased grain yields and plant height in no-till treatments in the program's initial maize experiment (Table 1) were believed to be entirely related to physical and chemical phenomena in the soil (Shenk, 1979), until increased insect populations were noticed. Farmers in the area corroborated early research observations that insect problems in plowed fields were greater than in non-plowed fields. Thus, an experiment was designed to study the interactions between insects and six vegetation management systems (Carballo, 1979) that were devised to represent a wide range of options for small farmers (Table 2).

Table 2

VEGETATION MANAGEMENT SYSTEMS

system no.	treatment
1.	Slash vegetation at ground level; apply glyphosate (1.5 kg/ha) on regrowth 20 days later; plant 7 days after herbicide.
2.	Slash vegetation at 40 to 60 cm above ground level; apply glyphosate (1.5 kg/ha) on regrowth 20 days later; plant 7 days after herbicide.
3.	Slash vegetation at ground level; apply "farmer's mix" of MSMA + paraquat + atrazine (4.0 + 0.5 + 1.0 kg/ha) on regrowth 20 days later; plant 7 days after herbicide.
4.	Slash vegetation at ground level; plant same day; 22 days after planting apply paraquat + MSMA (0.4 + 2.0 kg/ha).
5.	Plowed, disced, planted; paraquat + 2,4-D, + 2,4,5-T (0.4 + 0.4 + 0.4 kg/ha) 22 days after planting.
6.	Slash vegetation at ground level; plant same day; manually weeded 22 days after planting.

Figure 1. INSECT EFFECT ON MAIZE YIELD



Insect control: carbofuran (1.0 kg/ha) at planting & methomyl (0.145 kg/ha) 8 DAP & trichlorform (0.5 kg/ha) 25-35-45 DAP.

Columns with the same letter do not differ significantly at the 5% level as determined by Duncan's Multiple Range Test.

Adapted from Carballo, 1979.

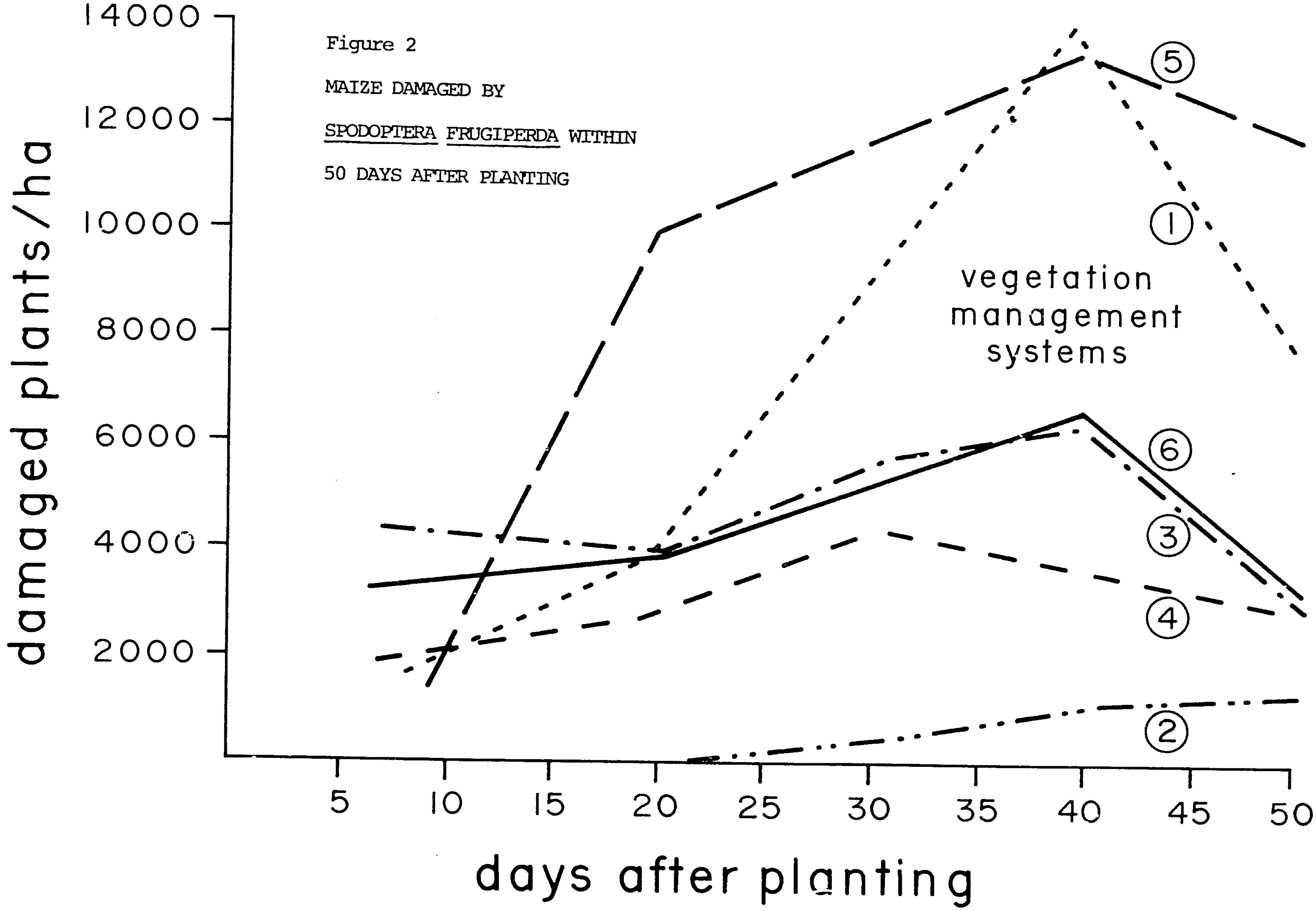


Figure 2

MAIZE DAMAGED BY

<u>SPODOPTERA</u> <u>FRUGIPERDA</u> WITHIN

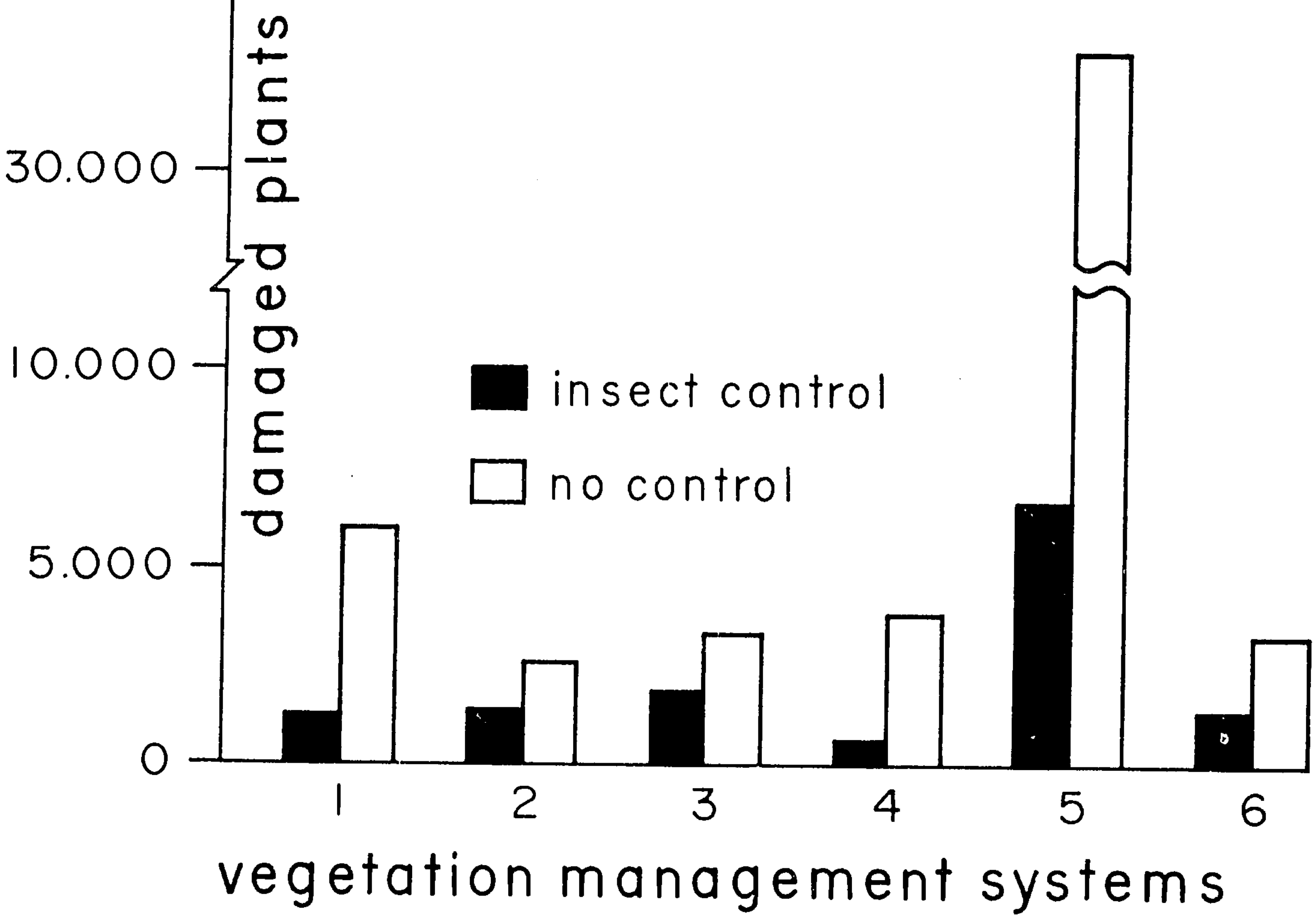
50 DAYS AFTER PLANTING

To assess the effect of insects, each of the six systems was repeated with and without insect control. Grain yield in plowed plots of system 5 was 1500 kg/ha, or 49.8% of the average yield (3011 kg/ha) in the 5 no-till systems, if insects were not controlled. If insects were controlled, plowed plots produced 68% of the average yield obtained from the no-till systems. Yields were reduced 24.1% in no-till treatments and 44.4% in plowed treatments if insects were not controlled. Apparently, pest damage as well as several soil associated phenomenona have separate but confounding affects on yields.

Figure 3

MAIZE DAMAGED BY <u>DIABROTICA BALTEATA</u>

15 DAYS AFTER PLANTING



Figures 2 and 3 indicate that vegetation management systems strongly affected the number of maize plants damaged by Spodoptera frugiperda (J.E. Smith) and Diabrotica balteata Leconte (Carballo, 1979). S. frugiperda populations in treatment 1 were similar to those in the plowed plot (treatment 5). The weeds in this treatment were cut at ground level and glyphosate applied to regrowth 20 days later, eliminating the predominant species Paspalum fasciculatum. The prostrate mulch on the soil surface 12 days after planting (DAP) left maize highly exposed, as in the plowed plot. Weeds in treatment 1 did not interfere appreciably with visual and chemical stimuli for insect colonization of the maize.

Increased colonization by D. balteata in plowed plots probably was influenced by insect response to color contrast between the crop and the plowed soil and by preference for oviposition in plowed soil (Carballo, 1979). No significant differences were found among Phyllophaga spp. populations in the soil, although population trends followed weed populations in the various treatments.

P. fasciculatum was the predominant weed species when the experiment was initiated. Other species, including Digitaria spp., Eleusine indica, Setaria sp., and Borreria sp., composed 10% of the weed complex. Glyphosate reduced grass populations more effectively than the other treatments (Table 3). The regeneration potential of weeds in the humid lowland tropics was demonstrated by rapid recovery of weed populations after weed control. Although weeds were controlled for 22 DAP in treatments 4,5, and 6, weeds/m² 40 DAP in all treatments approached the levels existing 20 DAP. Weed counts and maize yields were not correlated. Broadleaf weeds tended to invade the plots with more effective grass control, but competition from broadleaf weeds was insignificant.

Table 3

WEED POPULATIONS[1/]

system	20 DAP[2/] grass	20 DAP[2/] broadleaf	40 DAP grass	40 DAP broadleaf
	(plants/m^2)			
1	13.8	11.8	21.9	12.9
2	3.5	10.0	13.7	72.5
3	33.6	13.3	39.3	25.9
4	39.1	18.2	30.7	17.4
5	26.9	19.6	21.5	21.0
6	33.4	24.8	34.6	38.2

1/ Guapiles, Costa Rica, 1979
2/ Days after planting.

A tillage experiment to study physical-chemical factors in tilled and no-till treatments was established in 1977 on a clayloam soil in Turrialba, Costa Rica. The field had been in pasture for 15 years with *Panicum maximum* and *P. fasciculatum* the predominant species. Maize and cassava monocrops, and maize-bean and cassava-bean polycrops were planted during the first two years. In 1979, a study of interactions between insects and vegetation management systems in maize (Table 4) was initiated in the same field (Shenk, *et al.*, 1980).

Unlike the previous experiment, shelled maize yields were the same for both tillage methods when insecticides were applied. However, yields were significantly less in plowed plots without soil insect control. Foliar-feeding insect damage did not reduce yields significantly.

Table 4

INSECT-VEGETATION MANAGEMENT INTERACTION EFFECT ON MAIZE YIELD

insect control[1/]	plowed plots		no-till plots	
	(kg/ha[3/])			
A. none	2776	e	3617	cd
B. aldrin in soil	3788	bcd	3787	bcd
C. aldrin in soil + foliar control	3731	bcd	3812	bcd
D. carbofuran in soil	4292	abc	4751	a
E. carbofuran in soil + foliar control	4873	a	4498	ab
F. foliar control only	3393	de	3763	bc

1/ carbofuran: 1.0 kg AI/ha - applied in hill with seed.
aldrin: 1.0 kg AI/ha - applied in hill with seed.
foliar control: 0.15% carbaryl - applied to foliage 10 DAP, 1g phoxim 2.5 g - applied to whorl when *S. frugiperda* was present.

2/ shelled maize

3/ values followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

cv=13.02%

The greater yields in the treatments with carbofuran leave unanswered several questions; did carbofuran physiologically simulate maize, or does all of the increased yield reflect protection of maize roots from insects and/or nematodes? A preliminary study[1/] indicates that carbofuran does not induce a physiological stimulus in maize.

1/ Phillip Shannon, personal communication

Plant height and plant population 40 DAP had correlation coefficients with yields of 0.74 and 0.86 respectively. Increased plant height probably reflects superior protection of roots, allowing better nutrient and water uptake. Plant population maintenance reflects protection from soil inhabiting pests.

Responses of six cropping systems with two nitrogen levels and two tillage systems were studied in the same field in 1980 (Jimenez, 1981). Residual nitrogen following the different cropping systems also was studied in a relay planting of maize.

Maize and common beans both had significantly higher yields in the no-till plots. Lima bean (Phaseolus lunatus) yields were significantly lower for no-till, but slug damage (Mollusca: Gastropoda) in the no-till plots was severe. Increased slug attack in no-till plots was attributed to environmental effects of mulch on slug populations. When lima beans were intercropped with maize, slug attack was significantly reduced.

Four fertility levels, control and no control of insects, and two tillage systems were studied in well drained loam soils in the Atlantic Coast area of Guacimo, Costa Rica, in 1980 (Shenk, 1980). The harmful effects of soil inhabiting insects and tillage were demonstrated. The average yield for the plowed treatments was 2960 kg/ha compared to 4410 in no-till. Insect control increased maize yields. Yield significantly correlated with plant population and plant height, two parameters that permit an indirect measure of damage caused by soil inhabiting insects.

The fertilizer levels reflect an attempt to evaluate current farmer practices in the area and thus did not include a wide range of fertilizer rates. The response to fertilizer was minimum. Foliage-attacking insects were not apparent in this experiment. Sampling method for detecting soil inhabiting insects (20 cm x 20 cm x 20 cm soil sample around eight plants/50m^2) did not permit the detection of significantly different insect populations.

CONCLUSIONS

Experiments in two different areas, with different soil types and varied field histories, have consistently shown that insects reduce maize grain yields in plowed fields more than in no-till fields. Soil inhabiting insects (or perhaps nematodes) frequently reduce plant vigor and population in plowed treatments.

The incidence of *Spodoptera frugiperda* and *Diabrotica balteata* was much greater in plowed plots than in no-till plots. No-till treatments with plant residue cover flat on the soil surface also experienced increased *S. frugiperda* attack. Insect damage may be reduced in no-till situations because of some of the following:

1. abundance of vegetative materials may provide alternate food sources;
2. vegetative material provides a habitat for more insect species, including predators;
3. vegetative cover provides a physical barrier to the free movement of certain insects;
4. vegetative cover may mask olfactory stimuli;
5. mulch cover reduces the visual contrast between the crop and the background, as compared to a plowed field; and,
6. certain insects prefer to oviposit in plowed fields (Altieri, *et al*., 1977; Carballo, 1979).

These findings imply that, for the small traditional farmer, no-till techniques are probably more appropriate than mechanization. In addition to providing agronomic benefits, such as improved soil and water conservation and greater economic efficiency, insect attack severity was reduced which could help reduce insecticide use. Furthermore, if plowing-disking are used to prepare a field for maize planting, insect control should be practiced to realize optimum yield.

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PESTS AND THEIR CONTROL IN NO-TILLAGE IN THE TROPICS

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INTRODUCTION

Zero tillage with the use of ground covers has long been an established practice in tree crops, especially in tropical countries (Douglas, et al., 1976; Ruthenberg, 1976). In permanent farming systems, where ground covers are not used, minimum or zero-tillage became feasible after the discovery of the phenoxy herbicides. The advent of soil-applied herbicides during the 1950's, such as the substituted ureas and triazines, provided additional chemical tools to replace cultivation before and after sowing. In the early 1950's, dalapon was introduced as a means of killing grass swards prior to reseeding (Elliot, 1975). In Japan, minimum-tillage in rice was an accepted practice in 1973 (Brown and Quantrill). Herbicides such as paraquat, dalapon, and glyphosate can be used to reduce the number of cultivations during seedbed preparation (Mittra and Pieris, 1968; Seth, et al., 1971; DeDatta, 1974).

No-tillage farming of annual crops has developed in the U.S.A., first in the drier parts of the country, and later in more humid areas. Young (1973) stated that in the northern U.S.A. almost 2 million ha of crops, mostly grains, were produced by no-tillage farming. Phillips, et al. (1980) said that in 1974 2.23 million ha were under no-tillage production. In other temperate countries development of no-tillage farming is considerably less common. In the tropics, commercial development of no-tillage in annual crops has occurred mainly in Brazil, especially in soybeans grown on large farms. Research on no-tillage production of soybeans started in Brazil in 1971 (Wiles and Guedez, 1975). In 1979, 120,000 ha were planted using no-tillage techniques (Hayward, Wiles, and Watson, 1980). Recently, small farmers in El Salvador and other Latin American countries have started using no-tillage techniques in growing maize and beans (Hayward, Wiles and Watson, 1980).

A. No-tillage Related to Climate

In cold climates no-tillage may not be successful in annual crops because of slowly increasing soil temperatures in the spring when soils are covered with crop residues. This delay in soil warming is an advantage in the tropics where soil temperatures can be too high for satisfactory germination and emergence of crops on well drained soils. Heavy rains may delay seedling development in non-tilled fields because of the high water holding capacity of the mulch. Mulching prevents erosion, conserves soil moisture, and protects the soil structure against direct damage caused by sun and rain. No-tilled soil has a higher density and lower porosity than plowed soil. Mulching helps maintain the density and improves porosity and fertility of the soils due to increased biological activity of earthworms and other soil micro-organisms which use mulch as food (Lal, 1975).

Experience with no-tillage in the tropics indicates that 3 to 5 t/ha of dry weight of mulch (from desiccated weeds and crop residues) must be available (Wijewardene, 1980). Root growth under no-tillage may be restricted during the early stages of the crop due to the compacted surface layer, lower porosity, and inadequate nutrient distribution in the soil profile, but 3 to 4 weeks after planting, relatively rapid root elongation occurs in no-tilled fields. This results (on many soils) in near to full recovery of the crop (Baeumer and Bakermans, 1973; Maurya and Lal, 1980), but may not be the case under excessive moisture and for soils with low permeability (International Institute of Tropical Agriculture, 1979).

B. No-tillage Related to Soils

Minimum or no-tillage techniques are necessary in hilly, high rainfall areas to reduce erosion, and to help maintain porosity, infiltration, and fertility of the soils. In areas not susceptible to erosion, the choice between no-tillage and conventional farming is more difficult. If soils are fertile and contain sufficient levels of clay and organic matter, zero and conventional-tillage techniques produce about the same yields. Under adverse conditions, such as drought, no-tillage may outyield conventional plowing. At the International Institute of Tropical Agriculture (IITA) in Nigeria, yields of maize during 7 years of cropping on fertile soils with a good structure were not influenced by tillage methods. However, continuous cropping on poor soils resulted in low yields where no-tillage was practiced, despite the fact that ample fertilizer was applied (International Institute of Tropical Agriculture, 1975). Maurya and Lal (1980) recorded (in Nigeria) that maize produced slightly less grain without tillage during a good rainy season, and more in a season with prolonged dry spells, compared with yields after plowing. In India, zero-tillage and mulching of cassava outyielded conventional farming of this crop (Thamburaj, et al., 1980).

No-tillage in acid soils with a pH lower than 5 is not possible if lime has to be incorporated to neutralize the exchangeable aluminium (Kamprath, 1971; Juo, 1976). However, the use of aluminium and manganese tolerant varieties is another approach to overcome soil acidity problems. Wheat varieties developed in acid soils of Brazil resist high levels of exchangeable aluminium (Foy, et al., 1965). Coffee, rubber, pineapple, certain pasture grasses, and legumes tolerate high levels of aluminium saturation. Rice and black beans are fairly tolerant, but sorghum and cotton are not. Important varietal differences in relation to aluminium tolerance exist in rice, maize, wheat, beans, and soybeans (Sanchez, 1976). In dry regions where crop residues, etc. are destroyed by termites or used as cattle feed or building materials, soil compaction and bulk density are usually too high for satisfactory root development, implying that tillage operations have to be conducted. This was noted by Nicou (1979) in the Sahel on soils with a clay content lower than 20% and virtually no organic matter. In dryland agriculture, management should make optimum use of precipitation, accomplished in some cases by tilling the soils for storing of water in the subsoil.

Thus, if climate, topography, or soil character do not dictate the crop production system, control of diseases, entomological pests, and--in particular--weeds will influence the level and nature of tillage.

Yield losses due to weeds are caused mainly by competition, but losses in production also may occur if weeds are hosts of insects, fungi, nematodes, bacteria, mycoplasms, and viruses that attack crops. However, quantitative data to verify this statement are rarely found in the literature. Weeds also can host predators, parasites, and disease-causing organisms such as fungi-attacking insects. Information is available for plants as hosts of pests and plant pathogens, but limited in regard to plants being the hosts of predators, parasites, and organisms causing diseases of insects. A great deal of literature on host plants in the tropics has been summarized by Kranz, Schumtterer, and Koch (1977) in "Diseases, Pests and Weeds in Tropical Crops".

Insects, fungi, etc. generally will be more numerous in the presence of weeds, but so will the population of predators and other useful organisms (Lopez and Teetes, 1976). Plowing under crop residues controls insects that cannot develop underground and assists in controlling diseases attacking the aerial parts of the plants. The organic matter added to the soil by plowing aids non-parasitic organisms to multiply rapidly, and intensifies the inhibiting effect (antibiosis) they have on soil pathogens. In some areas, plowing-in a legume markedly reduces the effect of soil-borne diseases. The use of green manure in dry areas may be detrimental in following crops because the soil remains moist and insects may escape dry-season desiccation.

Stubble mulching may encourage pest and disease carry-over, but also survival of predators and parasites. Stubble burning is practiced when crop residues are infected with fungi, viruses, etc. causing diseases. Instead of plowing or burning, herbicides can be used for crop destruction.

Rotations are also very important for control of soil insects and fungi, especially if the latter are fairly specific in their choice of host. Furthermore, rotations are used for control of nematodes, including a fallow period free of weeds, or free of the hosts of nematodes. Suppression of nematodes occurs by growing *Crotalaria* and *Tagetes* spp. (Birchfield and Bistline, 1956; Oostenbrink, *et al.*, 1957). Plants attracting many insects (so-called trap crops) can be grown together with crops that are less susceptible to these organisms; for example maize is used as a trap plant in sugarcane for control of the African pink stalk borer, Sesamia calamistis, in Reunion and Mauritius (Breniere, 1970).

Teuteberg (1968) found that, for orchards in Germany, the percentage of antagonists to Phytophthora cactorum was not significantly decreased by repeated applications of herbicides, although the number of Actinomycetes and bacteria was decreased, not only compared to the mechanical treatment, but also to plots with green cover crops. He concluded that in herbicide treated, weed-free soils, the decreased number of micro-organisms is not only due to the direct influence of herbicides, but also to reduced growth of weeds and the lack of cultivations for several years. Heitefuss (1975) stated that although no lasting influence of normal application of herbicides on soil fertility and soil pathogens could be observed, this aspect should be studied further because of the complexity of all factors involved.

WEED CONTROL IN NO-TILLAGE FARMING

Susceptibility to competition with weeds differs greatly among crops. The slow growing onion does not form a leaf canopy because of its upright growth habit, and weed control is required for at least 7 to 8 weeks after transplanting to obtain yields comparable to those when the crop is weeded until maturing (Paller, et al., 1971). In contrast, densely planted dwarf beans need only to be weeded during the 2nd and 3rd week after emergence (Kasasian and Seeyave, 1969). The implication is that weeds should be controlled from emergence until the crop forms a closed canopy, or until 1.5 to 2 months after planting of annual crops which do not from canopies.

A. Handweeding

Handweeding is the weed control method used on most farms in the tropics smaller than 2 ha. Two to three handweedings are required to obtain satisfactory control, taking approximately 70% of the farmer's time (International Institute of Tropical Agriculture, 1979). As other farming practices--such as land preparation, sowing, and harvesting--are also carried out by hand, farmers need help. If labor is scarce or expensive, the farmer may choose to neglect weeding, which results in low yields.

B. Cultural Measures

Weeds are controlled to some extent if rotations include competitive crops, if high plant densities are used, and if application time and placement of fertilizer favor crop growth over weed growth. At IITA, good weed control has been obtained by almost continuous cropping of melons followed by batatas. In this way, a permanent, thick ground cover is maintained to reduce weed growth (International Institute of Tropical Agriculture, 1979).

Mixed cropping is frequently used in the tropics on small farms to maximize production and as insurance against total crop loss. Less weed control is necessary when two or more crops are grown at the same time on one field.

Crop or weed residues can be used to control weeds that germinate only in light such as Ageratum conyzoides and Portulaca oleracea (Van Rooden, Akkermans, and Van der Veen, 1970). On small fields, it may be feasible to carry vegetation from a nearby source, but on larger fields this is rarely practical.

Living mulches historically have been used as ground cover only in tree crops. They are effective in reducing erosion, suppressing weed growth, and (in the case of leguminous plants) fixing nitrogen. However, various species introduced as ground covers have turned into pernicious weeds. Examples are the serious problems experienced with the twining, perennial vine Mikania cordata introduced in plantation crops such as tea, rubber, coffee, cocoa, coconut, and oil-palm; the explosion of the introduced ground cover Oxalis latifolia as a weed in coffee in East Africa as well as in pyrethrum; and the invasion of Mimosa invisa and M. pigra in plantations and arable land in S.E. Asian countries (Kasasian, 1971; Holm, et al., 1977; Ngugi, 1978; International Plant Protection Center, 1980).

Recently, the use of live mulches for control of weeds in annual crops was studied by Akobundu (1980) at IITA. He achieved good weed control after planting maize in fields covered with the legume centro (Centrosema pubescens) and wild winged bean (Psophocarpus palustris). Before planting maize in the legume covers, paraquat at 0.5 kg ai/ha was applied to clear 15-cm wide strips. In order to prevent the legumes from climbing up the maize, a growth retardant (CGA 47283) was applied at 2 kg ai/ha as an overall spray 3 days after maize emergence. In the non-fertilized field, yield of maize grown with the legume was significantly higher than that of the conventionally or no-tilled maize, that was kept weed-free. In fertilized, weed-free fields, yields of maize grown with legumes were equal to or better than those of the conventionally tilled or no-tillage maize.

C. Chemical Weed Control

This method of weed control is mainly applied on large farms, and to a small, but increasing, extent on small farms in the tropics. Herbicides were first used to replace handweeding and to reduce or replace cultivations after sowing. In Louisiana, U.S.A., sugarcane produced normal yields with little or no cultivation and the broadcast application of herbicides such as terbacil, fenoprop, fenac, TCA, or dalapon. But in areas with a high infestation of the perennial weed johnsongrass (Sorghum halepense), at least 3 cultivations were required in ratoon cane in addition to herbicide applications (Ricaud, 1972).

In regions with a distinct dry season, perennial weeds can be controlled by only cultivations, but from an economical point of view it is often advisable to combine cultivations with herbicide applications. Deep cultivations are performed to break the chains of tubers and to fragment stolons and rhizomes for breaking dormancy. After that, cultivations are carried out to expose the tubers to desiccation. At the onset of the wet season, cultivations are conducted to promote germination and emergence of the tubers, followed by cultivations later to kill the above-ground vegetation. If there is no dry season, cultivations are conducted only for breaking the chains of tubers to promote germination; foliage applied, translocated herbicides, such as glyphosate, are used for controlling the emerged shoots. Work on mechanical and chemical control of perennial weeds has been reported, among others, by Gopinath and Nalunjkar (1966), Rochecouste (1967), Thomas (1969), Idris (1970), and Terry (1974).

In recent years, herbicides have replaced mechanical seedbed preparation in certain areas of the tropics prone to soil erosion. Locatelli and Shenk (1978) and Shenk, et al. (1978) in Costa Rica noted no-tillage growing of maize, followed by beans, and after that upland rice, with some use of herbicides such as 2,4-D. Hayward, Wiles, and Watson (1980) reported that, in El Salvador and some other Latin American countries, it has become common practice by the small farmers to hand-sow maize wihtout cultivations after killing the weeds by application of paraquat. During the growing period of maize, weeds are controlled by a directed spray, sometimes mixed with 2,4-D.

Paraquat is applied again before sowing of the beans, after bending the stalks of the matured maize downwards; the beans climb up the stalks. After harvesting, all vegetative material is left to die during the dry season. On large farms in Brazil, low doses of paraquat and 2,4-D are used for chemical seedbed preparation, and after that a mixture of contact and residual herbicides is applied just before or after planting. In soybeans, mixtures of paraquat and metribuzin are most commonly used prior to planting. If annual grasses such as Brachiaria plantaginea and Digitaria sanguinalis occur, herbicides--oryzlalin or metolachlor--are often included in mixtures.

Weed control by hand or by mechanical or chemical means is necessary to establish living mulches. In Indonesia, a mixture of paraquat and diuron, each at 0.2 kg ai/ha, applied as an overall spray before sowing the legume mixture consisting of 10.5 kg Centrosema pubescens, 9.5 kg Calopogonium mucunoides, and 2.5 kg Pueraria javanica per ha, or as a directed spray between the rows after sowing, gave satisfactory control of weeds and good establishment of ground covers in rubber and oil palm. This chemical weeding technique reduced the labor requirements for handweeding about 85% (Stobbe and Hayball, 1973). However, much more work has to be done on screening herbicides for establishing various cover crops.

On small farms, herbicides are applied by a knapsack sprayer and seeds are planted through the mulch (desiccated weed vegetation and crop residues) with a stick, hoe, hand 'jabber,' or hand 'dibbler,' which deposits one or more seeds per planting hole, as well as fertilizer sometimes. At IITA, an efficient, simple herbicide applicator and a rotary injection planter have been developed (Wijewardene, 1978), and, based on the IITA prototypes, commercial machines have been made for use on small farms. The sprayers have battery-operated spinning discs, and apply herbicides at volumes of 20 to 40 l/ha, or less. Recently, Coffee (1979) has developed an electrostatic low-volume sprayer. For large-scale planting, many high-volume sprayers and specialized planters are available, especially for growing of no-tillage maize.

D. Integrated Methods of Weed Control

Control of weeds by a single mehtod is rarely possible, unless frequent handweeding is practiced. No-tillage with only herbicide applications results in marked changes of the composition of the weed flora, because each herbicide controls only a certain, wide or narrow, range of weeds. Easily controlled weeds are replaced by more difficult to control species, such as the perennial weeds Cyperus rotundus and Cynodon dactylon. Throughout the years it becomes more difficult to control the weeds, even when many herbicides are used. Integrated control of weeds, including the use of hand labor, is therefore advised (Doll and Piedrahita, 1976; Parker, 1976, 1977).

If no combination of mechanical and chemical weed control can be practiced, especially for the control of perennial weeds, emphasis has to be laid on the use of dead and living mulches, combined with selective applications of herbicides and proper choice of rotations and mixed cropping systems. Recent research shows that chemical weed control in mixed croppi is quite feasible. At IITA, the mixture of atrazine plus metolachlor appeared to be selective in maize/cassava, maize/yam, and maize/cassava/yam crop mixtures (International Institute of Tropical Agriculture, 1979); in Kenya a commercial recommendation exists for the use of metobromuron and metolachlor in a mixed cropping of beans and maize.

THE RESPONSE OF INSECTS, DISEASES, AND WEEDS TO MULCH

A. In Perennial Crops

Crops such as cacao, coffee, oil palm, rubber, and tea are generally grown on forest soil. Forest trees, including their roots, have to be eradicated and removed 1 to 2 years before crop planting to reduce the risk of root diseases caused by the fungi Armillaria mellea, Fomes lignosus, F. noxius, and Ganoderma pseudoferreum. Build-up of these fungi can be prevented by ring-barking the trees 1 to 3 years before felling. Girdling depletes the carbohydrate reserves of the roots; Armillaria then cannot grow in roots (Tea Research Institute of East Africa, 1968). In addition, the trees can be killed using 2,4,5-T applied to frill girdles (Mapother, 1957). Old dead trees tend to decay more rapidly under legume creepers than where the ground is kept weed-free. However, F. lignosus can flourish and spread under legume creepers, and this implies that these ground covers must be kept back from the tree stumps if this disease is prevalent (Rubber Research Institute Malaya, 1958). Commonly used leguminous shrubs are Crotalaria anaegyroides, C. usuramoensis, Tephrosia vogelii, T. candida, Moghania macrophylla (Flemingia congesta), and Cassia sophora. C. anaegyroides and T.

candida prevent the spread and development of Armillaria. However, T. candida is a host plant of Helopeltis spp. and Pseudococcus virgatus. Furthermore, Tephrosia is susceptible to the nematode Heterodera radicola (Schoorel, 1949; Haarer, 1956). Outbreaks of the thrips, Diarthrothrips coffeae, damaging leaves suffering from moisture stress, can be controlled by dead mulch, and preventing moisture stress (Ackland, 1971).

In citrus orchards in Florida, U.S.A., the spreading of the nematode Radophlous similis can be stopped by removing all citrus around the nematode-infested area and keeping this buffer free of weeds (Kretchman, 1962). In the same state, weed control in citrus resulted in control of foot rot caused by the fungus Phytophthora parasitica (Hogan, 1968). The broad-leaved Commelina spp., favored as a ground cover in bananas, are hosts of the nematode Rotylenchulus in the Windward Islands, and hosts of banana virus diseases in Puerto Rico (Edmunds, 1969). In Kenya, mulching with chopped up dried suckers and old stems of bananas discourages the banana weevil (Cosmopolites sordidus). However, this mulch should not be brought into contact with the growing banana stems as this encourages the entry of the banana weevil (Ackland, 1971). In pastures, the insect Teleogryllus is controlled by removal of Ranunculus spp., and the insect Costelytra is controlled by removal of Hordeum spp[1/].

These examples illustrate the control of pests and diseases by removing weeds, as well as the role of dead and living mulches in decreasing or increasing the development of harmful organisms. Plants that are hosts of useful organisms should be preserved, and if these are weeds causing considerable competition, they should not be controlled too drastically (van Rijn, 1973). So far, research dealing with this aspect has been limited and only some practical findings can be recorded.

In the tea areas of North Sumatra, Indonesia, the leafroller insect Homono coffearia was kept under control by the Ichneumon wasp (Macrocentus homonae) which occurred naturally in Indonesia prior to both uses of insecticides that affected the wasp and removal of host plants by intensified hand-weeding and chemical weed control. It is not known exactly what plant species are preferred by the wasp[2/].

1/ Personal communication, L.J. Matthews, FAO.
2/ " " , J. Werkhoven.

In California, U.S.A., vineyards are seriously affected by a destructive leafhopper only in areas where wild blackberry is not present. This destructive leafhopper is parasitized by a native wasp that also preys on a non-economic species of leafhopper which uses the blackberry as its source of food. This harmless leafhopper species appears to be crucial to the survival of the wasp, because the leafhopper overwinters in a growth stage within which the immature wasp can spend the winter. As a result, the University of California has recommended carefully controlled interplanting of blackberry in the vineyards (Peterson, 1975). In Hawaii, a parasite was introduced for the control of the sugarcane weevil. However, it appeared that the female parasite must feed on the pollen of certain wild *Euphorbia* spp. for survival and carrying out her reproductive activities. This implies that these weeds must remain in the sugarcane fields to some extent (Peterson, 1975).

B. In Annual Crops

In contrast to tree crops, tillage plays a much greater role in annual crops, because of recurring need for seedbed preparation. After land has been prepared for sowing, tillage can be replaced during the next seedbed preparation by handweeding and/or herbicide application if only weeds have to be controlled. However, in considering no-tillage and mulching with crop residues, the occurrence of pests and diseases must also be taken into account.

In annual crops pests and diseases are controlled by various integrated methods, such as by using disease-free seed, rotations, destruction of crop residues, and pesticide applications. Certain diseases, such as rust caused by *Puccinia* spp., cannot be controlled by rotations and destroying crop residues, because these fungus diseases are spread by air-borne uredospores. It is best to breed resistant crop varieties. In cotton, a closed season may be necessary for controlling the pests that have few alternate hosts and which cannot go into diapause (dormant stage of pupae), such as the pink bollworm (*Pictinophora gossypiella*), and the spiny bollworm (*Earias* spp.). The American bollworm (*Heliothis armigera*) cannot be controlled in this way, because it goes into diapause and has many alternate hosts, such as maize, tobacco, tomato, sorghum, millets, sunflower, pigeon peas, and beans.

If fungus diseases occur, such as Anthracnose caused by *Colletotrichum lindemuthianum* and angular leaf spot caused by *Phaeoisariopsis griseola*, the use of clean seed, crop rotation, and destruction of crop residues are important precautions. Crop rotation and removal of crop residues and volunteer plants are necessary for controlling the bean fly Melanagromyza spp. of which the larvae bore downward and pupate in the stems at ground level. Crop destruction must also occur if it is infected by viruses, such as those transmitted by the white fly (Bemisia spp.) causing mosaic disease in cassava and leaf curl in tobacco. Wheat straw infected with glume blotch caused by the fungus Leptosphaeria (Septoria) nodorum, leaf blotch caused by L. tritici, or with leaf blight caused by the fungus Pyrenophora (Helminthosporium) should not be plowed in, but burned.

These examples derived from Ackland (1971) (to which, of course, many can be added) show that destruction of crop residues is a very important method of controlling a considerrable number of pests and diseases. Destruction can be accomplished by tillage or herbicidal applications; the last method might be used instead of burning infected material that is not allowed to be plowed in. Until now, no comparisons have been made between the effects of the destruction methods on the degree of control of pests and diseases, except for a few preliminary studies at IITA (1979) which showed that stalk borer damage caused by Busseola fusca was higher in conventionally plowed fields than where no-tillage with herbicide application for destruction of crop residues and weeds was applied. Furthermore, it was found in Nigeria that the population of parasitic nematodes in maize was five times greater in plowed plots than in no-tilled, herbicidal treated fields (International Institute of Tropical Agriculture, 1979).

Mulching can be useful for controlling certain pests and diseases. In the Philippines, the presence of mulch (rice stubble and straw) suppressed populations of leafhoppers and thrips in no-tilled cowpeas (Ruhendi and Litsinger, 1979). In Nebraska, U.S.A., no-tillage (eco-fallow) decreased the incidence of stalk rot caused by Fusarium moniliforme in grain sorghum grown in rotation with wheat (Doupnik, et al., 1975). In California, U.S.A., lucerne is planted as a trap crop in cotton to attract the bugs Lygus hesperus and L. elisus (Toscano, et al., 1979).

Johnsongrass (Sorghum halepense) is a good example of a weed that has to be controlled not only because of its competitive habit, but also for acting as the host of dwarf mosaic virus and chlorotic dwarf virus (Ross, 1978). However, much more research has to be conducted to determine the role of weeds as hosts of useful and harmful organisms, so that control of pests and diseases can be obtained by removing certain weeds, but maintaining others to such as extent that they do not compete markedly with the crop.

RESEARCH PRIORITIES

While a number of pioneering studies have attempted to consider the interaction of crop pests and various tillage or no-tillage systems, there remain more questions than answers. Thus, there is ample need for further extensive research.

Studies are needed for the following:

- integrated methods of weed control in no-tilled crops, taking into account rotations, mixed cropping systems, the use of dead and living mulches, and herbicide application;
- biological and chemical methods of controlling annual and, especially, perennial weeds that are not suppressed by ground covers;
- effects of methods of crop destruction on prevention or outbreak of pests and diseases;
- role of ground covers and weeds as hosts for organisms causing or preventing pests and diseases.

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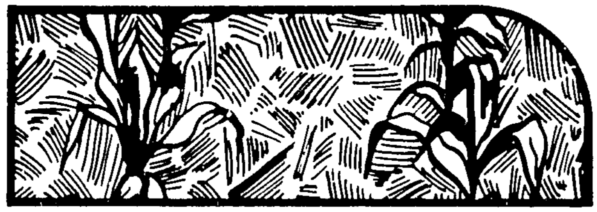
Section III
Crop and soil management in no-tillage crop production



AGRONOMIC CONSIDERATIONS OF NO-TILL FARMING

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INTRODUCTION

Present knowledge for management of highly weathered tropical Alfisols, Ultisols, and Oxisols is inadequate (Kellogg and Orvedal, 1969; Hartmans, 1981; Kang and Juo, 1981). Factors such as high soil erosion hazard and acidity, low nutrient status, and poor water-holding capacity of most tropical soils, together with low radiation during the growing season, severely limit utilization of the enormous arable land area available for food crops production (Uehara, 1977; Lal, 1975, 1976, 1979; Lawson and Juo, 1979; Sanchez, 1976).

Land management methods, such as shifting cultivation, or the bush fallow system, were efficient at low population pressure for the forest zone subsistence farmer. Soil erosion was minimized, crop yields were sustained, and adequate soil fertility was maintained (Nye and Greenland, 1960; Roche, 1973). This was possible because the system allowed a short cropping period and sufficiently long fallow periods for the soil to regain its fertility. As the proportion of non-farm population needing food from limited land area increased, the main land usage objective changed from sustaining yield after a long fallow period to that of continuous productivity per unit of labor input.

An alternative to shifting cultivation and the bush fallow system, extensively studied and publicized in recent years, is no-tillage crop production. In this approach crop seeds are planted on land that has not been disturbed by tillage, but where exciting vegetation has been killed earlier by application of herbicide.

Several interpretations have been proposed in recent years. Phillips and Young (1973) define no-till as farming without plowing. Seeds (and propagules) are planted in narrow slits, trenches, or holes made in killed plant residue from a sod or previous crop. Riggins (1978) regards no-tillage as tilling about 7% of a field (calculated as the ratio of 7 ha of strips actually tilled in a 100 ha. maize farm). According to Lessiter (1981), no-tillage is practiced when up to 25% of the surface area is worked employing strip, conservation, or mulch tillage. Minimum tillage amounts to limited tillage applied to the entire field surface, but using equipment such as a disk, chisel plow, or field cultivator; conventional tillage implies mixed or inverted soil using tilling and/or multiple disking equipment.

For the tropical environment, the most appropriate no-tillage system amounts to growing crops with a minimum disturbance of the top soil combined with effective weed control and employment of crop residue cover to reduce soil degradation and erosion.

CROP RESPONSE TO NO-TILLAGE

No-tillage may not always be advantageous since complex interacting factors influence crop response to the system. No-tillage has been reported to: (a) reduce crop production costs through saving time, labor, fuel, and machinery; (b) conserve moisture; (c) reduce erosion; (d) in general, increase farmers' income and benefits (Couper et al., 1969; No-till Farmer, 1980, 1981; Lal, 1975, 1976).

Some types of plant residue, for example, sudangrass (*Sorghum sudanense* (Piper) Stapf) and sorghum (*Sorghum bicolor* L. Moench) stubbles, have been reported to chemically inhibit weed growth. Their effectiveness has been demonstrated for many broadleaf plants (cucumbers, snapbeans, asparagus, tree fruits) but not for the grass types such as maize to which they are toxic, (De Frank, 1979). The effectiveness of some herbicides may be enhanced through their adsorption and gradual release by organic matter stubbles

(Grantham, 1981), an advantage of no-till since stubbles (or mulch) are its essential components.

A no-till farmer must cope with shifts in weed populations and types. He needs to know how to use herbicides as well as consider their cost. Mulch is an essential part of no-till or conservation farming; in some cases there is difficulty in planting and establishing crops through stubbles. On the other hand, the lack of mulch predisposes soil to erosion. Other problems of no-till farming are planting depth, seed spacing, and coverage of seeds in various plant residues (Robertson, 1979).

Examples of crop response to no-tillage are drawn from two broad categories: plants whose economic importance relates to their aerial parts; and root crops with economic value developed below ground.

A. Cereals and Grain Legumes

Results from extensive work on Alfisols in southwestern Nigeria show grain yields for no-tillage are equal to, or better than, those obtained with conventional tillage for maize, (International Institute of Tropical Agriculture, 1978, 1979) and cowpea and soybean (International Institute of Tropical Agriculture, 1973; Nangju, 1973).

Grain yield for a 6-year continuous maize cropping regime in an Alfisol at Ibadan, Nigeria, produced yields ranging from about 6% higher in 1975 for no-tillage, to over 170% in 1980 (Table 1). Yield difference was attributed to a higher rate of soil degradation due to erosion losses, and compaction in the conventional tillage plots (International Institute of Tropical Agriculture, 1980).

Couper, et al., (1969) estimated (from an unreplicated experiment) costs and returns of maize production in Southwestern Nigeria and showed that a mechanized no-tillage system was 100% more profitable than a conventional tillage system (Table 2). In this study, plowing and harrowing alone accounted for over 35% of the total production cost.

Table 1

MAIZE GRAIN YIELD COMPARISON

year	maize yield[1/] conventional tillage	no-tillage	increase
	(kg/ha)		(%)
1975	2650	2800	6
1976	3900	4500	15
1977	3800	4800	26
1978	3920	5000	28
1979	2800	3800	36
1980	1100	3040	176

1/ Mean of 2 crops/year

Table 2

MAIZE PRODUCTION COSTS AND RETURNS

	no-till	tilled	ratio of no-till to tilled
	(U.S. $/ha)		
field costs	111.6	134.4	0.83
total input costs	523.0	568.0	0.92
gross income	1000.0	800.0	1.25
net income	477.0	232.0	2.05

Adapted from: Couper, et al, 1969.

Agboola (1981) studied eight cropping management combinations involving fertilization, tillage, and herbicide applications and found that: (a) maize grain yield was significantly better when fertilizer was mixed than when surface applied to an Alfisol in southwestern Nigeria; (b) no-till with fertilizer banded was as good as minimum tillage with fertilizer mixed in strips, or conventional tillage with fertilizer mixed in loosened soil.

Results from semi-arid regions of West Africa, however, showed that plowing was essential for high yields of several crops (Nicou, 1972) because soils in this region are naturally compacted. For coarse-textured soil, plowing may be necessary to loosen the compacted soil surface after the long dry season. Soils high in silt and fine sand should be plowed at the end of the rainy season to minimize wind and water erosion (International Institute of Tropical Agriculture, 1980).

Data on rice from both high rainfall Ultisols in southern Nigeria (International Institute of Tropical Agriculture, 1978, 1979) and in Liberia (Lal and Dinkins, 1969) show no significant effect of tillage on grain yield. Earlier reports on long term land management comparing no tillage, conventional tillage, chisel plowing, and localized cultivation at optimum inputs revealed that when conducted on newly cleared Alfisols of high fertility, no significant differences in maize grain yields were observed. However, no-till maize yielded less than that under conventional till on degraded soil due to continuous cultivation (International Institute of Tropical Agriculture, 1975). Ballaux (1975)[1/] attributed the lower yield for no-tillage to higher incidence of insects (borers and *Buphonella*) in addition to the poor initial physical condition of the degraded soil.

In a small-plot study conducted on newly cleared forest land at IITA, no significant evidence of soil compaction was observed when seeding and harvesting were performed manually over 22 consecutive crops. This is in contrast with a larger field at a similar site in which yield reduction was observed in conventional as well as no-till maize after the fourth year of continuous cropping (Hartmans, 1981). Furthermore, maize varieties meant for no-till should be selected under no-till conditions. Thus, 33 test varieties of maize behaved differently in tilled and no-tilled conditions in Ohio[2/].

1/ Personal communication.

2/ Communication in *No-Till Farmer*, March 1980.

B. Root and Tuber Crops

Relatively little information has been published about the response of root crops to tillage. In one study conducted in Zaire, the effect of tillage systems on cassava (*Manihot utilissima* Pohl.) establishment, weight of stems, root number and weight were noted (PRONAM, 1978). The data show that in a highly leached Oxisol, plant establishment was inferior in the no-till treatment compared to the tilled (flat) and ridged plots (Table 3).

Table 3

TILLAGE IMPACT ON CASSAVA

tillage	per plot: plants	per plot: stems	per plot: roots	roots
	(kg)	(kg)	(kg)	(t/ha)
Condition A. - grown in highly leached Oxisol				
flat	19.0	17.8	82.5	7.3
ridge	19.5	17.5	73.5	5.9
no-till	17.0	9.5	40.5	4.0
Condition B. - grown in sandy loam				
flat	37.0	42.0	169.0	18.9
ridge	36.0	36.0	166.0	16.6
no-till	36.0	31.0	160.0	16.4

Source: IITA/PRONAM, 1978

Stem weight at harvest and root number were also inferior under no-till. Root yield from flat tilled culture was higher than in the ridged and no-till plots.

When the experiment was repeated on a sandy loam (at a different site), root yield from the no-till treatment was almost equal to that produced by the two tillage systems.

Although promising results have been reported for no-till carrot (Daucus carota Linn.) and sweet potato (Ipomoea batatas Poir.) in temperate regions[3/] a lot of study remains to be done to identify limitations to no-till production of root and tuber crops. Their response, in general, tono-till poses problems closely related to the crop's growth habit. Thus, for crops such as yam (Dioscorea spp.), taro (Colocasia esculenta), and cocoyam (Xanthosoma saggitifolium), tuber enlargement, penetration and expansion occur simultaneously in the soil.

Well loosened soil, either mechanically or naturally, is advantageous for tuber development. Synchronization of tuber development contrasts with cassava and sweet potato wherein the roots first penetrate the soil and then enlarge (Onwueme, 1978). Adaptation of root crops such as cassava and sweet potato to drought is partly explained by the ability of their feeder roots to penetrate deep into the soil and extract moisture. A tillage system that enhances these characteristics will probably be the most suitable for development of these root crops.

SUMMARY AND CONCLUSION

Crop response to a no-till system is modified by soil, climate, type of crop, and imposed management practices. Some of the advantages attributed to no-tillage include reduction in costs of production as well as moisture and soil conservation.

Present knowledge of the agronomy of no-tillage systems, particularly in Africa, is still too scanty to make firm conclusions as to its applicability. Current limited knowledge suggests that no-till holds a lot of promise as a component of an integrated management system in which all of the elements need to be considered. More information would be useful for such aspects as planting, crop establishment, fertilizer application and liming, and efficient use of pesticides.

The adoption of no-till farming in the tropics also requires extension education for farmers with regard to use of herbicides, the role of crop residue in no-till farming, and the best way to apply fertilizer.

3/ Communications in No-Till Farmer, 1978, 1980.

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FERTILIZER MANAGEMENT FOR NO-TILLAGE CROP PRODUCTION

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INTRODUCTION

Development of sustained food crop production systems under rainfed upland conditions have been the concern, for sometime, of many agricultural scientists working in the humid and subhumid tropics. Observations in the humid-subhumid transitional zone of southern Nigeria, for instance, have shown that sustained high crop yields can be obtained with judicious fertilizer use on either small plots under no-tillage and residue mulching, or conventional tillage with proper erosion control (Lal, 1975; Kang, et al., 1977).

Various problems are encountered in developing large-scale mechanized food crop production systems in this zone. Soil erosion has been shown to be a major problem with large-scale conventional tillage on sandy textured Alfisols, associated Entisols, and Inceptisols, the dominant soil types in the area (Lal, 1975; Wilkinson, 1975). This problem can be minimized by using no-tillage with residue mulch (Lal, 1975). Observations on an Alfisol in the humid-subhumid transitional zone of southern Nigeria have also shown that sustained high maize yield could be obtained on a large-scale mechanized farm using no-tillage (Couper, et al., 1979).

Despite the potential of no-tillage with residue mulch as an alternative soil management system, and the fact that traditional farmers have practiced no-, or minimum tillage for many generations in connection with land preparation, only limited information is available for fertilizer requirements of crops grown under these systems in the tropics. Most of the fertilizer use investigations for food crop production primarily have been concerned with conventional tillage systems.

Results of many investigations indicate that fertilizer requirements, and the best methods of applying fertilizer to no-tillage crops, may differ from conventional tillage (Baeumer and Bakermans, 1973; Moschler and Martens, 1975; Shear and Moschler, 1969). Since, only a small portion of the soil surface is tilled in minimum tillage systems, fertilizer incorporation sometimes is considered more difficult. Banding fertilizer at high rates, particularly with nitrogen and potassium sources, near the seed is known to cause seedling injury. Therefore, most fertilizer must be applied on the surface with no-tillage.

NITROGEN FERTILIZER MANAGEMENT

Nitrogen generally limits crop production in the humid and subhumid tropics, except on land newly cleared from forest or after leguminous fallow, where decomposition of organic matter will release sufficient nitrogen to satisfy crop needs. As indicated, nitrogen requirement of no-tilled crops sometime differs from those grown under conventional tillage (Kang, et al., 1980; Lal, 1975; Thomas, et al., 1973).

Depending on soil type, soil fertility status, and the rate at which nitrogen is applied, crop yield may be lower in no-, or reduced tillage than in conventional tillage systems. Poulain and Tourte (1970) investigated the effects of deep plowing and surface tillage on yields of millet and sorghum grown at Bambey, Senegal. They found that: (i) with no nitrogen application, plowing resulted in small to moderate yield increases with millet and sorghum on the very sandy soil, while a large yield increase was observed on sorghum grown on heavier textured soil; and (ii) lower nitrogen rates were required for obtaining maximum yields with both crops comparing plowing with surface tillage only.

Kang, et al. (1980) also reported lower maize yields (in southern Nigeria) with no tillage than with conventional tillage on a nitrogen deficient Alfisol with low rates of nitrogen applications. Yields with both tillage systems were the same at high nitrogen rates. Recent studies in southern Nigeria (Table 1) also showed distinct effects of soil fertility on maize grain yield response to tillage. On more fertile soil, no-tillage generated equal or higher maize yields. However, on sandy, less fertile soils, tillage resulted in higher maize grain yields at no or low rates of added nitrogen. At high nitrogen rates in no-till plots, grain yields were lower or equal to those observed with conventional tillage.

Table 1

TILLAGE AND N-RATE EFFECT ON MAIZE

treatment	N-rate	yield: fertile soil	yield: infertile soil	yield: infertile soil
		(kg/ha)		
tilled	0	3799	761	1627
	30	3827	1185	1984
	60	4045	2175	3507
	90	4020	2553	4036
	120	3779	3229	4804
	150	4053	3233	4952
no-tilled	0	3628	403	756
	30	3946	706	1066
	60	3606	1178	2297
	90	3900	2076	3181
	120	4088	2567	3304
	150	4153	2680	4652
LSD .05:				
between N-rates within tillage		377	247	678
between tillage		497	583	800

Source: Kang, 1979; unpublished data.

Several reasons have been suggested to explain lower yields realized with no-, or reduced tillage systems: (i) reduced mineralization of soil organic matter with no-tillage (Bakermans and de Wit, 1970; Dowdell and Cannell, 1975). With plowing, there is a large increase in the nitrate produced, probably because of mixing soil nitrifiers and organic matter with the soil. With no-tillage, the organic matter remains as mulch at the soil surface and the nitrate produced is considerably less (Juo and Lal, 1977); (ii) increased leaching of nitrates (Thomas, et al., 1973; Tyler and Thomas, 1977). Tyler and Thomas (1977) showed, for example, that a rain of 5.5 cm had no effect on nitrate distribution under conventional tillage. The surface nitrate, however, moved deeper into the soil profile under killed sod mulch, with the nitrate in the subsoil moving beyond the 90 cm depth. The higher leaching rates of nitrate with no-tillage were attributed to: presence of many undisturbed pores facilitating water and nitrate movements; and, a lesser degree of evaporation loss in the presence of mulch. (iii) root growing conditions with no-tillage are not always ideal. Consequently, higher nitrogen rates are required to produce high yields (Baeumer and Bakermans, 1973; Bakermans and de Wit, 1970). Also, a possible increase in nitrogen volatilization loss from decomposition of surface applied mulch may suppress crop yield.

Choice of a nitrogen fertilizer source is important to realize high efficiency in a no-tillage system. Volatilization losses can be very high with surface broadcast or top dressing of certain nitrogen sources, such as urea or anhydrous ammonia (Acquaye and Cunningham, 1965; Messan, 1980). Because of urea's rapid hydrolysis when applied at high temperatures to moist soil, NH_3-N volatilization losses can take place within 24 hours after surface application to the soil (Ayanaba and Kang, 1976; Messan, 1980). To minimize volatilization loss, urea probably could be best applied by spot placement in the soil with no-tillage. The magnitude of nitrogen volatilization loss is affected by fertilizer source and soil type (Figure 1). Volatilization loss is less from compound sources, or on strongly acidic soil; losses are higher on slightly acidic soils.

Surface soil acidification can also become a serious problem with no-tillage and application of high nitrogen rates. Blevins, et al. (1977) observed that, with no-tillage, pH in the upper 0-5 cm tends to be more acid than the lower soil horizons, particularly where high nitrogen rates are used. In cultivated soil, the whole plow layer will gradually become more acid. Observations of a sandy loam Alfisol in southern Nigeria have not indicated any acidity problems, even after 5 years of continuous no-tillage with the addition of 120-150 kgN/ha/year. Recent observations in southern Nigeria confirm these results.

PHOSPHORUS FERTILIZER MANAGEMENT

Phosphorus deficiency is common in soils in the tropics, particularly in the subhumid and semi-arid regions. Unlike nitrogen, phosphorus shows low mobility in the soil (Bray, 1954). The slow and limited movement of phosphorus into the soil profile has raised questions about the availability of surface applied phosphorus. Phosphorus must either diffuse to the root surface or roots must develop in the proximity of the phosphorus fertilizer for it to be absorbed.

Results of several investigations (Juo and Lal, 1978; Kang and Yunusa, 1977) have indicated that surface applied phosphorus with no-tillage resulted in a high concentration of phosphorus near the soil surface. The higher concentrations of total and extractable phosphorus near the soil surface with no-tillage is in part the result of lower retention of the applied phosphorus when not mixed with the soil. This high phosphorus accumulation near the soil surface coupled with higher soil moisture content under the mulch will favor greater phosphorus absorption and increased root growth, particularly during early growth (Belchem and Ragland, 1972; Blevins, et al., 1971; Lal, 1975; Singh, et al., 1966; Triplett and Van Doren, 1969).

Observations on an Alfisol with low phosphorus status and low phosphorus fixing capacity showed that surface applied phosphorus was equally effective as banding or spot application for maize grown under no-tillage with phosphorus rates that are equal or greater than 20 kg P/ha (Juo and Fox, 1977; Kang, et al., 1980). The results may be different if lower phosphorus rates are used. Phosphate placement studies in southern Nigeria on an Alfisol derived from sedimentary rocks revealed that on this low phosphorus fixing soil, the effect of phosphorus placement is only noticeable at rates that are equal or lower than 16 kgP/ha (Fox and Kang, 1978). Kang and Yunusa (1977) also showed that a maize crop had higher phosphorus uptake from surface applied phosphorus in a no-tillage system than with soil incorporated phosphorus in a conventional tillage system.

Further studies are needed to determine the effectiveness of rock phosphate sources for surface application and also the effectiveness of surface applied phosphorus on high phosphorus-fixing soils.

MANAGEMENT OF OTHER NUTRIENTS

The management and uptake of potassium, other secondary elements, and micronutrients with no-tillage crop production has not yet been researched in the tropics. Potassium, because of its higher mobility, moves freely into the soil profile compared to phosphorus. Results of various investigations in the temperate zones also indicated that surface application of potassium is a satisfactory method with no-tillage, and that potassium availability is not affected by tillage method (Moschler and Martens, 1975; Shear and Moschler, 1969; Triplett and Van Doren, 1969). The same results may also be expected for tropical soils.

Regarding secondary elements and micronutrients, Riley, et al. (1975) indicated that, in general, uptake is similar in no-tillage and tilled crops.

SUMMARY

For soils with low fertility, yield of no-tilled maize may be less than conventionally tilled maize. However, yields may be equal or higher on fertile soil or by applying high rates of nitrogen. Surface application on non-volatile nitrogen sources is satisfactory for no-tillage. However, care should be taken when using volatile nitrogen sources.

On the predominantly low phosphorus-fixing soils in the humid and subhumid region of tropical Africa, surface application of soluble phosphorus sources, readily available for the crops is satisfactory.

Further studies need to be carried out on the management of potassium, secondary elements, and micronutrients in no-tillage crop production in the tropics.

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WEED CONTROL IN NO-TILLAGE CASSAVA IN THE SUBHUMID AND HUMID TROPICS

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INTRODUCTION

Cassava (Manihot esculenta Crantz) is a popular staple food crop in tropical Africa. About 67% of the cassava grown in Africa is confined to the humid and subhumid regions of West Africa (Food and Agriculture Organization, 1978). It is well adapted to farming systems in most parts of the tropics. Its popularity among traditional smallholder farmers is attributed to its adaptation to diverse environmental conditions, ability to grow and produce a modest yield in low fertility soils, and a high multiplication ratio. Unlike most arable crops, both the roots and leaves of cassava are popularly used as food in most parts of the tropics.

Although cassava is now widely grown in regions of tropical Africa ranging from humid to the semi-arid regions (Hahn, et al., 1979), the humid and subhumid tropics are still the regions where optimum moisture and temperature conditions for cassava production can be found (Jennings, 1970; Rogers and Appan, 1971; Tan and Bertrand, 1972). It is also in these regions that uncontrolled weed growth causes extensive reductions in cassava root yield (Akobundu, 1980).

Weeding and land preparation are the two most labor-demanding operations in cassava production (Pinstrup-Andersen and Diaz, 1973). These operations will limit cassava production unless labor-saving devices are introduced. High root yields have been reported with such preemergence herbicides as fluometuron + metolachlor (4.0 to 6.0 kg/ha), atrazine + metolachlor (2.5 to 3.0 kg/ha) and alachlor + cyanazine (3.0 + 1.5 kg/ha) and diuron + paraquat at 2.8 kg/ha used as a directed postemergence herbicide mixture (Akobundu, 1980).

Various studies on land preparation show that high root yield in cassava is obtained when land is cultivated (Coursey and Booth, 1977; Hahn, *et al.*, 1979; Ofori, 1973). The need to reduce erosion hazards has stimulated interest in no-tillage production of cassava. The studies reported here were devised to assess crop performance and the efficacy of preemergence herbicides in selected tillage systems.

MATERIALS AND METHODS

A. No-till Cassava Production in an Alfisol

Weed control in conventional and no-tillage cassava was evaluated in a field that had been fallowed for 2 years. The fallow vegetation consisted of perennial weeds such as *Panicum maximum* Jacq. (guineagrass), *Eupatorium odoratum*, *Alchornia laxiflora*, and *Ficus* spp. The fallow vegetation was first slashed 2 months before onset of rains and the regrowth was sprayed with glyphosate at 3.0 kg/ha 6 weeks after the initial slashing.

In the conventional tillage treatments, the dead fallow vegetation was plowed under and the field harrowed to provide a weed-free seedbed for planting cassava cuttings. In the no-tillage plots, paraquat was sprayed to destroy seedling weeds prior to planting cassava. The experiment was set up as a split plot design with tillage as main plot and weed control treatments as subplots. The treatments were replicated three times. Data were collected on weed dry weight and cassava root yield.

B. No-till Cassava Production in an Ultisol

The effects of tillage and weed control on cassava production were investigated in an Ultisol that was cleared of forest and fallowed for 2 years prior to this study. Glyphosate was applied to the bush regrowth at the onset of rains at 3.0 kg/ha. Land preparation consisted of no-tillage; plowing and harrowing; and, plowing, harrowing and ridging. These tillage treatments were the main plots while weed control treatments served as subplots in a split plot design. The treatments were replicated five times. Cassava plant height was taken at 10 weeks after planting (WAP) and this time corresponded to the point when at least 50% canopy cover had occurred in this crop. Additional data were taken on weed weight at 16 WAP and cassava root yield at 12 months after planting.

RESULTS AND DISCUSSION

Cassava root yield was generally greater in the plowed and harrowed field than in the no-tillage plots in cassava grown in an Alfisol (Table 1). Also, uncontrolled weed growth caused greater yield reduction in the no-tillage plot (71%) than in the plowed and harrowed plot (54%). Similarly, crop yields in the conventional tillage plots in which herbicides were used were higher than in the no-tillage plots. Within each tillage method, yield reduction caused by weeds was significantly lower when weeds were not controlled than when weeds were controlled either with herbicides or by hoe weeding.

Table 1

TILLAGE AND WEED CONTROL EFFECT ON CASSAVA

treatment	rate (kg/ha)	time	tillage method: plow and harrow (t/ha)	no-till (t/ha)	mean (t/ha)
atrazine + metolachlor	3.0	PE	25.08	13.98	19.53
fluometuron + metolachlor	2.0 + 2.0	PE	28.62	11.17	19.89
diuron + paraquat	3.0	Post E	27.27	11.9	19.58
weed-free	-	-	35.83	27.75	31.79
unweeded check	-	-	16.44	8.1	12.27
mean			26.65	14.58	

LSD 0.05: tillage=17.4t; weed control=4.89t; weed control for same tillage treatment=6.92t; weed control for different tillage treatment=17.76t.

Weed biomass at crop harvest was higher in the no-tillage cassava plots than in the conventional tillage plots across all weed control treatments (Table 2). Although there was no significant difference in weed biomass between the unweeded conventional tillage plot and the herbicide treated conventional tillage plots, there was significant difference in crop yield between unweeded and herbicide treated conventional tillage plots. This fact suggests that the herbicides effectively reduced weed interference during the early growth period when cassava is known to be most sensitive to weeds (Akobundu, 1980). Although subsequent weed growth in the herbicide treated plots reduced crop yield relative to the weed-free plot, this yield reduction was not as dramatic as that caused by the early weed interference that occurred in the unweeded plot.

Table 2

TILLAGE AND WEED CONTROL EFFECT ON WEED BIOMASS IN CASSAVA

treatment	rate (kg/ha)	time	tillage method: plow and harrow (t/ha)	no-till (t/ha)	mean (t/ha)
atrazine + metolachlor	3.0	PE	1.85	4.51	3.18
fluometuron + metolachlor	2.0 + 2.0	PE	1.94	5.81	3.88
diuron + paraquat	3.0		2.71	5.24	3.97
weed-free	-	-	0.93	1.30	1.11
unweeded check	-	-	2.13	4.65	3.39
mean			1.91	4.30	

LSD 0.05: tillage=2.91t; weed control=1.67t; weed control for same tillage treatment=2.36t; weed control for different tillage treatment=3.38t.

In the no-tillage plots, there was no significant difference in crop yield between herbicide treated plots and the unweeded plots. This is an indication that weed control was not enough to reduce weed interference at that early growth period when cassava is known to be very sensitive to weed interference. That yield reduction was higher in the no-tillage plots than in the conventional tillage plots when weeds were not controlled also shows that other factors, including tillage, may have interfered with cassava growth and development to ultimately reduce yield in the no-tillage plots.

The effects of tillage and weed control on cassava yield also were investigated in an Ultisol located in a high rainfall region. The soil in this region is an acidic, well-drained sandy loam. Plant height measurements taken at 10 WAP show that there were significant differences between planting cassava on ridges, flat, and in no-till plots (Table 3). There were, however, no differences in plant height associated with weed control method. The lowest plant height was recorded in the no-tillage plots. Plant height in the flat plots was intermediate while the tallest plants were in the ridged plots.

Table 3

TILLAGE AND WEED CONTROL EFFECT ON CASSAVA PLANT HEIGHT

treatment	rate (kg/ha)	time	conventional tillage: ridge	conventional tillage: flat	no-tillage	mean
			(cm)			
atrazine + metolachlor	3.0	PE	79.1	68.1	38.8	62.0
fluometuron + metolachlor	2.0 + 2.0	PE	80.9	66.9	42.7	63.5
diuron + paraquat	3.0	Post E	79.5	56.8	46.9	61.1
hoe weeding		3+8+12 WAP	79.8	56.1	47.1	61.0
weed-free	-	-	88.6	63.0	47.0	66.2
unweeded check	-	-	79.0	67.8	46.7	64.5
mean			81.1	63.1	44.9	

LSD 0.05: tillage=7.4 cm; weed control=4.9 cm; weed control for same tillage treatment=8.6 cm; weed control for different tillage treatments=10.7 cm.

Table 4

TILLAGE AND WEED CONTROL METHOD EFFECT ON CASSAVA

treatment	rate (kg/ha)	time	conventional tillage: ridge	conventional tillage: flat	no-tillage	mean
			----------	---------- (t/ha)	----------	
atrazine + metolachlor	3.0	PE	13.8	11.7	6.1	10.5
fluometuron + metolachlor	2.0 + 2.0	PE	12.2	13.1	6.3	10.5
diuron + paraquat	3.0	Post E	13.4	11.9	10.1	11.8
hoe weeding	-	3+8+12 WAP	13.4	14.0	9.0	12.1
weed-free	-	-	17.0	18.1	11.6	15.6
unweeded check	-	-	11.1	11.4	7.0	9.9
mean			13.5	13.4	8.3	

LSD 0.05: tillage=2.7t; weed control=1.3t; weed control for same tillage treatment=2.2t; weed control for different tillage treatments=3.3t.

Table 5

TILLAGE AND WEED CONTROL METHOD EFFECT ON WEED BIOMASS IN CASSAVA

treatment	rate (kg/ha)	time	conventional tillage: ridge	conventional tillage: flat	no-tillage	mean
			----------	---------- (t/ha)	----------	
atrazine + metolachlor	3.0	PE	5.8	11.6	21.2	12.9
fluometuron + metolachlor	2.0 + 2.0	PE	5.3	6.6	15.5	9.1
diuron + paraquat	3.0	Post E	0	0	0	0
hoe weeding	-	3+8+12 WAP	5.3	5.3	4.7	5.1
weed-free	-	-	0	0	0	0
unweeded check	-	-	25.1	24.6	22.1	24.0
mean			6.9	8.0	10.6	

LSD 0.05: tillage=6.2t; weed control=4.6t; weed control for same tillage treatment=8.0t; weed control for different tillage treatments=9.5t.

Root yield was similar (12 months after planting) in the flat and ridged plots and both were significantly higher than yield from the no-tillage plots (Table 4). Crop yield in the no-tillage plots was as poor in the unweeded plot as it was in the plots treated with preemergence herbicides, an indication that the efficacy of preemergence herbicides used for no-till cassava was not as good as in conventional tillage cassava.

Table 5 reveals that weed biomass at 16 WAP was higher in the no-till plots than in the conventional tillage plots. While the no-till plots treated with preemergence herbicides had high weed biomass (greater than 15.0 t/ha) at 16 WAP, similarly treated conventional tillage plots had low weed biomass (less than 6.0 t/ha), an indication that weed control was better in the conventional than in the no-till plots.

Results of the two studies show that cassava root yield is lower in no-tillage plots compared with conventional tillage (flat or ridge). While no-tillage crop production has desirable soil conservation attributed, and, crop yield in cereals and legumes have been shown to be comparable to conventional tillage plots, root yield is definitely lower in cassava. The higher root yield observed in the conventional tillage plots is in agreement with results reported by earlier workers (Coursey and Booth, 1977, Ofori, 1973). The need to reduce erosion hazards makes it necessary to use tied ridges rather than planting cassava on the flat in conventionally cultivated fields.

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NO-TILLAGE PRODUCTION OF MAIZE, RICE, AND COWPEA IN NIGERIA

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INTRODUCTION

The traditional systems of allowing crop land to revert to natural fallow for restoring the fertility and productivity of the soil has met the food needs of people in the tropics for many years. The improvement in fertility and productivity that results from natural fallows is associated with the increase in organic matter content of the soil during the fallow period. Every attempt at replacing shifting cultivation by large scale mechanized farming, especially in the humid tropics, has met with limited success or, in some cases, outright failure. This has been due to rapid deterioration in soil productivity after land clearing, a result of accelerated soil erosion and structural degradation, decreasing organic matter content and moisture holding capacity, and the irreversible changes in soil properties which are often associated with the formation of hardpans near the soil surface. The abandonment of the Niger Agricultural Project at Mokwa is a Nigerian experience of the failure of large scale mechanised farming (Baldwin, 1975) owing to soil erosion.

However, population pressure has so drastically shortened the fallow period that an urgent need exists to develop techniques and effectively manage Nigerian soils without degradation under continuous cropping systems.

The concept of no-tillage as a possible solution to this problem has been described by various authors (Ajuwon, et al., 1978; Kang and Yunusa, 1977; Lal, 1976; Triplett and Van Doren, 1969) and only recently has relevance of this concept to the Nigerian situation been revealed (Lal, 1975; 1976). Field experimentation has been limited to a few ecological zones in Nigeria. This study sought to explore no-tillage applicability to a range of ecological zones in the country.

MATERIALS AND METHODS

The study was initiated in 1977 with two locations in the rain forest and a third in the guinea savannah zone. The experimental areas at each location were cleared in 1976 and 1977 to compare the effect of conventional tillage and no-tillage maize yield. Soils varied at each site including a sandy clay soil (Ibadan), a light textured soil (Amakama), and a soil derived from sandstone parent material (Mokwa).

There were four treatments; these were layed out in 10 by 20 m plots in a randomized complete block design with four replications. The treatments included: (a) slash, burn, and plow; (b) slash, no burning, and plow; (c) slash, burn, no plow, and chemical weed control; (d) slash, no burning, no plowing, and chemical weed control. Plowing consisted of discing and harrowing. The no-tillage treatments involved the use of paraquat (3 kg a.i./ha) applied pre-planting to destroy existing vegetation and atrazine (3 kg ai/ha) applied preemergence to maize.

Maize variety Farz 27 (TZPB) was planted at spacing of 90 cm between rows and 30 cm within rows. Fertilizer was applied at the rate of 75 kg N/ha, 52 kg/ha P_2O_5 and 60 kg/ha K_2O. Half of the nitrogen fertilizer was applied together with the phosphorus and potassium one week after planting, while the remaining half was applied 6 weeks after planting. Infiltration capacity of the soil under the different treatments was measured using a double infiltrometer.

Table 1

CULTIVATION METHOD EFFECT ON MAIZE YIELD

treatment	Amakama 1977	'78	'79	'80	Ibadan 1977	'78	'79	'80	Mokwa 1978	'79	'80
	(t/ha)										
slash, burn, plow	3.84	2.45	3.30	0.74	2.63	3.58	2.22	3.04	2.31	1.70	3.13
slash, no burn, plow	3.26	2.45	3.53	0.80	2.43	2.97	1.93	3.05	2.17	1.73	3.55
slash, burn, no-till	3.61	2.95	3.96	1.70	2.53	2.88	2.37	3.18	2.90	1.60	3.63
slash, no burn, no-till	4.09	2.85	3.97	1.37	2.30	3.80	2.30	2.94	2.13	1.53	3.92
S.E.	0.53	0.20	0.39	0.10	0.28	0.37	0.26	0.17	0.29	0.36	0.24
C.V.	14.20	7.40	10.50	16.80	11.20	20.60	11.70	11.40	24.60	21.90	13.20
Level of sig. at P=0.05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table 1 compares maize yield for several years of continuous cropping at three locations for the four treatments. No significant difference was observed among treatment means at Amakama and Ibadan during the first 3 years. However, in 1980 maize yield at Amakama was significantly higher in the no-till treatments than in the conventional tillage plots. The yield differences caused by management of the acid soil at Amakama were absent in the similarly managed high-base saturation soils of the Ibadan site. These latter results reflect those from other work in a similar ecological zone (Ajuwon, et al., 1978).

At the Mokwa site in the savannah zone, yields varied by year, but not significantly among treatments.

The significantly lower yield in the conventional tillage plots where plant residue was burned could have been due to higher run-off and soil loss. Table 2 shows that the reduction in water entry into the soil was greater for the conventional tillage treatment. Consequently, there probably was more run-off with less infiltration. This result coincides with that reported by Lal (1975) indicating that there was greater run-off and soil loss in plowed plots, compared to no-till plots, under maize and also cowpea.

Table 2

TILLAGE METHOD EFFECT ON INFILTRATION CAPACITY OF SELECTED NIGERIAN SOILS*

treatment	location Amakama	Ibadan	Mokwa
	(cm/min)		
conventional	-0.71	-1.17	-0.52
no-till	-0.44	-0.68	-0.07

* mean values for 1977-80

CONCLUSIONS

On the whole, these results have not shown any distinct advantage of conventional tillage over no-tillage with regards to crop performance. However, for continuous cropping, no-tillage appears to have some advantage, particularly on acid soils. A careful study of some implications of weed control and soil and crop management in the different ecological zones of the country must be considered before the widespread adoption of no-tillage can occur. For instance, perennial weeds must be controlled by effective herbicides like glyphosate while paraquat would suffice for annual weeds.

While the foregoing results demonstrate the applicability of no-tillage in crop production in Nigeria, some problems may arise due to changes in cultivation methods, such as shifts in weed species, insects, disease and nematode activity usually associated with accumulation of crop residue on the soil surface from previous crop. These may require new weed and pest management practices.

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CRITERIA FOR NO-TILLAGE CROP ESTABLISHMENT BY SMALLHOLDER FARMERS

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INTRODUCTION

No-tillage crop production not only solves many of the ecological problems which occur with conventional cultivation in the tropics, it is also suitable for use on small farms because of low cost and comparatively simple technology. The circumstances under which smallholder farmers in the tropics can effectively establish crops without tillage warrants examination including systems where some cultivation is performed post-crop establishment or post harvest, as well as systems of no cultivation at all.

Smallholder farmers require proven, profitable, low-risk systems with low recurrent costs and low capital investment. Technical complexity can be assimilated by many, providing that a new system is introduced with thorough long-term extension and efficient logistic support. While in some developing countries, these provisos may seem to rule out the introduction of technically complex systems indefinitely, there are many developing countries in which smallholder farmers already use complicated and technically sophisticated traditional systems. Though these systems no longer may be appropriate to changing circumstances, their existence should encourage the introduction of appropriate technological systems which satisfy the stated 'smallholder criteria' just mentioned.

A. Soil Type

Heavy clay soils can become so compacted in the absence of tillage that root impedance is experienced (Ogborn, 1976). It is doubtful, therefore, whether complete no-tillage crop production can be practiced in these soils. Also, higher rates of soil-applied herbicide possibly will be required compared to the same crop grown in a lighter textured soil.

B. Dry Season Length

The use of killed weed cover for no-tilled crop establishment in semi-humid or semi-arid areas is possible where sufficient rainfall precedes the sowing date. In most semi-arid areas, considerable yield increases have been obtained by sowing the staple crops at the time of the earliest effective rainfall. Smallholders will only be able to practice no-tillage involving use of killed weed cover on those crops which are customarily sown after the rains have started. Cotton and cowpeas exemplify this type of crop in West Africa.

Early sown crops in the semi-arid zones therefore have to be established on soils which are only protected by the dead residues of previous crops and weeds. These residues are always grazed by livestock, or are sometimes accidentally burned, or consumed by termites. If intense early rain occurs on soil which has been treated with a soil active herbicide and is only sparsely covered with plant residues, there is a risk of soil erosion. However, the erosion is localized and mild because the stubble of the previous crop will tend to arrest the movement of floating debris and prevent catastrophic sheet erosion of the surface soil. The most serious effect of the erosion is that the herbicide cover is disrupted and weed control weakened.

C. Herbicide Residues

Herbicide residues generally disappear quickly in the warm moist conditions which prevail in the tropical soils of humid and semi-humid climates. When the dry season is long and severe, the surface soil characteristically dries very rapidly. Any herbicide residues which persist after harvest could remain undecomposed until the rains start again.

Good husbandry and commercial profitability both require that smallholder farmers should be able to grow either crop mixtures or sole crop rotations. Their freedom to do so will be restricted by the presence of herbicide residues unless there is sufficient rainfall between harvest and subsequent crop establishment. Rainfall that tends to be highly variable at the commencement and end of the rainy season in semi-arid areas is unpredictable. No-tillage by smallholder farmers in the semi-arid zones is, therefore, likely to be restricted to crop establishment using low rates of soil active herbicides which will decompose before harvest.

The variability in the length of the rainy season increases sharply as the average length decreases. Hence, the probability that a given dosage of herbicide will decompose before harvest also decreases as the rainy season becomes shorter. This is a further reason for predicting that smallholder farmers in semi-arid areas will not be able to use no-tillage systems that depend entirely on herbicides for weed control.

D. The Live Mulch Systems

There is a possibility that living mulch cropping can be used in semi-arid zones provided that the mulch crop produces abundant seed which germinates before the sowing dates of the crops. If planting of the crop is delayed--possibly because the living mulch fails to become fully established after onset of rains--yield of the late sown crop could be significantly reduced by insect pests. Another possible cause of yield reduction would be competition from the mulch for water in late harvested crops. Therefore, the system would be unsuitable for smallholder farmers of the semi-arid tropics who need to grow a wide variety of crops with staggered harvest dates. The system might be useful for growing high value, early harvested crops such as cowpeas.

It appears that live mulch systems for smaller farms will be confined to mainly those areas which are humid enough for the mulch to survive the drier season and not to compete for moisture before crop harvest.

E. The Alley Cropping System

Alley cropping appears technically possible to practice in semi-arid areas up to the limit where perennial tree species can remain in active growth during the dry season. The continuous pruning of the alley crop should ensure that competition for moisture can be minimized. Late season fires and/or unchecked browsing by livestock are probably the main hazards to alley cropping in areas of the semi-arid tropics where the tree species can be established successfully.

CROP SOWING

A. Hand Sowing

Where simple hand broadcasting of seeds and light harrowing on bare soil cannot be used, it is essential to employ some sort of dibbler. A heavy demand is placed on family labor where dibbling is used for crops such as soybean that require high plant populations. Data collected from a no-tillage experiment at Samaru, Nigeria, revealed that man-hours/ha required for dibble-planting soybeans on a bare soil surface varied from 31 for 1.0 by 1.0 m spacing to 1008 for .25 by .25 m. It seems likely that smallholder farmers will only be able to use dibbling when family labor is abundant and has a low opportunity cost.

B. Rolling Injection Planter

The rolling injection planter holds promise as a useful implement with potential to speed up planting (and reduce burdensome labor requirements) under some conditions in the semi-arid as well as the humid tropics. However, existing models are not capable of sufficiently penetrating a hard soil surface. A modified model is needed which can inject seed into the hardest untilled soil surface before smallholder farmers can use these no-tillage planters routinely in the semi-arid tropics.

POST-EMERGENCE WEED CONTROL

A. Supplementary Hoe Weeding

The smallholder farmer, with a limited but constantly available supply of family labor, is usually able to control late season weed infestation in crops by spot hoeing, even as late as harvest if necessary. This is one of the great strengths of the no-tillage approach which is expensive for larger scale farmers to imitate. By using this 'minimum tillage' hoeing, it is possible to contain the build-up of the late flowering weeds which are such a problem in larger scale agriculture (Parker, 1977).

B. Post-emergence Directed Foliar Applications

In widely spaced crops with paraquat-tolerant stems, it is possible to apply a directed spray of paraquat, as well as selective foliar herbicides, with a knapsack or normal hand-held spinning disc applicator. The success of this technique profoundly depends on the skill of the operator. It is hoped that a precision inter-row sprayer will eventually be developed which is cheap enough and simple enough to be used by smallholder farmers.

USING HERBICIDES SAFELY

Ideally, all controlled droplet application (CDA) herbicide solutions should be supplied from an agricultural service station. Where this is not possible, herbicides likely to be used for CDA by the smallholder farmer should have low mammalian toxicities and color coding so that they cannot easily be mistaken for food or drink.

The outstanding exception is paraquat which is exceptionally hazardous due to its toxicity and the fact that there is no practical antidote which could be used by smallholder farmers. Therefore, this herbicide always should be sold diluted to field strength and should contain both an emetic and odorant.

FAMILY LABOR RESOURCES

A. Labor Availability and the Choice of Farming System

No-tillage has lower labor demand than traditional tillage systems. Consequently, a family with a low proportion of productive farm labor will be more likely to adopt a no-tillage approach than a family with a high proportion of effective laborers. This holds true irrespective of the reasons for the labor shortage.

B. The Special Case of Alley Cropping

Alley cropping, while almost free from dependence on imported inputs, appears to require a large stable labor force comparable to the traditional hoe cultivation systems. Any sophistication of the technique to reduce labor required for the manual pruning of the alley crop (e.g., by the use of a defoliant) is likely to reintroduce dependence on imported inputs and thereby limit appeal to smallholder farmers.

FUTURE PROSPECTS

The future no-till systems for smallholder farmers in West Africa are likely to include alley cropping and cropping procedures involving use of herbicides. To be widely adopted, no-till systems must be based on more effective planting tools, safe and easily used herbicide application methods, and minimum dependence on imported production inputs. Only in this way can cropping technology be kept within reach of the smallholder farmer.

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NO-TILLAGE IN RELATION TO SOIL CONDITIONS AND CLIMATE

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INTRODUCTION

Any tillage system's real test of appropriateness considers the effect it has on suitability for root growth and, ultimately, shoot growth and yield. Furthermore, in the longer term, the system must preserve soil fertility and continued suitability for root growth and function. The extent to which tillage is likely to increase erosion is particularly important. The more fragile the soil, and the more extreme the climatic conditions, the more important this consideration becomes.

CROP RESIDUES

The method of tillage may involve incorporation of crop residues into the soil (e.g., by moldboard plowing) or leave part or all of the residues on the soil surface (e.g., stubble-mulch tillage with sub-surface sweep blades). The method of crop residue management may partly reflect tradition, but often relates to an area's climate. Because of their influence on soil conditions, crop residues are an integral aspect of tillage.

With no-tillage, retention of crop residues on the soil surface can have and overriding effect, especially on wind and water erosion. Not surprisingly, this aspect has dominated research in the USA and the term 'conservation tillage' is used widely (Onderdonk and Ketcheson, 1973). Spectacular effects have been found; for example, in Mississippi, on a highly erodible soil, annual erosion was reduced from 17.5 t/ha^{-1} to 1.8 t/ha^{-1} when no-tillage was used (McGregor, et al., 1975). In Brazil, where the intensity of rainfall is often very high, soil losses were much less with direct drilling in a double crop soybean/wheat annual sequence (Mondardo, et al., 1979).

The presence of crop residues can have other important consequential effects including: (i) more rapid infiltration of rainfall, thereby reducing the likelihood of surface run-off (Marston and Perrins, 1981; Triplett, et al., 1968) and increased snow trapping and enhanced water storage (Stobbe, 1979); (ii) less evaporation of soil water, which in combination with greater infiltration, can increase yield of maize in well-drained soils (Blevins, et al., 1971; Van Doren, et al., 1976); (iii) lower soil temperatures which are believed to be a limitation for direct-drilled maize in north-central USA (Griffith, et al., 1973), but an advantage in warm areas, e.g. Nigeria (Lal, 1974); (iv) interfere with seeding, often requiring the development of specialized seed drills for direct drilling; and, (v) formation, in anaerobic soil conditions, of phytotoxins which may retard seedling growth. This latter effect is most likely to occur in humid areas with heavy quantities of straw residues, up to 10 t/ha^{-1}, e.g., in the Pacific northwest of the USA (Elliott, et al, 1978) and in the United Kingdom (Lynch, 1979).

For successful no-till (direct drilling) in the U.K., residues should be removed, preferably by burning (Ellis and Lynch, 1977). Burning may have other beneficial effects including improved soil aggregate stability and friability of the surface layers for drilling, killing weeds, and making the environment less favorable for pests such as slugs.

SOIL STRUCTURE AND ROOT GROWTH

The ability of roots to penetrate soil freely depends on the presence of continuous pores or channels that roots can easily enter. In soils of low mechanical strength, roots will readily extend through the soil; expansion ease decreases as soil strength increases. Depending on the forces involved, the rate of root elongation may be greatly limited. Relatively small external pressures can drastically slow the rate of root elongation (Goss, 1977). Although root elongation will continue in compact soil, the slower rate of root extension restricts the rooting depth which may be especially important in the supply of water (Taylor, 1979). If soil pore size is too small to be entered or enlarged easily by main root axes, but the laterals are not restricted, the latter will proliferate causing a heavily branched root system. Where pore size also prevents the laterals from entering, their growth is restricted, and the root system is stunted (Goss, 1977). Apart from the effects of restricted rooting depth and density on uptake of nitrogen, phosphorus, and potassium (Kubota and Williams, 1967) and water in compacted soil, the movement of water may be slower and aeration restricted.

EFFECTS OF NO-TILLAGE ON SOIL CONDITIONS

Tillage affects the biological, physical, and chemical properties of the soil; therefore, it can be expected to affect the suitability of the soil for root growth and function, and perhaps yield. The most obvious effect of no-tillage is on the physical characteristics of the upper layer.

A. Surface Conditions

With no-tillage, the surface conditions must have sufficient tilth to provide satisfactory aeration and water relations for germination of seeds, and sufficient porosity and/or lack of mechanical impedance for root development. A coarse-tilled, rough, cloddy surface may aid infiltration of water, but restrict germination, whereas a fine surface may be prone to slaking and crusting.

Clay soils with an expanding lattice arrangement, such as montmorillonitic clays, often self-mulch in the surface layers. This can provide ideal conditions for germination. This characteristic is particularly pronounced in parts of the wheat belt in Australia and, to a lesser extent, in clay soils in Britain, where these soils often provide favorable conditions for germination of autumn sown cereals and oil-seed rape.

Where no-tillage is continued for several years, surface soil physical conditions may improve. The stability of pores is difficult to measure and recourse must be made to aggregate stability which is related to it. More stable aggregates in the topsoil, associated with increased organic matter content, have been found on several soils in Britain (Douglas and Goss, 1982; Ellis and Howse, 1980). On a silt loam, this change was associated with better plant establishment and yield after direct drilling in later years of an experiment (Ellis, et al., 1982), but the higher yields also may have been due to better knowledge of the effect of soil moisture content on behavior of the soil, and therefore more timely drilling to create some tilth.

In Western Australia, on coarse, sandy soils with low organic matter, no evidence of improved surface conditions has been found (Hamblin, 1980), and in other Australian soils, improvements in aggregate stability were much less evident than in Europe (Hamblin, 1979). It is not clear how much the latter observation reflects differences between the two environments or to what degree it is associated with analysis of a deeper layer of topsoil, thus perhaps masking differences.

In Britain, straw burning, a pre-requisite for successful no-tillage of small grained cereals sown in the autumn (Ellis and Lynch, 1977), also improves aggregate stability of the top soil and the friability of the surface layers for drilling (Ellis, et al., 1977). On many soils surface ponding has been no more frequent with direct drilling, but on some fine textured silt and clay loam soils surface waterlogging has been more evident on uncultivated land (Hood, et al., 1964; Kahnt, 1969).

B. Total Porosity

The most obvious effect with no-tillage cropping is the soil's greater compaction and strength in comparison to after tillage. Greater bulk density, therefore less total porosity, in the upper layers of the soil and greater resistance to penetrometers in those layers have been reported from many countries: Europe (Ellis, et al., 1977); USA (Gantzner and Blake, 1978); West Africa (Nicou and Chopart, 1979).

Cultivation can affect the pore size distribution. In many soils the proportion of transmission pores has been less after direct drilling than after cultivation (Cannell and Finney, 1973).

C. Pore Continuity

There is increasing evidence from experiments in Europe that, although the total and air-filled pore space may be less in untilled land than after cultivation, in some soils the pores may become continuous.

In clay soils in England, deeper and more continuous cracks have been found in direct-drilled land (Ellis, et al., 1979). More earthworm channels (and earthworms) have been found in no-tillage land. This difference has been most evident at the depth of plowing which disrupts the channels (Barnes and Ellis, 1979; Ehlers, 1973). More rapid infiltration of water occurred in no-tilled clay soils leading to increased storage of water available to the crop (Goss, et al., 1978). In clay soils, the saturated hydraulic conductivity was greater in undisturbed soil cores from direct-drilled land, but blockage of discrete earthworm channels (1 to 8 mm diameter) reversed the ranking (Douglas, et al., 1980). When plaster of paris was poured on top of the soil, the suspension did not penetrate much below the plow sole, but did move down fissures, especially earthworm channels, in no-tilled land[1/]. In spite of this, in wet winters aeration of the heaviest clay soils (measured as oxygen concentration) may be less at the end of the winter (Dowdell and Crees, 1980), perhaps reflecting slower lateral hydraulic conductivity. In silt loam soils in Germany, more rapid infiltration in no-tilled land also was due to the earthworm channels (Ehlers, 1975).

In vertisols in tropical regions, shrinking and fissuring when the soils dry out is the principal factor in forming transmission pores (Greenland and Lal, 1979). A long dry season (e.g., in Australia) severely limits any permanent presence of active soil fauna such as earthworms.

ROOT GROWTH AND FUNCTION

A. Root Growth

After direct drilling, the more compact soil which contains fewer transmission pores is mainly confined to the depth equivalent to the cultivated layer. It is not surprising, therefore, that many of the reports of restricted root growth are concerned with the early stages of growth. Slower rates of elongation of seminal roots of direct-drilled wheat and barley have been reported (Ellis, et al., 1977, 1979) with a tendency for roots to proliferate in the surface few centimeters of soil surface (Drew and Saker, 1978); this latter effect may also be associated partly with the accumulation of phosphate in the surface layers of uncultivated soil, since roots proliferate in phosphate-rich zones (Drew, 1975).

1/ Goss, M.J. Personal communication.

In the United Kingdom, growth of winter wheat roots has been studied during 6 years in tillage experiments on three clay soils, two with about 35 to 40% clay, the other more poorly drained with 50% clay. A characteristic feature has been the greater number of roots at the beginning of stem elongation at 80 to 100 cm depth (but not at anthesis) after direct drilling, especially in dry seasons (Ellis and Barnes, 1980). This difference, which has been observed on several occasions, is a good example of the limited value of measurements of bulk properties of the soil to predict root growth. In these soils, the bulk density has been greater after direct drilling than after plowing, yet root growth has not been associated with this difference, except in wet winters on the heaviest soil where the depth of rooting has been less after direct drilling (Fig. 1). Observation of these soils shows that many roots grow down earthworm channels and in the fissures that form planes of weakness between the soil peds (Cannell, 1981).

In Nigeria, in a sandy loam over clay with a gravel horizon, the depth and lateral spread of maize root systems was similar after about 45 days in plowed and uncultivated but mulched soil (Lal, 1974). In a further study of this soil, the depth and lateral spread of maize roots was less in unmulched than mulched uncultivated soil; roots concentrated immediately beneath the mulch (Lal, 1978). Earthworm channels also facilitated deep rooting in this soil. In the U.S.A. (Indiana), growth and weight of maize roots were less in an uncultivated silt loam than after plowing, but in spite of this, yield was unaffected (Barber, 1971).

Growth of tap-rooted crops can be greatly restricted by direct drilling: this has been noted in cotton (Stibbe and Ariel, 1970); in sugarbeet (Bakermans and de Wit, 1970); and in kale (Cannell and Finney, 1973).

Restricted root growth after direct drilling has been most evident on coarse sandy soils in widely different climatic conditions, in West Africa (Nicou and Chopart, 1979), in Holland (Bakermans and de Wit, 1970), and in the U.K.[2/] where root growth also may be restricted in some silt soils (Drew and Saker, 1979).

[2/] Davies, D.B. Personal communication.

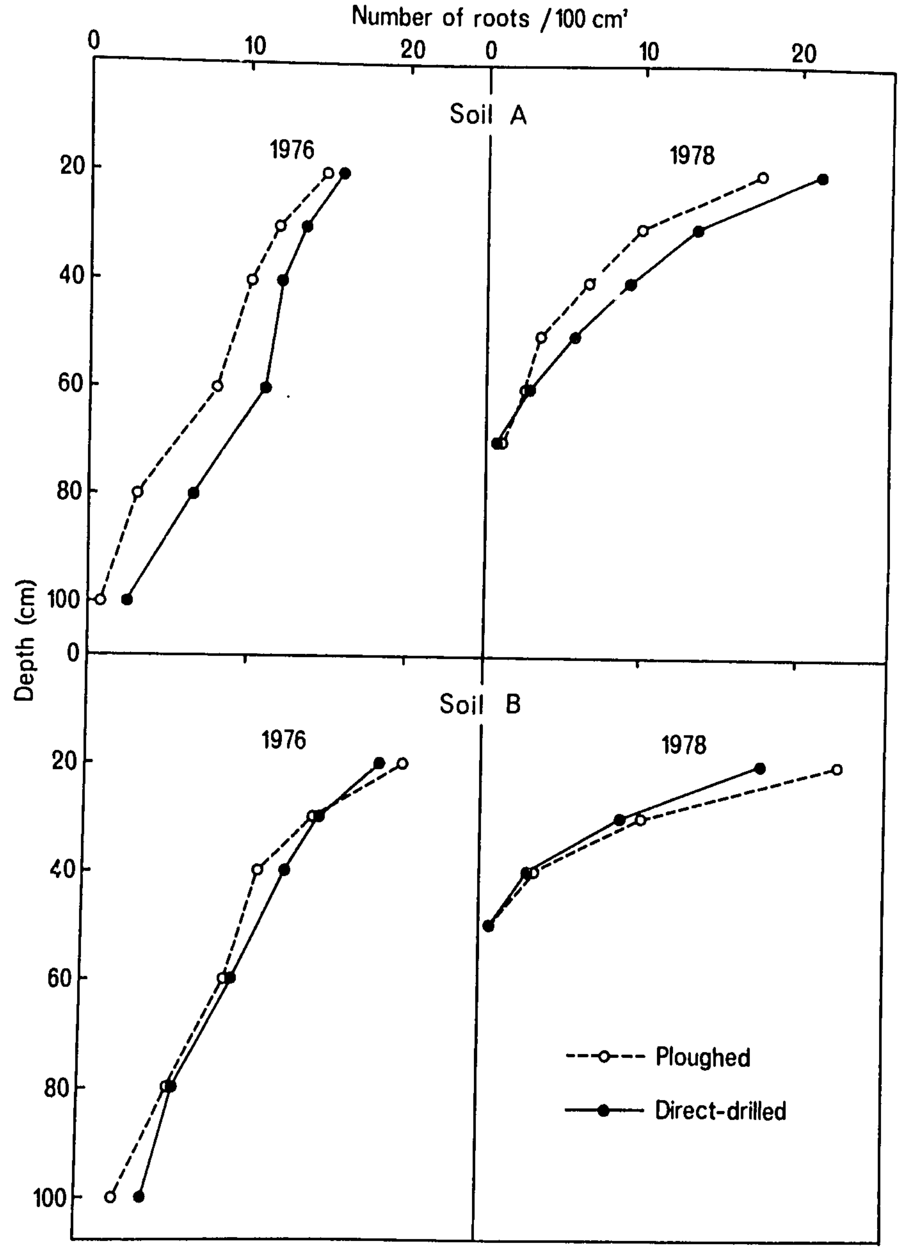


Figure 1. Root growth of winter wheat in two clay soils in England after direct drilling or plowing, measured in April at Zadoks growth stage 30.

In 1976, which was unusually dry, roots grew deeper than in the wet year 1978. In the dry year, roots grew more rapidly in both direct-drilled soils, but in the weat year root growth on the heavier soil (B) was restricted after direct drilling (Ellis and Barnes, 1980).

Early root growth and seedling establishment can be adversely affected in the presence of decomposing straw. This effect has been attributed to phytotoxic substances from microbial degradation of the straw in the stubble mulch farming area of the U.S.A. (McCalla and Norstadt, 1974), as well as in Australia (Kimber, 1967). It has been particularly pronounced with winter cereals no-tilled in the presence of straw when wet anaerobic conditions favor formation of potentially phytotoxic acetic acid (Lynch, 1979) and restrict root growth (Ellis, 1979). With crops sown in narrow rows, such as wheat, crop residues also can adversely affect the mechanical performance of direct drills by causing "clumping" of the seed rather than even distribution in the row.

B. Nutrient Uptake

Despite the formation of step gradients of phosphate and potassium in land that is not plowed, the concentration of these nutrients in the crop usually has been similar after no-tilling and plowing, for example, even on soils of low fertility cropped with maize in the U.S.A. (Singh, et al., 1966; Triplett and Van Doren, 1969). Sometimes this is attributed to the presence of a mulch of crop residues that lowers temperature and maintains moist conditions which may favor diffusion of nutrients (Onderdonk and Ketcheson, 1973).

Where the straw of the previous crop is burned or removed prior to no-till (no mulch present), the concentrations of phosphate and potassium in the crop also have been unaffected generally, even in dry seasons (Cannell and Graham, 1979). The exceptions have been in winter cereals when wet winter soil conditions restricted rooting depth (Ellis and Barnes, 1980), and in late-sown spring cereals when rooting also was restricted.

There is widespread evidence that the uptake of nitrogen by no-tilled crops is often slower, especially in the early stages of growth (Cannell and Graham, 1979; Cannell, et al., 1980). Often this is partly due to slower mineralization of nitrogen from soil organic matter (Dowdell and Cannell, 1975), but in wet conditions in heavy soils, more denitrification has been found in no-tilled land (Burford, et al., 1981). Although little is known about the effect of cultivation on leaching losses or immobilization, there is some evidence that the efficiency of fertilizer usage is unaffected by differential cultivation (Dowdell, et al., 1980).

C. Water Extraction

The amount of water that can be extracted from the soil profile by soybeans is influenced mainly by the rate of root elongation and the depth of rooting, rather than by rooting density (Taylor, 1979). Relatively few studies have been conducted for any species where the pattern of root growth and soil water extraction have been examined together. In experiments with wheat in the U.K., M.J. Goss[3/] found good agreement between soil water extraction pattern and differences in root growth. The deeper rooting of no-tilled winter cereals in the early spring facilitated greater and deeper water extraction. In dry seasons, this led to heavier yields. In one case, in one year no-tilled crops on three clay soils extracted on average 17 mm more water from the top 100 cm of soil (Goss, 1977), and this was associated with a mean yield increase on 16% (Cannell, et al., 1980, Ellis, et al., 1979).

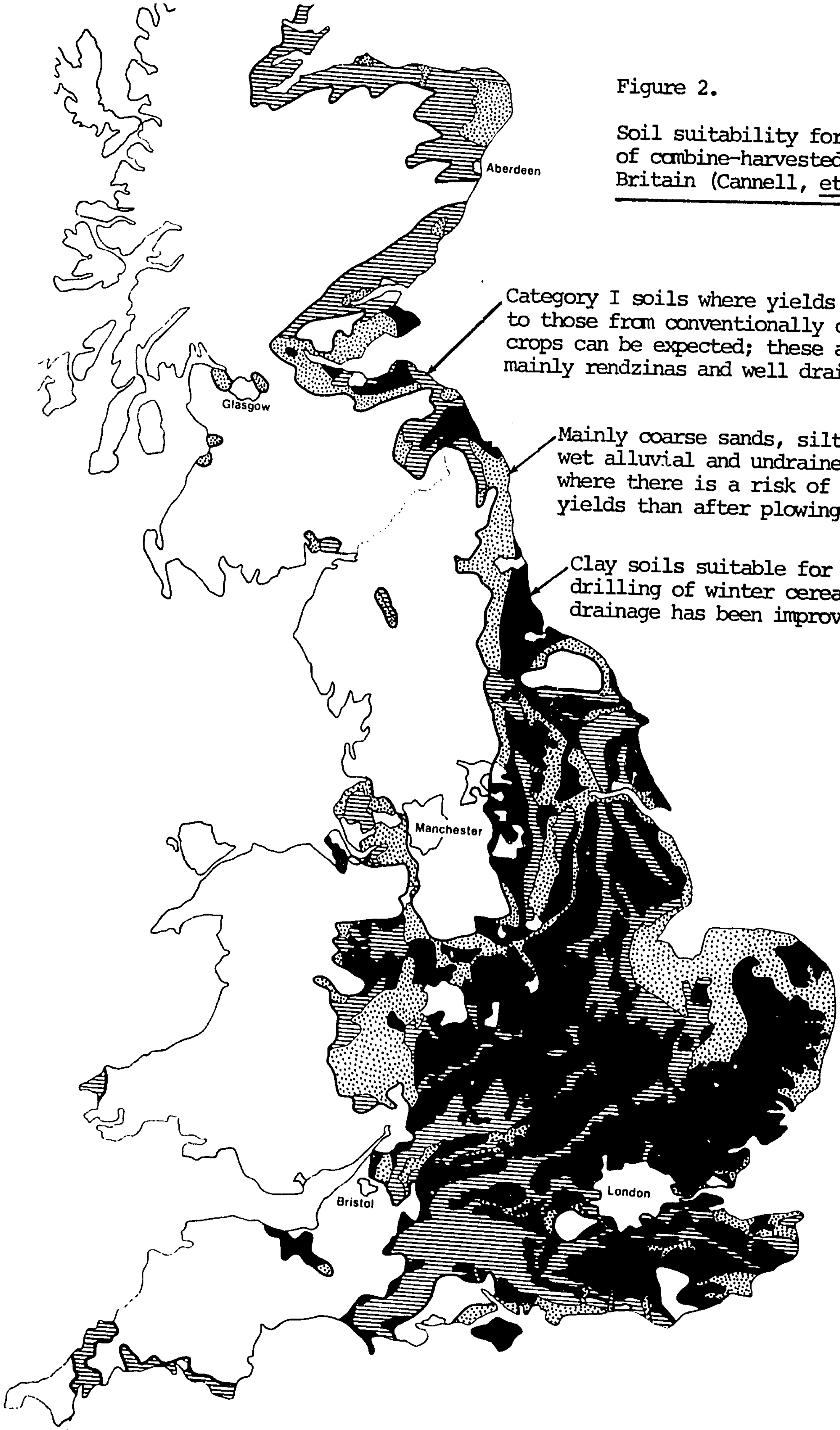
The fact that root growth of no-tilled crops is restricted for some species in some soil types indicates that crop yields may also be adversely affected. Attempts to assess the suitability of soils for direct-drilled crops have been made, for maize in Ohio (Triplett, et al., 1973) and for small-grained cereals in Britain (Cannell, et al., 1978). In the latter case, account was taken of soil, site, and climatic factors to produce a classification with three categories. The basis of the classification was to assess the results of experiments comparing no-tilling with conventional tillage (moldboard plowing) in relation to the national soil map. This enabled creating a map of the suitability of soils for no-tilling cereal (and other combine-harvested crops) to be produced (Fig 2).

While not purporting to comprehensively review in this paper no-tillage effects on crop yields, some soils of the semi-arid tropics--sandy soils in Senegal, for instance--seem to need deep tillage to permit adequate root growth to withstand drought (Nicou and Chopart, 1979). By contrast, cultivation appears to be unnecessary in the majority of Alfisols and Ultisols of the humid tropics (Greenland and Lal, 1979).

3/ Unpublished results.

Figure 2.

Soil suitability for direct drillin of combine-harvested crops in Britain (Cannell, et al., 1978).



Category I soils where yields similar to those from conventionally cultivated crops can be expected; these are mainly rendzinas and well drained loams.

Mainly coarse sands, silts and other wet alluvial and undrained clay soils where there is a risk of lower yields than after plowing.

Clay soils suitable for direct drilling of winter cereals if drainage has been improved.

It is sometimes questioned whether crops grown after simplified cultivation can produce yields equal to those after deep soil disturbance, when conditions favor high yields. In 1977-78 and 1979-80 these conditions existed in the United Kingdom and yields of winter wheat of more than 10 t/ha^{-1} were obtained after no-tillage, shallow tine cultivation, and plowing (Cannell, et al., 1980). These yields are close to the potential for winter wheat in the U.K. of about 12 t/ha^{-1} (Austin, 1978).

THE NEED FOR DEEP LOOSENING

Many soils exist that require very little disturbance to support satisfactory crop growth. However, the worldwide trend to develop and use larger, heavier farm machinery can lead to soil compaction damage. Compaction by combine harvesters and grain trailers may be the worst aspect of the problem. With shallow cultivation systems, there is no opportunity to remove more than the most superficial damage. In many situations, a means of minimizing wheel-caused soil compaction should be investigated, since the adverse effect of poor cultural practice can extend 30 to 40 cm below the soil surface (Oschwald, 1978).

The role of subsoil loosening and deep placement of nutrients in any cultivation system has not been adequately assessed. Thorough subsoil loosening of a weakly structured sandy loam increased rooting of spring sown vegetable crops grown after conventional tillage (Rowse and Stone, 1981). There was no associated advantage for yield in wet seasons when water supply was adequate, or in dry seasons, but yield was increased by subsoil loosening in intermediate rainfall years.

CONCLUSIONS

Experiments in many countries point to the possibilities of simplifying cultivation, and when erosion can be diminished, utilizing no-tillage and other tillage systems that leave crop residues on the surface may enable yields to be sustained at a desirable level. Soils such as coarse sands which readily compact, and weakly structured silts that have little means of naturally regenerating lost structures, may be unsuited for no-tillage.

Although a general pattern of effects of no-tillage on soil physical and chemical conditions is emerging, sufficient information for the tropics is lacking. Where the climate is more extreme, soils have less organic matter and are often more erodible. The importance of retaining crop residues on the surface to protect the soil, and to conserve moisture, is undoubted, but in practice this may be hard to achieve because of the low yields. In more humid temperate areas, there can be other constraints to the adoption of simplified tillage.

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EFFECT OF TILLAGE SYSTEMS ON WATER CAPACITY, AVAILABLE MOISTURE, EROSION, AND SOYBEAN YIELD IN PARANA, BRAZIL

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INTRODUCTION

Soil degradation through water erosion is one of the major problems of agriculture in Parana. Water erosion was drastically accelerated with the expansion of soybean and wheat cultivation (2.5 and 1.3 million ha respectively), because the soil had to be tilled twice a year and the land left bare, loose, and unprotected for many months. Excessive soil tillage and the lack of protective cover crops or residues in times of heavy rainfall are the main causes of soil erosion and degradation.

Lack of efficient soil conservation and management practices have led to a situation where, in less than 10 years, the soils of Parana have lost their natural fertility (organic matter, nutrients, etc). Degradation of organic matter, nutrients, and also physical soil characteristics make the crops very susceptible to drought. Fertility losses, as well as lack of moisture, are the main reasons for poor crop stand and yield decline.

The development of tillage systems and crop rotations that include cover crops which will protect the soils against erosion, are important in order to make permanent land use possible in the state of Parana.

The purpose of this paper was to examine the effect of three tillage and seeding practices on soil moisture, water erosion, and yields of soybeans on an Oxisol.

MATERIALS AND METHODS

A. Soil and Climate

The experiment was conducted on a soil derived from basalt which developed into a red Oxisol. The chemical and physical properties of the soil are shown in Table 1. Climatic conditions in Londrina, as well as rainfall during the growth period of soybeans in the 4 years of the experiment, are shown in Table 2 and 3.

Table 1

CHEMICAL AND PHYSICAL PROPERTIES OF SOIL AT DIFFERENT HORIZONS OR DEPTHS

depth	pH	C	clay	silt	soil moisture: field capacity*	soil moisture: available**	permeability	infiltration rate
cm		(%)	(%)	(%)	(%)	(%)	(cm/day)	(mm/day)
0-8	5.9	1.6	76	13	33.5	10.6	4102	70
8-20	5.1	1.6	79	13	43.0	9.2	75	
20-45	4.7	0.2	82	10	40.5	11.9	276	
45-120	4.6	0.5	81	11	37.0	7.4	231	

* Soil water content at 0.1 bar
** Difference in content at field capacity (0.1 bar) and wilting point (15 bar)

Table 2

CLIMATIC CONDITIONS AT LONDRINA/PARANA/BRAZIL (MEAN OF A 20-YEAR PERIOD)

Rainfall, annual mean	1608 mm
Rainfall, mean, summer crops, Oct.-March	1080 mm
Rainfall, mean, winter crops, April-Sept	528 mm
Rainfall, mean, wettest month, January	245 mm
Temperature, annual mean	20.8°C
Temperature, mean, coldest month, June	16.8°C
Temperature, mean, hottest month, January	23.9°C
Temperature, absolute minimum, July	-3.5°C
Temperature, absolute maximum, February	37.5°C
Relative humidity, annual mean	71.0%
Sunshine (hours/year)	2549

Table 3

RAINFALL DURING SOYBEAN GROWTH PERIOD

months	years 1977/78	1978/79	1979/80	1980/81	mean
	(mm)				
November	183.1	171.0	153.2	122.6	157.5
December	283.7	281.6	136.9	329.8	258.0
January	81.6	71.5	272.3	223.2	162.2
February	64.6	156.0	359.5	155.4	183.9
March	145.0	32.4	267.5	69.2	128.5
TOTAL	758.0	712.5	1189.4	900.2	

B. Soil Sampling

Soil sampling was performed once a week with samples taken at three points per plot and at four different depths: 0 to 10 cm, 20 to 40 cm, and

40 to 60 cm. Samples from the first two sampling dates were used for chemical and physical analyses. A total of 48 mean values were used for the statistical analyses of physical properties, including pH, organic carbon, nitrogen, water holding capacity, and permeability. Erosion data for this soil were collected with the use of a rainfall simulator (Mondardo, et al., 1979)

C. Treatments

The experiment began in late 1977 at a site located on a 5-6% slope. The main treatments were: conventional tillage (disk plow and two diskings); minimum tillage (chisel plow with packing rings and cage roller); and, no-tillage (rotary hoe drill, that cuts 2.5 to 5 cm-wide slots in the soil). Each tillage treatment was combined with four crop rotations. Each rotation plot was 32 m long by 10 m wide. In order to minimize erosion between neighboring plots, a strip of permanent grass was planted between the plots. Six 21 m^2 samples were combine harvested from each rotation plot, the replicates being located one after the other, following the slope and the theoretically greatest soil differences (Schuster and Lochow, 1979).

Soil tillage and sowing, as well as all other operations, utilized farm-size equipment along the direction of the slope. Traditional row spacings and seeding rates were used. Soybean (Glycine max, Merr.) was planted in November. In the winter, wheat was planted in rotations #1, #2, and #3, while cover crops were planted in rotation #4. Rotations #2 and #3 received a short term cover crop after wheat.

Fertilizer was uniformly broadcast over the experiment site once a year and before sowing the winter crops at 30 kg/ha N, 60 kg/ha P_2O_5, and 40 kg/ha K_2O (Probst, 1977).

Erosion data were obtained using a rotating boom rainfall simulator on 11 by 3.5 m plots. Collection and measurement of runoff was made with HS flumes, equipped with water level recorder.

RESULTS

A. P^F Values and Available Soil Moisture

Fig. 1 shows that the maximum water holding capacity of this soil is 65 to 72% and that permanent wilting point is 23 to 27% water content (values based on dry soil). In the 0 to 10 cm and 10 to 20 cm soil layers, and at a pressure of 0.33 bar, the water content was 4 to 5% higher under no-tillage than under conventional tillage. Also, soil water content in no-tillage plots was consistently higher than in conventional tillage plots at all pressure readings lower than 1 bar.

Water content values under minimum tillage plots that were chisel plowed persistently showed an intermediate position between the other two tillage treatments. Nearly 30% of the water content from the saturated soil samples was released at a pressure of 0.06 bar. But an increase in pressure from 0.06 to 1 bar released only 8 to 9% of the water (Fig. 1).

In the case of the conventional tillage treatment, a decrease of 5% in water content from the field capacity (Fig. 1, 0.33 bar) in the 0 to 10 cm soil layer is equal to a water content of 28%; in order to be able to use the remaining water, the plants have to develop suction forces of more than 5 bars. On the other hand, in no-tillage treatments with the same decrease of 5% water content from field capacity (32% water content), plants will have to develop suction forces of only 1 bar. The values of available water capacity were at 0.06 bar and also at 0.33 bar, in the 0 to 10 cm, 10 to 20 cm and 20 to 40 cm soil layers, highest under no-tillage, and lowest under conventional tillage (Fig. 2). Under no-tillage in those soil layers and a pressure of 0.33 bar, the values are 48.4, 22.8, and 16.1% (respectively) higher than under conventional tillage. The highest value of available water capacity under no-tillage was measured at a depth of 0 to 10 cm, while under conventional tillage, it was observed at a depth of 40 to 60 cm.

B. Water Availability

During March 1981, the values of available water under conventional tillage were always less than 30% in the soil layers of 0 to 10 cm, 10 to 20 cm, 20 to 40 cm. In the conventional tillage treatment, the level of available water was 18% (0 to 10 cm) and 10% (10 to 20 cm) below wilting point while there was 20% to 70% available water for plants in the no-tillage plots.

In order to learn about the unfavorable moisture conditions under conventional tillage when compared to direct drilling and to chisel plowing in the rainy year of 1980/81, the values of the 20 to 40 cm depth during the ripening phase of soybeans have to be analyzed. This soil layer is less

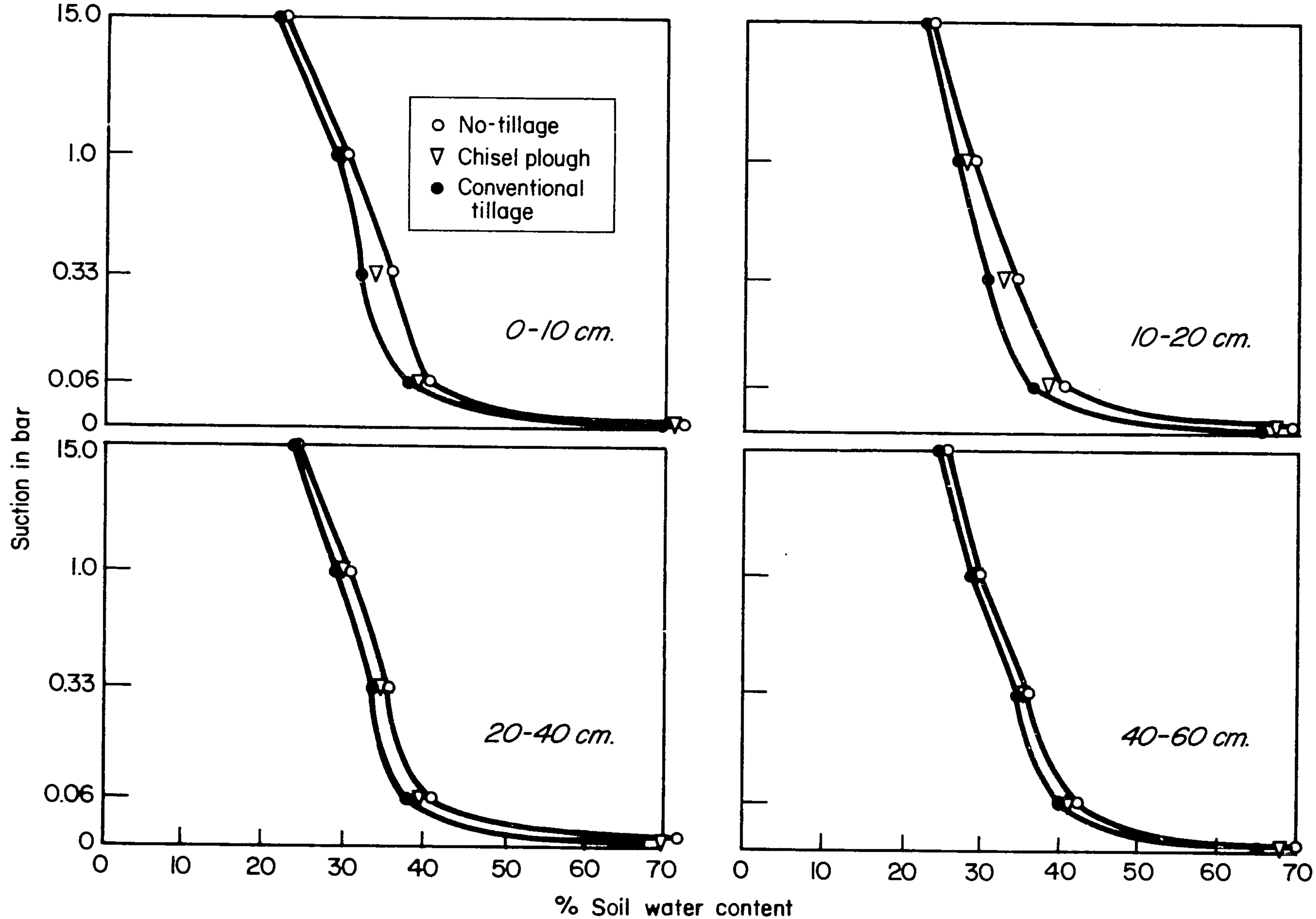

Fig. 1. Water content at different soil depths and different suctions (pF) after 4 years of conventional tillage, chisel plough and no-tillage (Oxisol, Londrina).

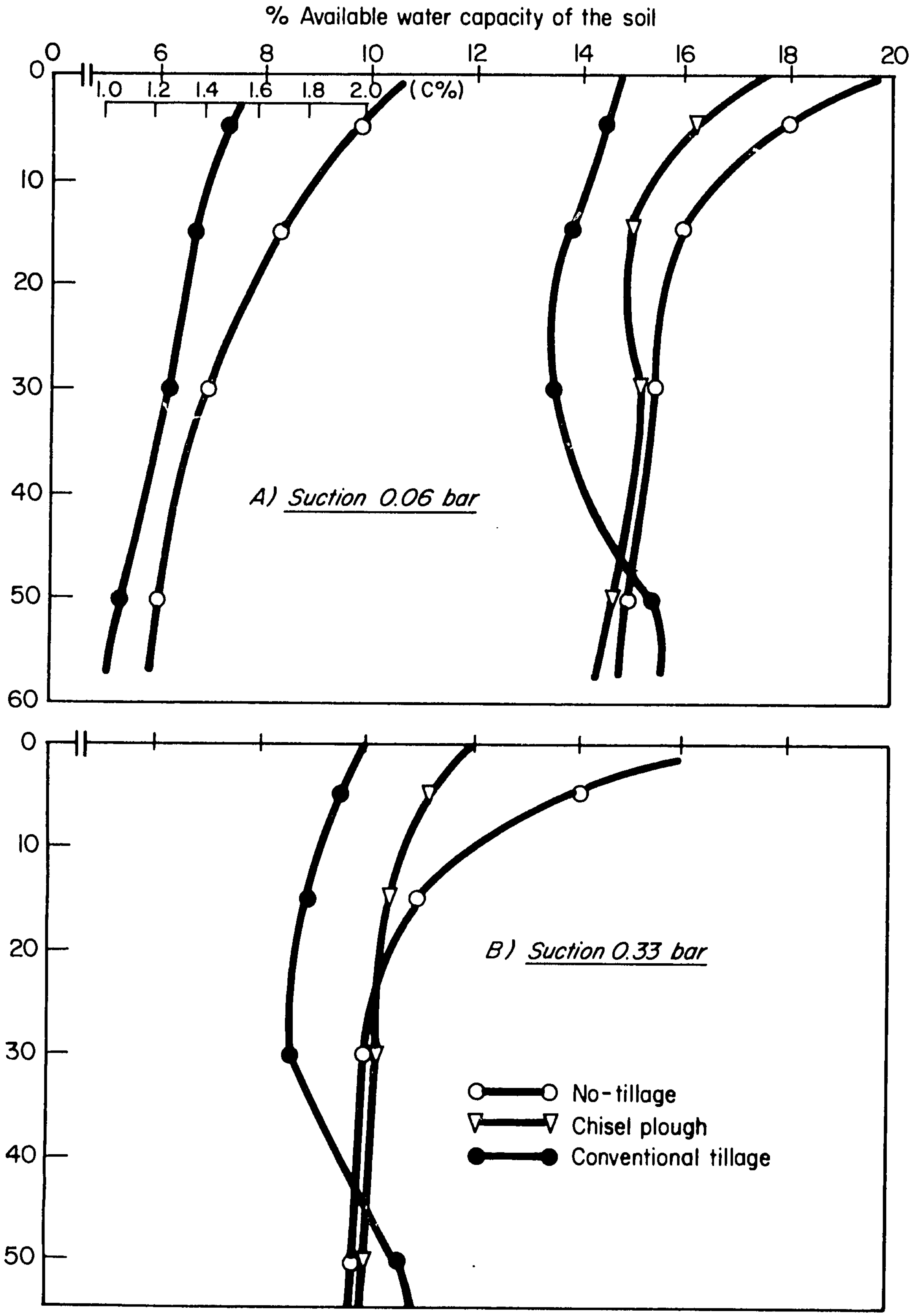

Fig. 2. Available wa... capacity of the soil at suctions of 0.06 and 0.33 bar after 4 years of conventional tillage, chisel plough and no-tillage. (Oxisol, Londrina).

exposed to the environment; the lowest value of available water capacity was found here on 16th March and the highest on 23rd February. The measurements were 47% and 111% for no-tillage, 40% and 105% for the chisel plow treatment, and only 11% and 90% for conventional tillage respectively. Only in the depth of 40 to 60 cm did the values of available water stay over 50% in the three tillage treatments throughout the whole vegetative period of soybeans.

C. Water Erosion Under Different Tillage Systems

Erosion measures using the rainfall simulator in the year 1975/76 showed soil losses of 2.1 t/ha under no-tillage, while on conventional tillage losses reached 7.4 t/ha. In the year 1978/79, losses were 1.1 and 7.5 t/ha respectively (Table 4). Soil losses were reduced in the first year by 72% and in the second year by 85%. Erosion losses were generally smaller during the wheat than to the soybean growing period. In the less erosive time of the year, erosion could be reduced with no-tillage by 30% in the year 1975/76, and 33% in the year 1978/79 in comparison to conventional tillage.

The amount of crop residues that have been left on the soil surface also has a great influence on soil and water losses (Table 5).

When 3.4 t/ha of wheat straw covered the soil surface, water runoff losses were reduced by 12% and soil erosion by 48% in comparison to the plot where straw was burned. Water and soil losses were reduced by 48% and 76% respectively when 5.3 t/ha straw were left on the soil surface.

D. Yields of Soybean Under Different Tillage Systems

As seen in Table 6, soybean yields were significantly higher under no-tillage and the chisel plow treatment than in conventional tillage, except in 1980/81. The 3 year average yield of soybeans under no-tillage was 33%, and under chisel plow 10%, higher than the conventional tillage. The increased yields are a result of plant population (r=0.74**), but mainly of the 1000 seed weight (r=0.84**). The number of pods per plant, as well as the number of seed per pod, did not correlate with the yields in this experiment.

Table 4

SOIL LOSSES UNDER DIFFERENT TILLAGE SYSTEMS AND CROPS USING A RAINFALL SIMULATOR

treatments	soil loss 1975/76 (t/ha)	(%)	1978/79 (t/ha)	(%)
Soybean, conventional tillage (previous wheat crop also conventional tilled)	7.4	100	7.5	100
Soybean, conventional tillage (fallowed previous to soybean)	-	-	1.3	17.3
Soybean, direct drilled (previous wheat crop, direct drilled)	2.1	28.4	1.1	14.7
Wheat, conventional tillage (previous soybean crop conventional tillage)	4.7	100	3.0	100
Wheat, direct drilled (previous soybean crop direct drilled)	3.3	70.2	2.0	66.7
Bare soil	103.0		97.4	

Note: soil losses are the total erosion losses during the whole vegetative period and after harvest, including the following growing stages: I - sowing to 30 days; II - 30-60 days; III - 60-90 days, and IV - after harvest.

Table 5

WHEAT STRAW INFLUENCE ON SOIL AND WATER LOSSES

treatment	soil losses (t/ha)	(%)	water runoff (mm)	(%)
All straw burned	6.45	100	14.8	100
3.4 t/ha straw left	3.34	52	12.0	88
5.3 t/ha straw left	1.53	24	7.0	47

(Vieira, M.J., IAPAR, Londrina)

Table 6

SOYBEAN (GLYCINE MAX. MERR.) YIELDS UNDER DIFFERENT TILLAGE SYSTEMS ON AN OXISOL (14% MOISTURE)

years	no-tillage	chisel plow	conventional	mean
	(kg/ha)			
1978/79	1964**	1509*	1369	1614
1979/80	3088**	2875**	2438	2800
1980/81	2727**	2062	2037	2275
mean	2593	2149	1948	

* p = 0.05 (statistically significant in relation to conventional)
** p = 0.01 (statistically significant in relation to conventional)

DISCUSSION

Several workers have reported that organic matter content of the soil tends to increase under no-tillage and to decrease when the land is plowed (Kahnt, 1971, 1978; Lal, 1975, 1979; Probst 1976; Richter 1965). The improvement of the available water capacity of soil in the no-tillage system and chisel plow cultivation can be explained by the organic matter increases in the soil. In the conventional tillage treatment, on the other hand, significant correlations could not be found, and this is attributed to the small differences in organic matter content between the topsoil and the subsoil layers.

The highest value of available water capacity was found in no-tillage plots at the depth of 0 to 10 cm and in the conventional tillage treatment at the depth of 40 to 60 cm (Fig. 2). In the first case, this could be due to the higher C content (1.95% which was the highest value in the topsoil) and in the case of conventional tillage, probably because of the higher clay content of the subsoil (74% clay in 0 to 10 cm and 81% clay in 40 to 60 cm; 1.48% C in 0 to 10 cm and 1.18% C in 40 to 60 cm).

Greater soil protection against water erosion occurs in no-tillage; the reduced hazard of erosion can be attributed to:

i. presence of plant residues on the soil surface that protect the soil aggregates from direct impact of raindrops (reduction of soil splashing, disaggregation, and sealing of soil pores);

ii. presence of surface residues that slow water movement down the slope; small dams and basins are formed increasing infiltration time in the soil, decreasing runoff velocity, and thus reducing the erosive power of runoff water;

iii. higher structural stability of the topsoil layer (soil is not loose and crumbled);

iv. increase in field capacity of the soil more water can be stored by the soil.

Under the progressive erosion, as it occurs in the case of conventional tillage, (Benatti, et al., 1977; Harrold, 1972; Phillips, et al., 1980), the soil has a tendency towards more extreme moisture conditions, especially in dry periods. This can be attributed to its lower organic matter content and to its unsatisfactory unsaturated permeability, i.e., the lower capillary water movement to the soil surface in conventional tillage, when the soil is too loose (Ehlers, 1977; Hartge, 1978; Johnson, 1978; Sidiras, 1978).

The influence of higher moisture content in the no-tillage and chisel plow treatment, in comparison to conventional tillage (Blevins, et al., 1971; Kemper, et al., 1981) has a positive effect on the number of plants/m² and also on the 1000 seed weight. This was especially evident in the year 1980/81 when a drought period occurred at the end of February and in the beginning of March. In this part of the growth period, the transport of assimilates to the soybean seeds took place. The plants under conventional tillage had matured and lost all green leaves by the beginning of March, while plants in the no-tillage plots still had 10 to 20% green leaves. This fact perhaps could have negative effects on yields of soybeans in years of high rainfall during the ripening phase.

Under no-tillage, the correlation between yields of soybean and rainfall in March was not significant, probably because of the relatively greater water content of the plots in March under this treatment.

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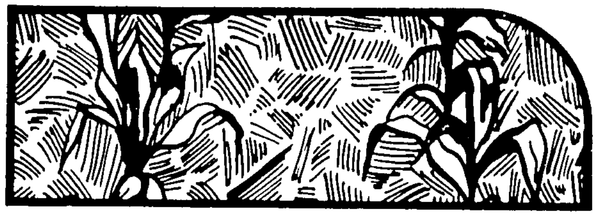
Section IV
Equipment for no-tillage crop production in the tropics



PLANTING EQUIPMENT FOR NO-TILLAGE CROPPING IN THE TROPICS

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INTRODUCTION

Over the last decade many names have been ascribed to the system of cropping where weeds are eliminated using herbicides and seed is placed in a planting hole or a narrow slot or furrow in untilled soil. These include, no-tillage, zero tillage, direct drilling, direct planting, and spray-seeding.

Frequently plant residues from the previous crop or fallow vegetation, are left on the soil surface as a mulch. In many parts of the tropics, this plant residue cover can be largely responsible for the benefits often ascribed to eliminating soil movement.

In this paper the term "no-tillage" is used and, unless otherwise stated, assumes that plant residues are present on the soil surface. The term "planter" is used for implements which plant, sow, or drill seed into the ground.

Improved systems of no-tillage are now widely recognized as offering several important benefits to farming, particularly in the tropics (Greenland and Lal, 1977; Hayward, et al., 1980). The benefits attributed to the system reported include reduced soil loss and run-off, improved moisture retention, lower soil temperature, improved weed control and crop growth, reduced fuel consumption, timely sowing, and ultimately a more flexible and appropriate system of cropping for tropical soils which are highly erodible and difficult to manage.

The equipment employed in no-tillage varies widely and can include sophisticated sprayers and planters together with ancillary equipment such as straw choppers fitted to combine-harvesters. However, in some small-farmer agriculture, it can be as simple as requiring only a hydraulic knapsack sprayer and a sharpened stick.

SUCCESSFUL GERMINATION AND CROP GROWTH

The basic requirements for crop seeds to germinate can be stated simply as adequate moisture, oxygen, appropriate temperature, and the absence of toxic substances. For successful emergence and continued vigorous crop growth, again adequate moisture and oxygen are required with the necessary supply of nutrients and the absence of critical physical barriers to either seedling emergence or to root extension.

Arnon (1972), writing about seedbed preparation in dry regions, comments on the desirable nature of the seedbed to satisfy the requirements of the germinating seed, and points out that these demands may be conflicting:

- close contact between seed and soil particles, particularly to facilitate rapid water movement, but not too close to exclude air or moisture movement or to impede root development or seedling emergence through surface crusting;
- free access of air to the germinating seed in view of the high oxygen requirement for germination; and,
- the opportunity to reach the soil surface and light as soon as possible without running the risk of "drying out."

With no-tillage, roots from previous crops and weeds remain _in situ_ and consequently, important physical changes can be identified. Changes in bulk density, pore space distribution, aggregate stability, aeration, drainage, and trafficability, as well as in soil pH, nutrient distribution, and availability are common (Russell, 1977; Lal, 1978). The soil in the planting slot can range from a finely pulverized medium surrounded by smeared or compacted slot walls to a well structured, aerated condition with no compacted barriers to early root-development and, therefore, ideally suited to the seeds' requirements. Thus, the design of the residue-handling and soil-working elements of no-till planters and how, and under what conditions of soil moisture, they are used are important. Little critical work has been done to measure the effects of implements planting seed in untilled soil, particularly in the tropics, and the subject is complex.

THE REQUIREMENTS OF A NO-TILLAGE PLANTER

No-till planters generally are required to perform two major functions which differentiate them from conventional equipment used in loose, cultivated soil: cut or displace surface residues; and, open a hole or slot suitable for planting seeds in undisturbed soil.

Several other common planter functions are often more difficult to achieve in undisturbed soil: place seeds at a uniform depth; cover the seed with soil; and, firm the soil around the seed without over-compacting or inducing surface crusting.

The functions of residue cutting or displacement and slot or hole formation (on occasions, seed deposition) can be performed by several devices, e.g., tines, blades, or disks. Conditions vary widely, however, and the differences in farm size, topography, cropping pattern, soil conditions, and surface crop residues make it difficult to conceive of one implement that meets all needs. Combinations of devices often provide the best solutions.

CATEGORIES OF NO-TILLAGE PLANTER

Machinery can be conveniently, though somewhat arbitrarily, grouped according to the farming system and the degree of mechanization. The range extends from small-scale manually worked units of often less than 1 ha to large-scale, fully mechanized operations covering many thousands of hectares.

A. Small-Scale Manual Systems

Planting equipment ranges from the traditional pointed stick, or hand hoe planting methods, through the more recently devised rolling injection planters initially developed and promoted by the International Institute of Tropical Agriculture in Nigeria (Wijewardene 1978) and now produced by several firms.

1. Single injection-planters

Where a pointed stick or a hoe is the only tool used, it must perform both the residue displacement/cutting and hole-opening functions in one operation. Seeds are normally planted by hand and soil firmed over the seed by the operator's foot.

Hand operated (one- or two-handed) mechanised injection planters are commonly used throughout the tropics and particularly in South America. Many models exist only differing in their degree of complexity. All, however, perform the basic functions of displacing residues, opening a hole, and delivering seed through a simple mechanism (normally a slide, but sometimes a rotary plate); the most sophisticated units also will deliver fertilizer. Certain models can be used for no-tillage in their current form, but others require modification to the planting tip-spout to penetrate both residues and undisturbed ground.

2. The rolling injection-planter

An interesting development of the simple injection principle is reflected in the rolling injection planter. The planting spouts are placed at regular intervals on the periphery of a wheel, each point having its own gravity-activated closing device and ground-activated opening device (Wijewardene, 1978). A following press wheel firms soil around the seed.

This rolling planter incorporates penetration opening, planting, and firming functions in one discreet unit. Compared to single injection units, it offers advantages of regular plant spacing, higher work output (under favorable conditions), and ability to be "ganged" for further increased work output.

The concept has several limitations such as: (i) fixed in-line spacing that restricts crop range; (ii) difficulty penetrating hard ground or large amounts of residue; (iii) unsuitability for difficult terrain (e.g., recently cleared, or rocky ground); (iv) greater operating energy requirement; and, (v) higher purchase cost. Availability, repairs, and robustness naturally need to be considered as well.

B. Small-, Medium-Scale Low Power Systems

By introducing power to the rolling injection planter principle, substantially increased work rates can be achieved; this form of no-till planting becomes a possibility for intermediate (approx. 1 to 10 ha) farms, particularly when adapted to animal traction or low-powered (5 hp) tractors. All other principles related to planting are similar to hand-operated models, but the increased weight of the powered unit improves its penetration ability. Excessive wear from usage in abrasive soil appears to represent a potential problem as does blockage by sticky soils where larger areas are to be planted.

The pulled or powered rolling injection unit helps to overcome several other important constraints to the adoption of no-tillage by the small farmer. Now a trailer unit can be added to facilitate the increased transport requirement associated with both the need for additional inputs as well as increased production from the farm. While weed control can be achieved using hand-held or knapsack sprayers, now larger applicators can be fitted to the transporter, facilitating application of herbicides to increased areas.

C. Large-Scale Fully Mechanized Systems

The basic requirements of a no-tillage planter for high technology farming do not differ from those for simpler system. In practice, however, all commercially-available planters for large-scale use cut through crop residues to open up a continuous slot for seed (and often fertilizer) compared with the injection planter which provides intermittent, but regularly spaced planting, leaving the mulch and the soil surface between the seeds in the row undisturbed.

Some major agronomic factors have influenced the design of coulter units for high technology no-tillage over the last 10 to 15 years.

1. The row spacing of the crop being planted

Spacing can vary between 12 cm to over 1 m and the closer the rows, the more difficult the job of straw cutting or displacement, and the more prone the machinery becomes to blockage.

2. The quantity and nature of crop residues

The quantity of residue varies widely. In the U.K., the practice for small grains is to burn straw, an act which greatly facilitates planter efficiency. In Australia, wheat is planted into very closely grazed, sprayed pasture, while in many other regions where soil erosion and water loss from the surface are problems, large quantities of residue are maintained. The type of residue, the length of the straw (chopped or unchopped), the residue's condition (standing stubble or a thatched mat), its moisture state, and the state of decomposition greatly influence the performance required of a no-till coulter.

3. Soil type and surface condition at planting

In some situations, soil build-up on cutting units, planting units, and press wheels can pose a significant problem, while abrasive or rocky soils can promote excessive wear and damage. Hard soils are difficult to penetrate, while a soft surface reduces the cutting efficiency of disks and tends to encourage deep planting.

Uneven soil surfaces involve problems of following the contour to ensure constant depth of seed placement.

Soil conditions around the seed are important; the poorer the state of the soil before planting, the more critical it is for the coulters to alter this condition in favor of efficient germination and early growth. Equally important and highly relevant, favorable soil conditions which exist preplanting must not be destroyed or altered to adversely affect germination and crop growth.

4. Soil structure

Not all soils are suitable for no-tillage. Where the limitation is compaction, either natural or as a result of previous practice, special provisions can be made for breaking the compacted layer to promote rooting and improved moisture conditions. Under certain circumstances, this requirement can be incorporated into the design of the planter.

5. Requirement to place fertilizer

The need to use planters to also apply fertilizer depends upon the crop grown, the level of fertility, and the ease with which appropriate equipment can be obtained or designed. No-tillage planters have been developed that place fertilizer in a band below, and adjacent to, the seed while in other cases, the complexities of design required to provide this facility outweigh the value of the yield response. The practical choice is often either to broadcast fertilizer or to trickle it in front, or to the side, of the seed placement unit.

MECHANISMS FOR CUTTING OR DISPLACING SURFACE RESIDUES AND OPENING A PLANTING SLOT

A. Disks

Disks of one form or another are the most commonly used device in no-tillage for cutting through crop residues and opening seed slots. The type of disk and its setting affects its ability to: cut crop residues; penetrate; maintain slot width; disturb soil; create favorable soil conditions in the slot.

Residue cutting is influenced by both the quantity and nature of the biomass and by the surface condition of the soil. For efficient cutting, all forms of disks require a firm surface to prevent straw merely being folded into the slot. The smaller the disk, the greater the penetrating ability; but, below a certain diameter, blockage due to residues becomes a problem.

Disks used in commercially available no-tillage planters range from straight (single or double) entire, straight notched, rippled (fluted), convoluted, and dished. Straight (i.e., flat) disks require less weight for penetration compared with other discs, open up a narrow slot, and minimize soil disturbance.

Cutting can be improved, where high levels of residue and soft soils prevail, by notching (or scolloping) a straight disk. By replacing a straight disk with a convoluted or wavy disk, residue cutting, slot opening, and soil disturbance characteristics are altered as the width of the convolution increases. Use of a convoluted disk increases weight requirements, slot width, and soil disturbance. Residue cutting varies depending upon the conditions, but narrow fluting (or rippling) generally improves cutting.

Dished disks possess similar cutting and penetration properties to straight discs. Under adverse conditions, the chances of smearing both slot walls are reduced, although seed placement, cover, and seedling emergence can be inferior.

An apparent limitation of all disks is that they are costly to manufacture, primarily because of the need for sealed bearings for efficient operation. However, often this can be offset by capacity for high work rates, long life, and low maintenance requirements.

B. Narrow Tines (or Chisels)

This type of coulter system was primarily developed as a cheap way of opening slots. By such simple modification as altering working angles, increasing the ground clearance, and tine positioning (stagger), the ability to handle residues was somewhat improved.

Tines offer several advantages over disks. These include improved penetration of hard soils, lower weight requirement if correctly mounted, lower manufacturing costs, and ease of maintenance.

The principal disadvantages of tines compared to disks are their inferior residue-clearing ability, particularly in narrow rows, excessive wear in abrasive soils, and limited ability to follow contour.

C. Rotating Blades or Flails

Considerable success has been achieved by manufacturers in the USA, UK, and Brazil in modifying conventional powered rotary cultivator machines for no-tillage planting by equipping them with seed and fertilizer hoppers and delivery mechanisms. Modifications have involved removing cultivator blades from the interrow areas and reducing the cutting width of the remaining blades to open up a planting slot 2.5 to 5.0 cm wide, thus leaving the interrow undisturbed.

The principal advantages of rotating blades over tines and disks are that, over a wide range of soil and residue conditions, they efficiently cut residues, and that they create satisfactory planting slots. The major disadvantages involve high cost of manufacture and maintenance, high power requirement, lower work output because of narrower width and lower speed of operation, excessive blade wear in abrasive soils, and limited ability to follow contour.

The characteristics of the slot, in any given soil type, can be greatly influenced by the number and positioning of the cutting blades, rotor speed in relation to tractor forward speed, and the shape and section of the cutting blades.

Recently, a newer method employing the rotary principle solely for trash clearing is being developed by engineers in the UK and Brazil. This device uses a light rotating flail to displace residues (with some cutting action) just long enough for the following coulter to open a slot and deposit the seed.

SEED PLACEMENT AND SOIL FIRMING

In keeping with conventional planters, all slot-opening devices employ some form of seed tube to transport the seed from the hopper to the soil slot. The positioning of the tube, and sometimes its length, can determine whether the seeds are consistently positioned in the slot; the most common problem is that soil falls back into the slot before the seed arrives causing undesirable shallow planting, less available soil moisture, and other problems.

Some no-tillage planters require scrapers to pull soil from the sides of the slot to cover the seed. This feature should be avoided if possible as it tends to complicate the planter and contribute to residue clearance and blockage problems.

Press (or packer) wheels are fitted to many planters and a wide range of profiles, widths, and pressures are used. There is no universal rule, but indiscriminate use of press wheels can bring about accumulation of residual herbicides in the area of the seed, can induce surface crusting directly over the seed, and can stimulate weed germination along the "shoulders" of the row by creating a firm weed seedbed. In some soil conditions, however, press wheels are invaluable for breaking up clods along the slot and for improving seed-soil contact. The ideal situation involves access to a range of sensible wheels to meet the soil and crop requirements of a particular agriculture.

CONCLUSIONS

The development of no-tillage planting equipment is in its infancy; there is no ideal planter available to suit all conditions. Many of the machines working today are little more than simple modifications of conventional units that are capable of planting into untilled ground, sometimes through crop residues, but often only within a limited range of conditions. There are two obvious ways forward: the rational modification of existing equipment, which is an obvious and cheaper alternative; and, secondly, the design of completely novel equipment. In order to fulfill these requirements, research workers and manufacturers must adopt a more systematic approach to design and development of no-till planters.

Purpose-built equipment does exist, but there are few examples of creative appropriate design. Until engineers working together with agronomists and soil scientists address themselves more directly to the soil conditions required for efficient germination and crop growth, and how these can be best achieved by equipment working in residue-covered untilled ground, then no-tillage farming, which seems so right for tropical conditions, will not develop as rapidly as it should.

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APPROPRIATE MACHINERY FOR NO-TILLAGE CROP PRODUCTION IN THE TROPICS

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INTRODUCTION

Many scientists are inclined to dismiss no-till cultivation because of problems associated with it. These problems, which include weed control, residue management, appropriate planter, and seedling establishment, can be solved if attention is given to them. Conventional tillage practices can never equal no-till in simplicity, machinery, and man-hours-to-production ratios, or effectiveness of erosion control.

In the words of E.E. Behn (1977), "We have to find a solution and make it work. Our choice is not, 'will it work' or 'will it not', but how can problems relating to residue be solved?" If new problems occur that can be attributed to residues on the surface, we must never say "Plow them under." We must simply go to work on the problem in the same way we would if a man was farming conventionally and had problems.

NO-TILL REQUIREMENTS FOR THE LARGE SCALE FARM

A farm of over 50 ha organized to optimize use of agricultural machinery constitutes a large scale farm in this discussion. Prospects of no-till for this size farm enterprise in the tropics are favorable due to reduced soil erosion, a need for fewer machines and tractors, less labor, greater moisture retention, and several other factors, both known and unknown.

A. Land Clearing

The usual method of land clearing in the tropics removes large quantities of top soil and generally predisposes the soil surface to erosion. No-till planting does not require manipulation of the soil, except for the soil-engaging parts of the planter. This allows stumps and roots to be left in the soil, minimizing soil disturbance during land clearing. However, those stumps remaining in no-till fields can practically destroy those planters not designed to interact with stumps on a regular basis. To protect planters from damage, the soil engaging parts need to have some kind of spring-loaded release mechanism built into them.

The selection of no-till land clearing methods depends largely on the farming practices to be used. Only limited information is available on land clearing methods for the different crop production ecologies found in the tropics. Where post-clearing operations involve soil manipulation tools to relieve soil compaction, stumps and roots must be removed to the depth that equipment will operate. Therefore, land clearing for no-tillage crop production must aim at minimizing loss of top soil. Minimum soil disturbance can be achieved by hand-clearing (slow and costly) or by using a shear blade. The shear blade cuts off trees at the soil surface (Couper, et al., 1981). When the blade is equipped with hydraulic tilting cylinders, it can remove or shear off stumps below the ground surface (Caterpillar Tractor Co., 1974).

Land clearing taking place in the tropics currently often utilizes wrong equipment because of lacking the correct equipment, or not knowing what equipment would be correct. There is a need to develop methods to prevent erosion after improper clearing techniques have been used. Control of erosion could be improved using a cover crop that is easy to establish, covers the ground quickly, tolerates dry conditions, and is easily controlled with herbicides. However, the methods developed to salvage soil after improper land clearing also will help control erosion on land cleared by the best methods.

B. Pre-plant Clearing

In order to encourage microbiological activity (including earthworms) in the top few centimeters of soil, a good cover must be maintained on the surface of the soil to keep it cool and moist (Lal, 1975). Old standing crop residues and weeds may provide sufficient cover. These should not be cut down after harvest when the dry season is approaching. Cutting the standing plant residue and weeds with a rotary mower before the dry season speeds up the decomposition of the residue.

A rough comparison of organic matter above the soil surface on mowed versus non-mowed land has been made at the International Institute of Tropical Agriculture (IITA) (Nwazojie, 1981)[1/]. Two fields which had been under no-till maize in the late season 1980 were used in the study. One field was mowed after harvest and again about one month before planting. The other field was not mowed. The mowed field was nicer to look at, but it had only half as much organic matter on the soil surface (3t/ha) as the unmowed field (6t/ha). Since the original amount of maize stover production was not measured, this leaves a little room for error in these measurements.

When maize stalks are left standing in the field after crop harvest, the crop residue lasts longer in the field than when they are mowed after harvest. Preplant mowing should be avoided if the fallow vegetation can be controlled. However, standing dead vegetation may provide cover for birds and rodents which eat newly planted seeds and seedlings. Small fields surrounded by bush are extremely vulnerable.

C. Herbicide Application

The greatest problem with application of herbicides is proper sprayer calibration (Williams, 1979). Poor sprayer calibration may be caused by not knowing how to calibrate sprayers correctly, using different sizes of nozzles on the same boom (worn or mixed nozzles), and other problems. Frequently encountered sprayer malfunctions include plugged or partially plugged nozzles or screens and pressure variation due to wrong power take off speed, pressure regulator moved from correct adjustment, worn pump, or by-pass valve open.

Sprayer calibration is almost more important than the type of sprayer used. If herbicides are applied unevenly or in the wrong amount, weeds won't be controlled satisfactorily. On the other hand, if too much chemical is

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1/ O. Navazojie - unpublished data.

applied, the farmer incurs unnecessary cost and there may be a residue problem created.

An appropriate sprayer for the large-scale farmer in the tropics is the conventional boom sprayer. It is versatile and usable for all types of herbicide application. Also, clogged nozzles can be easily noted because the spray is visible. The major disadvantages of the boom include a high volume of water used, and the wide variation in droplet sizes. The smaller droplets drift very easily.

Controlled droplet sprayers, which apply 15 to 40 l/ha, are excellent sprayers. While their main advantage is the low volume of water used, their disadvantages include difficulty (for the operator) seeing the spray coming out of the nozzle and questionable effectiveness for no-till in the humid tropics. Other liquid herbicide applicators, such as the rope-wick wiper type of applicator, recirculating sprayers, and electrostatic sprayers, are inappropriate (at this time) for general weed control.

Weed control may not be always successful because of the time and method of application. A farmer needs a back-up system for weed control. The boom sprayer should be equipped with drop nozzles and, where necessary, shields for inter-row directed spraying (post-emergence).

D. Planting

The main problem encountered with no-till planting that relates to the tropics is trash on the soil surface. This situation has led to the development of planters for the small farmer which can plant through trash (International Institute of Tropical Agriculture, 1977). In the temperate zones, progress has been made in the development of no-tillage planters which function well in heavy mulch. Plant residue mulch is known to have a beneficial effect on soil, including weed control. While a certain amount of plant residue is essential, too much trash on the soil surface prevents the planter from penetrating into the soil. Trash may collect in front of soil engaging parts of the planter or where the soil is soft, trash may be pressed into the soil and seeds dropped on top of the depressed residues instead of in the soil. A U.S. agricultural engineer has suggested the use of a chisel opener with a powered rotovator tine on each side to cut heavy trash and prepare a narrow seed bed at the same time.

All planters presently available require that the trash be reduced in quantity or size before planting either by disking to cut trash into small pieces, mowing with a rotary mower at harvest time and then again a month before planting, or burning and letting the weeds and bush regrow before planting (the regrowth is necessary to provide a mulch cover on the soil). These practices are time consuming and energy wasting. The burning and waiting for a regrowth may delay planting, thus loosing one of the possible benefits of no-till (early planting).

SOIL COMPACTION AND EQUIPMENT

Soil compaction can occur when heavy machines work on the land. The most serious compaction occurs when soils have high moisture content as in the case where rains are long enough to allow two cropping seasons per year. Harvesting of first season crops quite often has to be performed when the rains are heavy. If machines are used, compaction will occur. Proper floatation equipment may be a partial answer, but staying off the land when it is wet is best. Growing a first season crop which would not require heavy equipment for harvesting should be investigated.

For continuous no-tillage, it may be necessary to interrupt the system with some practices designed to increase the organic matter content of the soil and reduce compaction such as: introducing a natural or planted fallow for several years; using tillage that inverts the soil and turns under the organic matter on the surface; chisel plowing to break up the soil, but not mix a significant amount of organic matter into the soil; and, using a field cultivator with very shallow sweeps that mix the organic matter just in the surface of the soil leaving the ground partially covered with trash.

NO-TILL REQUIREMENTS FOR THE SMALL FARM

A small farmer can be defined as one who farms 3 to 5 ha using hand tools. The introduction of equipment for the small farmer is extremely difficult. Small farmers will not invest money in machines which provide only a small productivity increase or only slightly reduce the energy required. In order for these farmers to invest in machines, there must be either a significant increase in productivity which will offset investment, or a significant decrease in personal energy input into farming (preferably both). Even when the farmer is convinced of the need to invest in machines, lack of financing limits his ability to change to a machine.

No-till for the small farmer can reduce both human energy and time inputs per unit of land and production. It will allow the farmer to farm more hectares profitably. However, small scale farmers who choose to use no-tillage will have to change their management, a highly developed management worked out over years through practical experience. But with proper presentation of the no-till system, the small scale farmer will make the change.

Government subsidies and a guaranteed supply of the necessary production inputs are probably the most important elements that will influence the farmer's decision to change his system of farming. The small scale no-till system requires land clearing, control of bush regrowth, control of annual weeds with herbicides, planting, and harvesting. Harvesting is included because production may increase so much that the old system of harvesting used on traditional small farms may no longer be able to cope with changed conditions.

A. Clearing the Land

Hopefully, land clearing needs to be performed only once and from thereon, bush can be controlled (within limits) using herbicides. There will be no heavy equipment on small farms to compact the soil. At some point, land probably will have to go back into a fallow. If cover crops are used that can control other vegetation, and be easily controlled themselves, then future land clearing problems would be small. Even if such a cover crop is not available and no-tillage is assumed to increase the length of time land can be cropped before returning to fallow, the problem of land clearing is lessened for the small scale farmer.

The present land clearing methods used by small scale farmers are probably relatively applicable for no-tillage. Some changes might be made to accommodate small hand planters, such as cutting small trees at ground level and killing larger trees (which are usually left standing) so they don't shade the subsequent crops. For the small scale farmer, total clearing of land should not be encouraged; economic trees should not be killed or cut down. There will be no problem operating around stumps and trees with the small hand equipment for no-tillage.

Tools which could be of help to the small scale farmer would be a chain saw for cutting trees (other than palms) and a hand winch that would facilitate pulling down palm trees. This type of equipment possibly would not be owned by the small scale farmer, but by a land clearing contractor.

B. Control of Annual Regrowth

Using conventional tillage, the small scale farmer can not clear the bush regrowth annually on areas large enough for small commercial farming which no-till will allow him to do. Hand cutting of regrowth each year before planting is time consuming and expensive. Small scale farmer-owned machines for this purpose are not feasible as maintenance and cost are too high. Management practices, such as cover crops or herbicides, will have to be developed to help the small farmer keep the land in a state that does not require clearing before planting.

1. Weed control with herbicides

The present methods of applying herbicides suitable for small scale farming are: using a knapsack or a controlled droplet applicator (CDA). The former is widely used and its operation and maintenance are better understood than the newer controlled droplet applicator. However, the latter has the advantage of a low liquid application rate per hectare. It works well with preemergence herbicides and systemic herbicides. Its effectiveness with some contact herbicides seems to be questionable under conditions which exist on the small scale farm. These sprayers are electrically operated and this creates a new dimension for maintenance which is not understood in the rural areas. Corrosion of the motor and bad electrical contacts are common problems associated with poor after-use cleaning of CDA equipment.

2. Safety in chemical application

Most CDA units have one thing in common: herbicide is applied in front of the operator who immediately walks through the sprayed vegetation. Many small farmers do not have, or will not wear, boots to protect themselves. One CDA sprayer is held behind the operator, but if he has a reasonable walking stride the back of his foot will be sprayed. One firm has been working with a CDA boom sprayer which is mounted on a single bicycle wheel and pulled behind the operator; if placed far enough behind the operator it would eliminate the problem. It is necessary to develop a boom sprayer for the small scale farmer, as it increases his output and reduces the spray skips caused by insufficient overlapping. This could be a 4-meter boom carried behind the operator, attached to the sprayer, thus eliminating walking through sprayed surfaces.

The small scale farmer needs safe chemicals to use. Paraquat, in its present formulation, should not be sprayed with the CDA. Also, sprayers should be cleaned after use and herbicides should be used at recommended rates and times of application.

Ideally, chemicals need to be packaged in containers which hold the amount of chemical to be put into a sprayer tank. This would reduced the chances of operators being contaminated with concentrated solutions. At the same time, sprayer tanks need to be standardized to accommodate standard amounts of chemical.

C. Planting

All presently available hand pushed planters for no-tillage are patterned after the rolling injection planter (RIP). The original concept of this planter was conceived by George Banbury in 1977. There are a number of punch planters which may work well on no-tillage, although most of them have very wide openers and do not plant properly in heavy mulch. A narrow opener, as designed at IITA in 1979, works better on heavy mulches. The rolling injection planter looks promising. It has now been developed to a stage where manufacturers can produce it with the confidence that it will work.

Variations in stand establishment when using the RIP have been noted by many IITA scientists. Stand establishment is known to vary from 30% to 90% with no apparent reason. In addition to possible damage by birds and rodents, reasons for poor stand establishment could be poor soil contact by seed, failure of seedlings to push through the mulch cover, pre-plant herbicides, depth of planting, soil-borne insects, and molds. These factors are now under investigation. Preliminary results show that when carbofuran (0.5 kg/ha) was applied at planting time in no-tillage maize, stand was much better and the maize plants were noticeably bigger than in plots that received no carbofuran. However, there was a large number of dead earthworms on the soil surface where carbofuran was applied. Similar observations have been made by other workers.

CONCLUSIONS

If no-tillage is adopted by the small scale farmer, the principle of the RIP will be used for planting. If a farmer owns a single row, rolling injection planter, a CDA or knapsack sprayer, and a fertilizer applicator, he can easily handle between 3 to 5 ha of no-till maize. The major constraint for this farmer will be harvesting. Using a small, 2-wheeled tractor, or pair of oxen pulling a trailer with four rolling injection planters mounted on a tool bar in front and a boom sprayer mounted on the back, a farmer (with his family) should be able to handle 10 ha of no-till maize.

The use of a walking tractor-trailer combination will require more land clearing than when hand operated tools are used. In the no-till system, small trees must be cut off at ground level and only a few large trees can be left in the fields. The farmer using such a system with the two-wheel walking tractor could also have a mower in front of the tractor to cut crop residues and weeds before planting.

Although problems still exist in no-tillage crop production, the prospects for small scale farmer adoption of this system are good. In order to make this system more attractive to farmers, additional work needs to be done in land clearing, crop rotation, planting equipment, sprayers, harvesting equipment, and soil management practices. This will make it possible to crop tropical soils intensively.

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ENERGY CONSUMPTION IN A NO-TILLAGE SYSTEM TO PRODUCE SOYBEANS

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INTRODUCTION

The evaluation of energy consumed in the production systems of the major crops barely has been studied. The energy crisis has guided most research efforts toward finding new alternative fuel. Therefore, the search for rational ways of saving energy by changing traditional systems has been neglected.

The calculation of energy consumed by a crop production system is not easy because of the many factors involved: the cost of the energy to operate farm equipment; the costs to manufacture, transport, and apply pesticides and fertilizers; the energy value of fuel consumed; and, the energy released by human labor. Fuel consumed by machinery working on a given crop depends on factors such as climate, topography, soil type, field size and shape, operator's ability, etc. Hence, it is difficult to calculate the exact amount of energy required by any system. However, there is increasing demand for such information and the research institutions have to improve the methods of estimating the energy requirements for agricultural machine operation and production systems.

The literature includes results of surveys and models developed to estimate energy consumption from machine operations and systems. Christenson (1977), studying the energy input and output of several production systems, considered energy consumed in the following operations: soil tillage, seeding, cultivation, production, application of pesticides and fertilizers, harvesting, drying, and transportation to market. He did not consider transportation of fuel, equipment, and chemicals to suppliers, manufacture of equipment, travel for repairs, shopping for equipment and supplies, and energy used to produce lubricants, tires, batteries, and other maintenance items.

On the other hand, White (1974) developed a three-column table which estimates low, average, and high fuel requirements, on a per area basis, for most farming operations. This table permits estimation of fuel consumed fairly closely since the data is complemented by additional information about tractor power and loading capacities.

Shelton, et al., (1979) reported on a study where 100 farmers from Kansas and Nebraska (U.S.A.) helped identify fuel consumption required for several operations to grow the main crops of those states. The results showed that tillage operations, such as plowing, disking, chiseling, and cultivation, were responsible for 35.5% of the total energy consumed. In a similar study, conducted in Michigan (U.S.A.), Robertson and Mokma (1978) found considerable fuel savings when tillage operations were suppressed. They further reported that increasing diversification of soil tillage operations, to grow the same crop, made it possible to identify one tillage method as the standard.

There are many surveys that show high fuel consumption for conventional tillage operations used to incorporate crop residues and to prepare the soil to gain optimum seed germination and root development.

The amount of consumed energy varies according to the size of tractors and implements, type of soil, number of operations, and other factors. Therefore, alternative systems suppressing one or more operations, like plowing, are under study and have already been adopted by many farmers. Lane, et al., (1973), for example, found reductions of around 50% in energy requirements for tillage, planting, and harvesting operations of reduced tillage systems when compared with conventional ones which involve plowing.

No-tillage systems present the best results in terms of fuel saving. The U.S. Department of Agriculture, according to Phillips, et al., (1980), estimated that 1.6% of U.S. cropland utilized no-tillage in 1974 with an expected 45% by the end of the century. At that time, 65% of the seven major crops in that country will be grown through no-tillage systems. In Brazil, Wiles and Kievit (1978) studied field performance of machines and compared respective fuel consumption in no-tillage and conventional systems. The results showed substantial savings in time and fuel when using no-tillage systems.

MATERIAL AND METHODS

The main objective of this study was to compare no-tillage with two systems, from the point of view of fuel and energy consumption and economical returns. It was conducted on single crop--soybeans--and began with the 1978/79 cropping season. Three tillage systems were investigated: conventional tillage (System I); reduced tillage (System II); and, no-tillage (System III). Table 1 compares operations.

Table 1

THREE TILLAGE SYSTEMS

	system		
operation	I	II	III
area	.64 ha	.78 ha	.75 ha
plowing	disk	-	-
harrowing (first)	offset disk	offset disk	-
harrowing (second)	offset disk	offset disk	-
apply herbicides	yes	yes	yes
harrowing (third)	offset disk	offset disk	-
planting/fertilizing	yes	yes	yes
apply insecticides	yes	yes	yes
harvest	combine	combine	combine

The data suggested by Christenson (1977) were used for estimating the energy values of fertilizers, pesticides, diesel fuel, and soybean seed. The energy for manufacturing, transporting, and repairing of tractors and implements was estimated by the Bridges and Smith (1979) method.

Fuel consumed during the operations was measured. The energy balance was obtained by dividing energy output (energy value of the soybean seeds produced) by the total energy input. In order to determine each system's energy costs, production costs were divided by the total energy input.

Table 2

AVERAGE FUEL CONSUMPTION FOR 2 YEARS

system	fuel consumed (1/ha)	energy values (B.T.V.)	comparative energy use (%)
I	69.8	2,471,242	329
II	48.7	1,724,542	229
III	21.2	751,655	100

RESULTS AND DISCUSSION

Table 2 shows that, for a 2-year average, conventional and reduced tillage systems required 3.29 and 2.29 more fuel than the no-tillage system.

The other comparative parameters for the three tillage systems studied are presented in Table 3. Column A shows operational costs: these include depreciation, interest, insurance, maintenance, repairs, and labor. Column B shows fuel costs. Column C includes the cost of herbicides, insecticides, fertilizers, and seeds.

Fuel cost is relatively small when compared with the other costs. Even in the conventional system, which consumed more fuel, diesel cost was less than 13% of other input costs. However, the energy value of fuel is greater

Table 3

PRODUCTION COSTS AND ENERGY RELATIONSHIPS FOR THREE SOYBEAN TILLAGE SYSTEMS

year	system	A costs operational	B diesel*	C other	D energy input	E output	F balance	G product costs / energy input
		(U.S.$		)	(million B.T.U.)		(E/D)	[(A+B+C)/D]
1978/79	I	26.19	11.47	93.65	4.412	21.690	4.92	29.76
	II	17.94	7.15	93.65	3.438	19.407	5.64	34.54
	III	13.20	3.45	132.59	2.690	15.677	5.83	55.48
1979/80	I	30.27	12.89	102.67	4.917	23.805	4.84	29.66
	II	25.54	9.84	102.67	3.617	21.005	5.81	38.17
	III	15.00	3.96	118.22	3.008	23.607	7.85	45.60

* Diesel cost = US$ 0.1745/liter.

than that of pesticides, fertilizers, and seeds. Column D shows total energy input per system. It is evident that the no-tillage system used the least amount of energy.

Column E shows the energy output based on the soybean seeds produced per hectare in each system.[1/] To get the soybean yields for each tillage system in kg/ha, the values in column E must be divided by 7,610.4 BTU. The energy balance is in column F. The no-tillage system presented the best energy balance, mainly in the 1979/80 crop, where 7.85 units of energy output were obtained for each unit of energy input. However, column G shows that the energy price in the no-tillage system was higher than the others. This was caused by the high energy prices included in other costs, mainly the herbicides which were used in substantial amounts in the no-tillage system.

Figure 1 presents a visual comparison among the total energy consumed by each of the three tillage systems and depicts the small percentage of energy related to fuel when compared with total energy input in no-tillage system.

CONCLUSIONS

Although no-tillage in Brazil is still in its early stages, results of this study indicate that it is the most economical tillage system, especially in regard to the volume of diesel fuel consumed. Conservation of fuel is an important advantage for no-tillage. Also, the energy balance (in the no-tillage system studied) was superior to other systems investigated. This suggests that no-till systems are capable of making the most efficient use of input energy resources.

The relation between production costs and energy input, however, showed that the energy cost of the no-tillage system was the most expensive, caused by the high cost of herbicides. This fact, added to the sophisticated technique needed for manipulating herbicides, and the lack of information about no-tillage practices, have limited its adoption by Brazilian farmers.

1/ Energy value of soybean seeds is estimated to be 7,610.4 BTU/kg of seed.

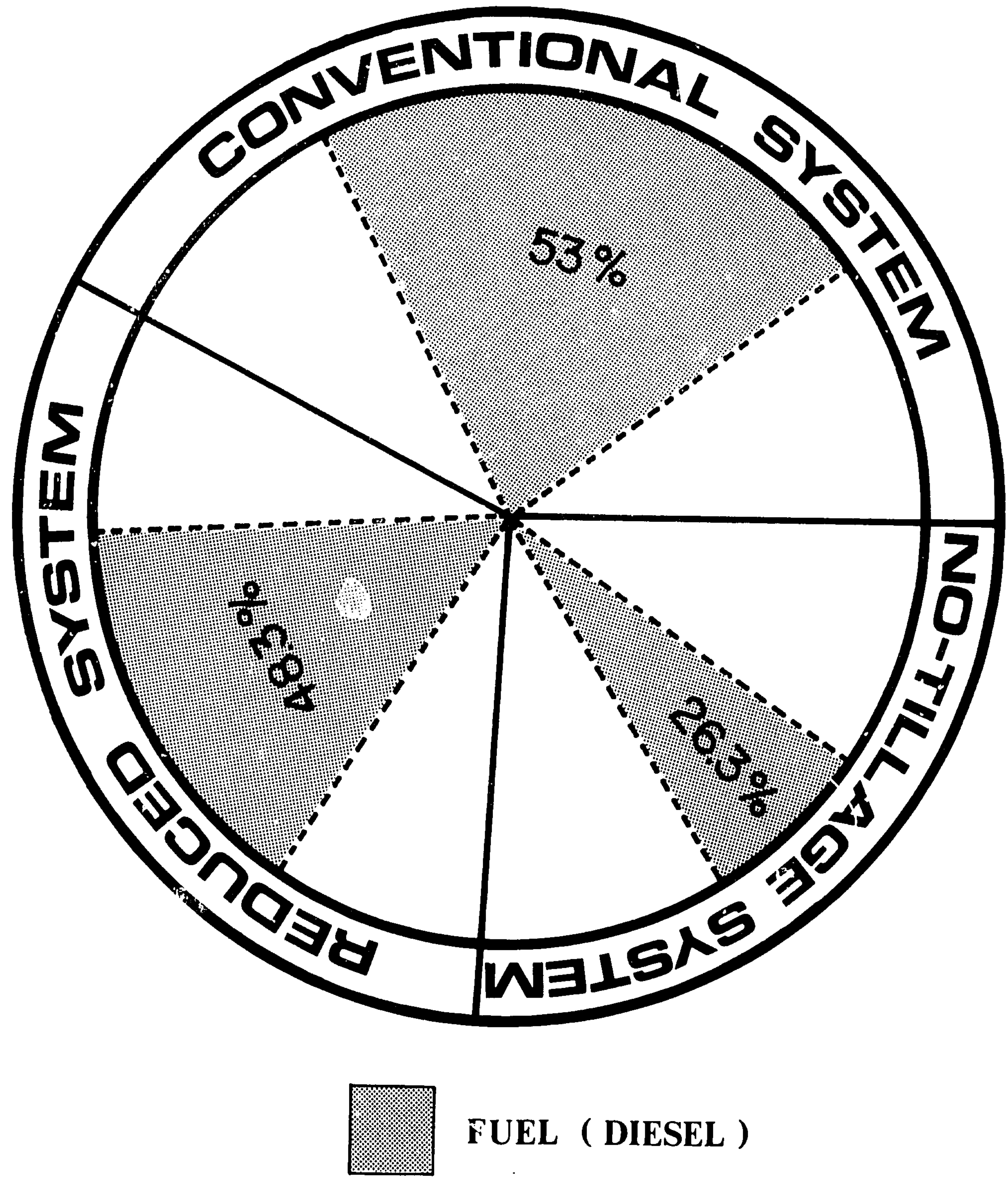

Figure 1. Comparison of average energy consumption within three soybean production systems and the percentage of fuel consumption in each system, for two crops of soybeans.

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Section V
No-tillage technology transfer in the tropics

EFFECTS OF PLOWING AND MINIMUM SOIL PREPARATION IN SENEGAL, IVORY COAST, AND TOGO[1/]

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SUMMARY[2/]

Most of the cultivated fields in Senegal have deep sandy and sandy-clay soils. There is only one rainy season which is very short. No-tillage soil preparation is widely practiced by traditional farmers.

Over the past 30 years, many experiments have enabled researchers to establish a line of comparison between the results obtained from no-tillage and conventionally tilled plots. Results have indicated that plowing increases crop yield by improving soil conditions (physical conditions and biological activities) and enhances moisture retention of the soil while promoting root-system development.

A more sophisticated method of soil preparation, consisting of minimum-tillage with added straw mulching, also has been tried out. In spite of a

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1/ "Comparison des effets du labour et du travail minimum du sol au Ivory Coast, et au Togo."

2/ Summary of the original paper.

few favorable results, mostly on increased water-retention potential, crop yield generally has been inferior to that obtained in plowed fields. Procurement of straw mulch and handling are among the difficulties encountered with no-tillage practices (involving use of straw mulch).

The oxen-pulled plowing method, preferably with over-turn of manure or straw, appears to be, at this time, the most effective method of soil preparation suitable to the sandy soils of Senegal. However, in other ecological zones of West Africa, studies made by IRAT experts indicate that other forms of minimum-tillage soil preparation show promising results. There is, therefore, no overall solution which could be applied to large areas.■

EVALUATION OF A NO-TILLAGE WEED CONTROL SYSTEM IN THE ATLANTIC PLAIN OF COSTA RICA AND NICARAGUA

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INTRODUCTION

The final test of the appropriateness of an introduced agricultural technology is its adoption. However, agricultural researchers have little information to help evaluate the appropriateness of a technology before it is introduced, and this has led to low rates of adoption by small farmers in less developed countries due to the inappropriateness of technology.

Two approaches to evaluating the likelihood of adoption of modern weed control technologies in identical ecologies of two neighboring countries--the Atlantic Plain of Costa Rica and Nicaragua--are reported here. Both were conducted by the International Plant Protection Center (IPPC) at Oregon State University through a contract with the U.S. Agency for International Development.

1/ Currently, deputy director, Consortium for International Development.

2/ Currently, agricultural economist, State of Oregon.

3/ Currently, agricultural economist, government of Nicaragua.

The Atlantic Plain of Central America, divided between Costa Rica and Nicaragua, is an alluvial plain with bimodal rainfall and ideal conditions for plant growth. Consequently, weeds are a major agricultural problem. Maize is the principal crop grown in both the early and late production seasons. Most maize is monocropped using traditional, labor intensive production methods.

A. Costa Rica

IPPC, working since 1976, has developed several promising methods for weed control in the North Atlantic Zone (NAZ) of Costa Rica. One method especially suited for small farmers is a no-till mulch system involving use of preplant herbicides. Since this no-till system appeared to be agronomically viable, an approach was developed to transfer the results from experimental plots to farmers who used the typical labor-intensive hand-weed and mulch system found in the NAZ.

To determine the potential effects of the technology on Costa Rican small-scale farmers, a survey of 20 farmers was conducted in 1977 (McCarty, 1979). The sample was drawn from an estimated population of about 1,000 farmers within one province. The survey was designed to obtain in-depth information about specific weed problems, cropping activities, labor use, and other factors related to weed control. A budget (accounting) worksheet was used to obtain cost information for each cultural practice for individual maize parcels on each farm surveyed. Cash costs were separated from non-cash costs. Family labor was reported in hours to permit evaluation by alternative opportunity wage rates.

Introduction of herbicides on small farms in the NAZ involves substitution of capital for labor. This, in turn, led to a shift to greater market orientation for factors of production. Other elements contributing to technology adoption, such as magnitude of cost differential, value of alternative uses for resources, riskiness of crop production, comparative riskiness of technologies, and information requirement, could not be quantified.

The 20 farmers (sample) were divided into groups by level of cash expenditures and family labor use per hectare of maize. Group I farmers utilized typical NAZ farming operations. The weed problem consisted of broadleaves and grasses.

Hand weeding was the dominant weed control method, and required 30 to 50 man-days/ha. There was limited reliance upon purchased inputs.

Generally weeds were cut three times with a machete during the growing season with the residue left on the ground as a mulch. The first cutting of standing weeds was in preparation for planting. Then, the maize was planted in rows through the mulch with the aid of an "espeque" or jab planter. Weeds were cut a second time during the growing season. A third cutting occurred just prior to, or during, the "doubling" of maize stalks at harvest (doubling serves as a field drying and storage practice). Assuming that the value for family labor used in weeding equals the prevailing wage rate, weeding will account for 50 to 75% of total maize production costs.

Group II and III farmers were capital intensive and relied heavily upon purchased inputs. Group II, like Group I, relied heavily on family labor, but additionally, had large expenditures of capital inputs to combat exceptionally difficult weeds. Group III farms faced typical weed problems, but relied almost entirely on purchased inputs, including hired labor. Cash costs typically ranged from ¢1,500 to ¢2,600 /ha* with 60 to 80% attributable to weed control.

The revenues, costs, and returns for each group are presented in Table 1. In Group I, using the existing weed control technology, return on cash costs were positive for all farms, except one. The residual cash return to family labor averaged 19 colones per man-day, which compares closely with the region's wage rate. Wages ranged from 20 to 35 colones per man-day, depending upon the maize production and coffee (Coffea arabica L.) harvest seasons which affect seasonal labor demand.

Group II farms used proportionally larger quantities of purchased inputs, including hired labor, to combat special weed problems. A dense infestation of Rottboellia exaltata was the major problem. Control was attempted using extensive family labor, moderately high amounts of hired labor, and a mixture of paraquat, MSMA, and diuron.

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* U.S. $1.00 = ¢8.54

Farmers in Group III (four farms) expended proportionally large quantities of purchased inputs and utilized relatively small quantities of family labor. All the farmers sampled in this group planted large areas of maize.

In the no-till system involving use of herbicides, IPPC agronomists found that paraquat and glyphosate, when applied prior to planting and matched to specific weed conditions, will serve as effective substitutes for slashing of weeds and still retain the mulch residue. No measureable difference in crop yield between herbicide and traditional mulching was detected.

To translate the agronomic results from the field experiments into the context of each of the 20 sample farms, several simplifying assumptions for budgeting purposes were made:

(1) Glyphosate is recommended for use where heavy stands of R. exaltata or Panicum maximum exist; paraquat is recommended for all other conditions.

(2) The cash cost for paraquat application is 250 colones/ha while that for glyphosate is 500 colones/ha.

(3) Labor (spraying time) required to apply the herbicide treatments is 3 man-days/ha.

(4) Labor requirement when chemical weed control was practiced equalled one-quarter of the hand-weeding labor demand at the preplant phase while post planting labor was eliminated; use of herbicides reduced preharvest weed control found in traditional agriculture by half.

(5) Hired labor was charged at 35 colones per man day, the typical rate paid in the NAZ.

(6) No wage charge was made for family labor; it became the residual unpaid claimant after cash costs were deducted from gross income, thus providing a direct comparison with alternative usage opportunities elsewhere.

A partial budget was used to incorporate the six assumptions into the weed conditions of each of the 20 farmers (McCarty, et al., 1981). The budget calculations under the assumed herbicide treatment technology are presented in the right half of Table 1. A graphic depiction of the results is presented in Figure 1 in the form of a vector diagram.

Table 1

A Preliminary Comparison of Cash Income, Cash Costs, Labor Use and Return for 20 Sample Farms Between Existing and Introduced Weed Control Technology Practices.

		Actual Cash Costs and Labor Use (First Season, 1977)					Estimated Cash Costs and Labor Use with Introduced Weed Control Technology (First Season, 1977)				
Group	Farm	Gross revenue (¢/ha.)	Cash costs (¢/ha.)	Family labor (Man-days/ha.)	Cash income (¢/ha.)	Rate of return to family labor (¢/Man-day)	Gross revenue (¢/ha.)	Cash costs (¢/ha.)	Family labor (Man-days/ha.)	Cash income (¢/ha.)	Rate of return to family labor (¢/Man-day)
I	A	1357	459	52.6	898	17	1357	941	43.2	416	10
	B	1865	441	54.4	1424	26	1865	714	50.7	1151	23
	C	1323	263	44.0	1060	24	1323	565	39.0	758	19
	D	1902	812	54.8	1090	20	1902	1132	52.5	770	15
	E	2169	401	34.9	1768	51	2169	832	31.1	1337	43
	F	1066	308	65.0	758	12	1066	876	58.3	190	3
	G	1379	1021	24.1	358	15	1379	1264	20.3	115	6
	H	1166	180	31.5	986	31	1166	435	26.5	731	28
	I	1808	740	38.6	1068	28	1808	974	30.7	834	27
	J	307	468	54.5	-161	0	307	578	38.3	-271	0
	K	1075	709	29.5	366	12	1075	1027	26.9	48	2
	L	1018	174	71.1	844	12	1018	450	65.0	568	9
	M	424	185	15.7	239	15	424	461	12.3	-37	0
Mean		1297	474	43.9	823	19	1297	789	38.1	508	13
II	N	679	1228	57.0	-549	0	679	1430	55.5	-751	0
	O	549	2465	50.7	-1916	0	549	2443	46.7	-1894	0
	P	1383	1175	130.0	208	2	1383	985	111.5	398	4
Mean		807	1623	79.2	-891	0	807	1619	71.2	-812	0
III	Q	1739	1805	16.8	-66	0	1739	1964	14.8	-225	0
	R	384	1093	0	-709	0	984*	1198	0	-214	0
	S	1413	2080	6.8	-667	0	1413	1802	4.1	-389	0
	T	2499	2636	15.3	-137	0	2499	2160	13.8	339	25
Mean		1509	1904	9.7	-395	0	1659	1781	8.2	-122	0
Sample Mean		1275									

Group I: Cash expenditures are kept low; family labor is the main resource.
Group II: Special weed problems: relatively high expenditures both in cash resources and family labor.
Group III: Capital intensive weed control methods: high cash expenditures; relatively low use of family labor.

*Use of the paraquat treatment on Farm R would have lessened the crop loss due to uncontrolled weeds.

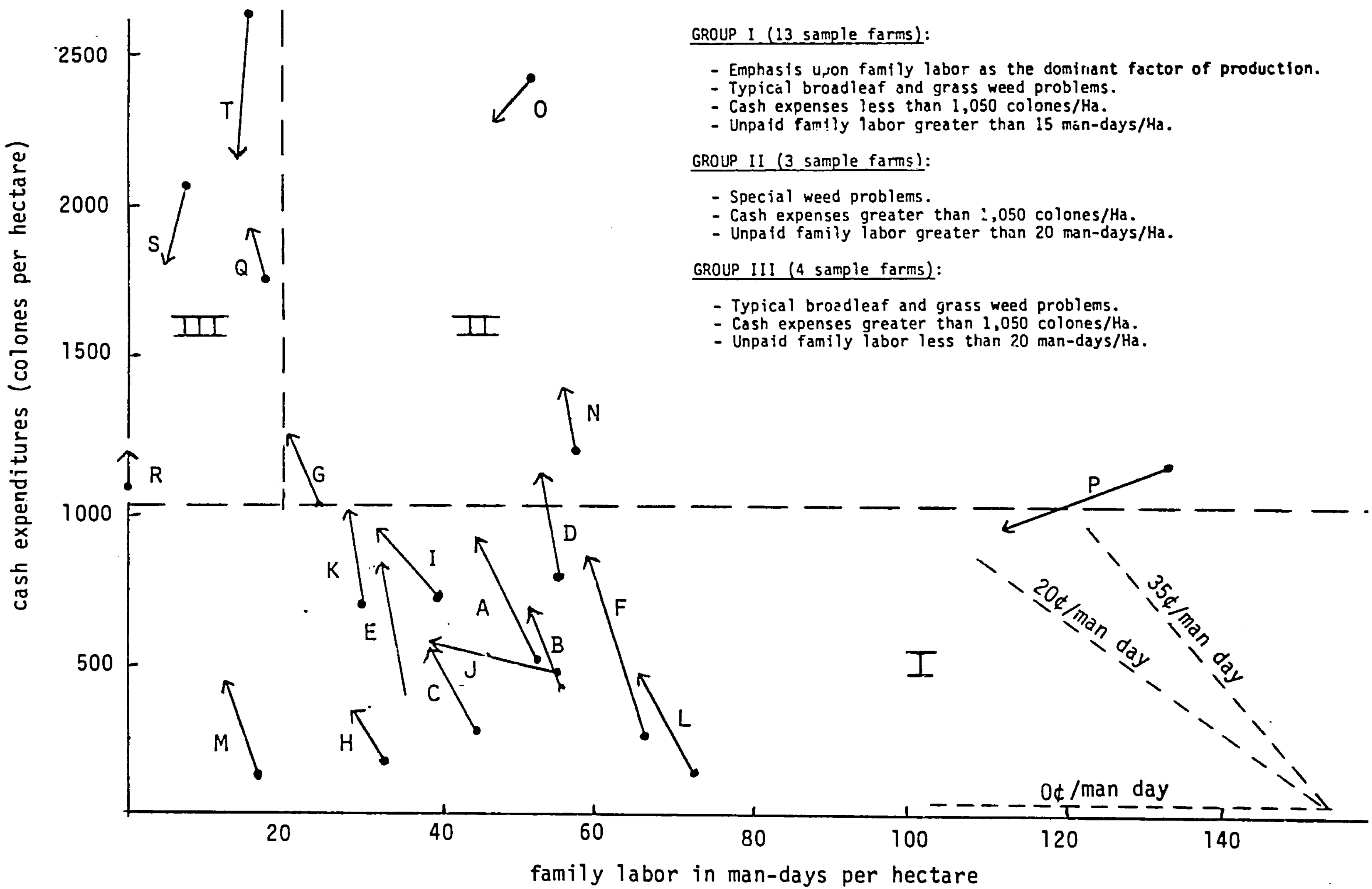

Figure 1. Expected changes in cash expenditure and family labor use levels for first season corn production on 20 sample farms; North Atlantic Zone, Costa Rica, by incorporating selected herbicides into the traditional weed mulching system.

The axes of the graph show levels of cash expenditures in colones and family labor in hours for maize production per hectare. The point of origin of each arrow vector shows traditional "as is" level of cash expenditures and family labor input found with each of the 20 farms. The arrow end of each vector marks the projected or estimated cash expenditures and family labor required if the introduced technology were used. The slope of each vector arrow represents the change in cash used relative to the change in quantity of family labor attributable to the new technology.

For example, with Farm G, an extra 240 colones would be expended on each hectare to save 4 man-days of labor, or an increase in cash expenditures of 60 colones for each man-day saved. If the true value of labor saved in its highest alternative use, other than weeding, is less than 60 colones per day, it would not pay the farmer to use herbicide, when evaluated on purely economic grounds. If the alternative use (opportunity cost) of labor exceeded 60 colones per day, in activities on or off the farm, it would pay to use a herbicide and transfer the labor to its higher economic use. Thus, the direction, slope, and magnitude of each vector provides economic insight into adoption potential of introduced herbicide technology on each of the 20 farms.

Three diagonal wage rays are included in the diagram as relative wage indicators. The slope of each ray represents an alternative use wage rate for family labor. These are rates the family might earn in on-farm work on one's own farm, or that of work on a neighbor's farm, or on a coffee, sugar-cane (Saccharum officinarum L.), or banana (Musa paradisiaca) plantation, or in town. The average annual wage rate for 1979 for NAZ ranged from 20 to 30 colones per day.

Some caution must be exercised in using average annual wage rates, however. Labor demand is often quite seasonal. Whether peak labor demands for other agricultural activities such as coffee, sugar cane, and banana harvest coincide with peak demands for maize crop weeding is not known yet, but is under investigation. If competition for labor between such seasonal activity is strong, the opportunity cost value of family labor rises and provides a further economic inducement for herbicide adoption.

B. Observations

Several general observations can be made from the vector diagrams.

(1) All 20 vectors point to the left. This suggests that incorporation of an herbicide into the mulch system is quite likely to result in savings of family labor in maize production, at least initially.

(2) Most of the vectors point upward, with exception of Farm O, P, S, and T. This suggests that incorporation of herbicide into the mulch system is likely to incur higher cash costs, at least initially.

(3) For Farms A through N, and Q, the vectors point leftward and upward, representing a substitution of cash expenditures for family labor. With exception of Farms I and S, the slope of each vector is greater than the slopes of either the 20 or 35 colon wage rate rays. This suggests that the new treatments, when viewed on a single season basis with no positive carryover effects to subsequent seasons, will increase the total cost of weed control if the opportunity cost value of family labor saved ranges from zero to 35 colones per man-day. In most cases, the value of family labor saved would have to exceed 45 colones per day to make herbicide treatments as cost efficient as the traditional mulch system.

(4) For Farm I, the slope of the vector is 29 colones per man-day, suggesting that adoption of herbicide might be justified on economic grounds if the opportunity cost of family labor in an alternative use to hand weeding were greater than 29 colones per man-day.

(5) In the case of Farm J, it appears that herbicide provides enough economic benefit that its adoption is quite likely since the opportunity cost of the labor saved is only seven colones per day. If the farmer values his labor comparable to the market wage rate, adoption is justified on economic grounds.

(6) Vectors for Farms O,P,S, and T point to the left and down. Use of herbicides in these cases suggest reductions both in family labor and cash expenditures. This situation provides the most likely case for herbicide adoption since definite cost reduction appears to exist. Three of these parcels had heavy infestations of *R. exaltata* or *P. maximum* in which glyphosate appears economically

beneficial, particularly if future treatment is not required resulting in cost reduction for weed control in subsequent seasons. One parcel had light infestations of grasses and broadleaf weeds in which paraquat appeared to be a cost-reducing alternative.

(7) Farm R is a special case. Most of the maize yield was lost, due to a temporary shortage of workers for weeding. While speculative, capability of paraquat to control light infestation of grass and broadleaf weeds which existed on Farm R appears very high. Hence, paraquat probably would have prevented more than enough loss in yield to overcome the small increase in production costs, and hence, the likelihood of its adoption in this case appears high.

C. Nicaragua

As the work proceeded in Costa Rica, a question was raised whether the system, as developed in Costa Rica, had potential for other countries. The South Atlantic Zone of Nicaragua, with a similar ecological zone, but different economic setting, was selected as the investigation site. Prices for agricultural products and inputs are considerably higher in Costa Rica than in Nicaragua (Table 1). Cereal yield has increased by an annual 2.8% in Costa Rica, while declining in Nicaragua by 0.1%. Also, the use of fertilizer and mechanization is very low in Nicaragua.

The adoption potential of the new technologies was estimated by a survey of 42 farms in the Rigoberto Cabezas Project (PRICA) (Cajina, 1981). It was found that the PRICA production pattern was generally similar to the NAZ of Costa Rica although cultural practices in PRICA generally start one month earlier and PRICA farmers do not use a mulch; the fields are burned before planting. Also, while NAZ farmers have experimented with herbicides, no interviewed PRICA farmer had used them. The timing of cultural practices for wet season maize for both areas is shown in Table 3.

Prica farms are larger than NAZ farms on the average (Table 4) although the amount of land used for annual crops in NAZ is twice that of the PRICA area.

Table 2

SELECTED ECONOMIC INDICATORS FOR COSTA RICA AND NICARAGUA

indicator	Costa Rica	Nicaragua
Population (millions) 1979	2.2	2.5
Population in Agriculture (%) 1977	37	45
GNP per capita ($) 1976	1,130	770
GNP growth (%/year) 1970-1976	3.0	2.5
Cereal yield (tons/ha) Avg. 1975-77	1.8	1.1
Annual change: Cereal yield (%) Average 1969-71 vs 1975-77	2.8	-0.1
Fertilizer Consumption (kg/ha) 1976	114	30
Tractor density (number/1000 ha) 1976	12	0.9

Source: International Agricultural Development Services

Table 3

TIMING OF CULTURAL PRACTICES IN WET SEASON MAIZE PRODUCTION

practice	PRICA	NAZ
land clearing	March-April	June
field burning	late April	-
planting	May-June	July
hand weeding	June-July-August	July-August
herbicide application	-	July
preharvest weeding	-	October
harvest	October	November

Table 4

RELATIVE USE OF LAND BY FARMERS

use of land	PRICA	NAZ
average farm (hectares)	34.1	19.2
annual crops (%)		
maize	7.4	31.1
rice (*Oryza sativa*)	2.0	1.0
other	-	4.2
perennial crops (%)	6.6	5.2
grassland (%)	35.5	45.5
virgin and fallow land (%)	48.5	13

To analyze the PRICA data, a linear programming model was developed. It maximizes net income discounted for total costs subject to a set of linear constraints. The constraints were taken from the surveyed data, experimental results from the NAZ (since no experimental data were available in PRICA), and from primary and secondary information provided by Nicaraguan institutions.

Based on family labor availabilities, three types of farms were identified: farms with the availability of one, two, or three family workers in the farm unit. Solutions of the model for each type of farm are constrained by the availability of weed control technologies (traditional and new), and level of capital available for production. The solutions of the model include net revenue, net cash income, system of land use, amount of maize allocated to consumption and sale, storage losses of maize in the storage place, capital use, amount of maize seeds used for planting, herbicide cost, fertilizer cost, total family labor use, total hired labor use, and amount of family and hired labor used to perform land clearing, field burning,

Table 5

FARM PLAN PREDICTED BY THE L.P. MODEL FOR VARYING SIZE FAMILY LABOR FORCE AND CAPITAL CONSTRAINT UTILIZING TRADITIONAL WEED CONTROL TECHNOLOGIES

factor		farm labor force one	one	one	two	three
capital		C[a/]	U[b/]	C,U	C,U	C,U
opportunity cost of labor		W[c/]	W	Z[d/]	W	W
net cash income		3778.4	4125.3	3748.3	5557.3	6430.3
total area		3.81	4.13	3.88	4.13	4.13
production system one (PSI)						
old land:	T_1					
	T_2	0.42		0.78		
	T_3			1.73		
new land:	T_1					
	T_2	0.84		0.84		
production system two (PSII)						
	T_1					
	T_2					
	T_3	0.45	4.13	0.53	4.13	4.13
total corn production		3520.6	4658.7	3524.3	4658.7	4658.7
capital use		840.0	2226.5	840.0	445.0	135.9
labor:	family	83.4	77.62	83.7	142.4	153.6
	hired	26.1	76.02	26.0	11.2	-
	total	109.5	153.64	109.7	153.6	153.6

a/ C = constrained capital

b/ U = unconstrained capital

c/ W = prevailing wage rate

d/ Z = zero

herbicide application, planting, first early weeding, second and third weeding, and harvesting. Each solution satisfied the subsistence requirement constraint.

Presently there are three weed control systems used for the production of maize in the PRICA zone. They are identified as: T_1, an early hoeing; T_2, a late hoeing; and, T_3, an early and late hoeing. They are approximately equally likely to be used by PRICA farmers regardless of the availability of family labor. T_3 provides the largest net return to the farmer as well as the largest cash income, but also requires the greatest amount of labor. Weed control technology T_2 yields the smallest net return and cash income, but also requires the smallest amount of labor, and the weed control labor occurs late in the season.

There are also two different traditional systems of production. Production system I (PSI) employs a combination (3:1) of previously tilled and previously fallowed land, while production system II (PSII) utilizes only previously fallowed land for production. Yields are also higher (10%) for PSI. Originally, only traditional weed control systems were allowed in the model solution.

CONCLUSIONS

Utilizing only traditional weed control systems, the model predicts the use of PSI when only one farm laborer is available, and a shift to PSII as more family labor is available (Table 5). However, when capital is not a constraint, even the farms with limited labor shift to PSII, hiring the labor they need. As would be expected, T_3 is the preferred weed control system when capital and/or labor are not constraints because it offers the greatest return. If capital and labor are limited, a combination of T_2 and T_3 are predicted.

When the new chemical mulch technology is examined in a riskless environment, the model predicts an immediate shift to weed control technology T_4, the IPPC proposed system. Most acreage is farmed using PSII when capital or labor are not constraints. Production system III (PSIII), a new system which allows the uses of fertilizer on previously farmed land, is the next largest. The traditional technologies are only used where capital and labor are limiting and then only in relatively small areas (Table 6).

Table 6

FARM PLAN PREDICTED BY THE L.P. MODEL FOR VARYING SIZE FAMILY LABOR FORCE AND CAPITAL CONSTRAINTS UTILIZING TRADITIONAL AND MODERN CONTROL TECHNOLOGIES

factor	farm work force						
	one	one	one	two	two	three	three
capital	C[a]	U[b]	C	C	U	C	U
opportunity cost of family	W[c]	W	Z[d]	W	W	W	W
net cash income	3922.7	6655.1	4028.6	6829.6	8194.8	8057.9	9413.7
total area	3.17	6.02	3.69	4.62	6.02	4.94	6.02
production system one (PSI)							
old land: T_1							
T_2			0.06				
T_3	0.52		1.23				
T_4	1.10		1.23	0.38			
new land: T_1							
T_2		0.84					
T_3							
T_4	0.54			0.13			
production system two (PSII)							
T_1							
T_2							
T_3							
T_4	1.01	3.50	0.33	3.46	3.50	3.86	3.50
production system three (PSIII)							
T_4		2.52		0.65	2.52	1.08	2.52
total corn production	3608.4	7257.2	3672.8	5692.7	7257.2	6119.2	7257.2
capital use	840.0	3812.7	840.0	840.0	1933.3	840.0	1309.7
labor: family	70.1	69.8	78.2	129.4	138.1	143.0	160.8
hired	13.5	91.0	15.6	3.3	22.7	-	-
total	83.6	160.8	93.8	132.7	160.8	143.0	160.8

a/ C = constrained capital

b/ U = unconstrained capital

c/ W = prevailing wage rate

d/ Z = zero

Net cash income rises significantly as the shift from traditional to proposed weed control techniques occur. This results from the higher yields (13%) obtained from T_4 with only a slight increase in costs, as well as a major increase in the area farmed. It should also be noted that when new technologies are employed, hired labor usage increases when capital is not constrained. Thus, unemployment may not be increased by the new technology if capital can be made available to farmers to expand the area they farm.

The NAZ analysis indicated that only 30% of the 20 NAZ sampled farms would benefit from the introduced technology. However, it was assumed at that time that there would be no yield increase associated with the new technologies. This was consistent with the experimental data available at the time. However, recent results in Costa Rica indicate that a yield increase is likely. The results were incorporated into the Nicaraguan L.P. model. Had the NAZ study assumed a 13% increase in yield, as in this study, the number of adopters would have greatly increased.

Another reason for the difference in results between the two studies is the amount of underutilized land in the PRICA area which allows farmers an option of employing PSII. Only PSI and PSIII are used in the NAZ. From the NAZ data, however, it is impossible to determine the number of farmers employing each system. Nevertheless, since PSII provides the highest yield, and the best environment for the new technologies, the new technologies appear to be less favorable in the NAZ than in PRICA.

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APPROPRIATE HERBICIDE FORMULATION AND PACKAGING FOR SMALLHOLDER TROPICAL FARMERS PRACTICING NO-TILLAGE

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INTRODUCTION

It should not be assumed that herbicides are an essential part of no-tillage systems. The use of ground-cover legumes as "living mulch" should help to minimize the need for herbicide, and Ogborn (1983) has suggested that the alley-cropping technique, in particular, may not need herbicides. In most systems, however, chemicals will be needed to destroy weeds (or legumes) either in place of fire, as used in traditional slash and burn agriculture, or mechanical cultivations.

While the aim should be to minimize use of herbicide, neither should paraquat and glyphosate be assumed to be the only compounds needed. According to the system and the local weed flora, a moderately wide range of herbicides may need to be available. Arboricides, such as picloram or 2,4,5-T, may be needed to suppress woody growth, at least until such time as de-stumping can be carried out. Although it has been emphasized that the activity of residual preemergence herbicides may be reduced in no-tillage situations due to physical interception by mulch material or adsorption by organic matter or ash (Moss, 1979), they will almost certainly be a vital part of many systems if only applied in bands along the rows to ensure quick weed-free establishment of the crop.

USE OF HERBICIDES

Post-emergence weed control largely may be achieved by carfully directed inter-row application of the same non-selective herbicides used for pre-plant application. This will have the advantage that precise calibration and dose control are not required. But selective post-emergence herbicides also will be required for the greatest flexibility, especially for perennial weeds that cannot be controlled fully by supplementary hand or hoe weeding. In this respect. the new grass-killing herbicides, such as fluazifop-methyl and NP 55C which can be sprayed safely over most broadleaved crops, will have particular potential. Other materials without inherent selectivity may prove useful in conjunction with herbicide direct contact application (DCA) wiping devices.

Even for the basic pre-planting destruction of weeds or ground cover, there will be a place for compounds other than paraquat and glyphosate. Wiles and Hayward (1981) have commented on a number of the weeds that are not adequately controlled by paraquat, while even glyphosate lacks activity on a number of species including *Talinum triangulare*, as pointed out by Akobundu (1983). Apart from the need for alternative compounds for such purely technical reasons, there is the overriding question of cost. New compounds, such as Hoe 39886 (Schwerdtle, *et al.*, 1981) may prove to have better activity on some of these species, but much more economical results may be achieved with older, cheaper compounds such as 2,4-D, which is an important component in the system in Southern Brazil, as described by Wiles and Hayward (1981). Yet, Nyoka (1983) has pointed out that the only herbicides available in Sierra Leone are paraquat and a relatively sophisticated mixture of propanil and fenoprop for rice, while 2,4-D is not available.

The point intended is that of emphasizing the importance of the simple availability of herbicides to small-scale farmers before discussing the detail of formulation and packaging.

A. Formulation

The formulation of herbicides is a highly complex and sophisticated topic and Marrs and Middleton (1973) have summarized the important principles involved in arriving at a formulation that is safe, reliable, easily applied, and stable in storage for long periods under severe conditions of extreme temperature. A company must spend years perfecting a formulation and conducting necessary environmental and toxicological testing for registration purposes. Any subsequent change in the formulation may involve considerable additional expense in further testing.

In arriving at their formulation, companies normally will ensure that it will suit the widest possible range of uses and conditions, including those to be expected in the tropics. Thus, from a purely technical point of view, formulations are likely to be suitable for use by small-scale farmers in virtually all respects. Improvements gained by addition of surfactants or other additives will be equally relevant to large-scale agriculture and so will be made in any case wherever the advantage is great enough. The one major improvement of the greatest significance to no-tillage would involve changing glyphosate to make it as rainfast as paraquat (manufacturers probably will make this change if they possibly can).

B. Equipment

Hence, there are no apparent technical grounds supporting special formulation for small-scale farmers, unless these farmers use very different application methods. In this respect, the current exceptionally interesting stage concerns a range of new application techniques being developed as potential alternatives to the standard knapsack sprayer fitted with "conventional" nozzles applying at least 100 liters liquid per ha. It is difficult to predict what techniques will be most widespread in 10 years.

Will the knapsack continue to be the standard, but used with very low volume (VLV) nozzles applying only 30 to 100 l/ha? Will the use of battery-operated spinning discs continue to increase in popularity? They have already contributed significantly to the popularity and practicability of herbicide use in West Africa. Perhaps the spinning disc will be used, but incorporated into ground-wheel driven sprayers such as those described by Chaudhary and Ogborn (1980) and Garnett (1981). These units offer the special advantage of automatic metering which helps eliminate dangers of inaccurate application due to incorrect walking speed or nozzle height. There is also the wide range of DCA wiping devices which may be valuable for applying herbicide directly to weed foliage protruding above or between crop rows. Also exciting are new devices such as the "Electrodyne," already at an advanced stage of development for insecticide use, and the electrostatic pulsed sprayer at a very early stage of development at the Weed Research Organization (Stent, et al., 1981).

C. Nature of Products Marketed

It could be argued that formulations may need to be adapted to whichever application technique becomes most popular, but it is more realistic to assume the converse: the most popular technique(s) will not require special formulation but will offer the greatest flexibility of use with a wide range of standard formulations.

Considering aspects of convenience, liquid formulations may be preferable to solids--and certainly the new flowable formulations of triazines and some other compounds are preferable to wettable powders--in that material need not be weighed out. But the new "flowable granules" of some water-dispensible herbicides can be measured volumetrically almost as readily as liquids and might be regarded as safer by not being drinkable. Water soluble compounds also could be made available in the form of pellets of convenient size for preparing appropriate volume in CDA or knapsack sprayers.

Conversely, the problems of volumetric measures and dilution might be avoided by providing the farmer with pre-diluted "formulations" ready for application by the standard local method. Ogborn (1983) has suggested that, to overcome the inevitable problem of transport costs for more dilute solutions, dilution and re-distribution could be the responsibility of local agricultural service centers. The prospect raises questions about the skilled and responsible supervision that would be required to avoid mistakes in dilution and labelling, or deliberate adulteration. Certainly, chemical companies would not readily accept any such arrangement for re-packaging their materials unless performed within a unit such as an estate which had its own tenant farmers, or perhaps some form of agricultural co-operative to whom all legal responsibility for the use of the product would be transferred. While feasible in some locations, it will not be applicable to more than a minute proportion of the total small-farmer population.

D. Practicalities

One of Ogborn's (1983) main reasons for discussing the supply of more dilute formulations to farmers concerned reducing toxicological hazards, especially with paraquat which is so much more dangerous as a concentrate. It would be comforting if farmers could be provided with a less concentrated formulation, but the problems of transport cost on the one hand, and local re-packaging on the other, would seem to preclude general adoption. Newer formulations of paraquat contain both stenching and emetic agents which should greatly reduce the risk of accidental consumption. These newer formulations should replace earlier ones everywhere as soon as possible.

One practical way for farmers to avoid diluting liquid formulation will be development of very low volume application of undiluted standard formulations. This approach is physically feasible with several of the new application devices. However, it may be inadvisable with paraquat; also, it will not necessarily be technically satisfactory with many foliage-acting herbicides which are likely to be less effective at such low volumes, glyphosate being one of the more important exceptions.

Granular herbicides provide another way of avoiding the need for dilution and at the same time the cost and complications of application equipment. Granular materials are to be encouraged wherever feasible, but unless made up locally (so requiring reasonably skilled supervision), they are more expensive to transport. The major drawback, of course, is that they are unsuitable for the quick knock-down of foliage, the main requirement of herbicides in no-tillage systems.

PACKAGING

The smaller farmer should be able to purchase herbicides in quantities sufficiently small to match his needs, which often will be for areas less than 0.5 ha. Small packs already are produced in many developing countries, and, although the cost of distribution is inevitably increased, there is no particular technical problem involved. The greatest challenge may lie in ensuring adequate intelligible labelling on a relatively small size pack.

Regulations often dictate extensive written instructions and warnings, which should not be abandoned. For the small farmer, these could be usefully supplemented by pictorial instructions aimed at the illiterate user. Loose folded leaflets normally will need to be attached to each container. Doubtlessly, ingenuity will be involved in the design of an appropriate package and label, but the wide range of relatively cheap packaging materials available should lead to many different solutions for this problem.

CONCLUSION

At present, far too few herbicides are readily available in developing countries, and still fewer are available in convenient sized packs for the smaller farmer. Industry cannot be expected to rapidly develop special packs and distribution systems, but should be given encouragement and assistance to do so. Meanwhile, government and aid organizations will need to make significant investment in development and educational work to ensure that farmers gradually acquire the understanding and skills necessary for safe, reliable use of any herbicide. This step is essential for improved systems of farming, particularly the very promising no-tillage techniques which now appear so near to full development.

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Section VI
Special contributed paper

SOIL CONDITIONS AND TILLAGE METHODS IN THE TROPICS

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INTRODUCTION

Estimates of the world's potentially cultivable land area range from 3,200 to 5,000 million ha., 1,400 million ha. of which is cultivated land. In the developing countries of the tropics, estimates of potentially cultivable land area range from 1,500 to 1,800 million ha., only 700 to 800 million ha. of which is currently being used (Food and Agriculture Organization, 1979; Schulze and Van Staveren, 1980). In the tropics, the land reserves are primarily available only in Central, South America and Africa, where, it may be said, that to increase food production is simply to increase the area under cultivation.

However, vast areas of land in the tropics are being rendered unproductive because of deforestation, improper soil management, and inappropriate land use. Consequently, irreparable damage has been done to this nonrenewable natural resource base. According to some estimates, the total area of degraded land in the world that was once productive is more than 2,000 million ha., about 40% more than the currently used area. The current rate of annual degradation of land that is being rendered unproductive by erosion, salinization, and urbanization ranges from 5 to 7 million ha. (Food and Agriculture Organization, 1979; Kovda, 1977).

One of the methods to curtail this alarming rate of soil degradation is to resort to the technique of conservation farming. No-tillage systems of cultivation with crop residue mulches are the basis of conservation farming because they prevent erosion and maintain organic matter content at high levels. Adequate amounts of crop residue--and the residue requirement varies with soil and environmental characteristics--is the best method to control erosion, conserve soil moisture, and decrease pollution due to water runoff (Lal, 1976; Larson, 1979; Unger, 1978).

The continuous use of no-tillage may result in soil compaction that can inhibit root growth and development of some crops and decrease infiltration rates. However, when this happens, ameliorative measures such as chiseling, controlling wheeled traffic, plowing at the end of the rains, and the use of cover corps and planted fallows have proven to be advantageous (Allmaras, et al., 1977; Kannegieter, 1969; Lal, et al., 1978; Lindstrom and Voorhees, 1980; Moreau, 1978; Nicou and Chopart, 1979).

In the humid tropics, the advantages of no-tillage generally outweigh the disadvantages. In addition to soil and water conservation and maintenance of soil fertility, there are definite savings in time required for land preparation as well as investment in farm machinary. This system of conservation farming abates non-point pollution from agricultural lands. Among the disadvantages are ineffective weed control, specific machinery and cropping systems requirements, and soil specificity. No-tillage has proven to be an attractive alternative for maize and other row crops on coarse-textured soils in the humid and subhumid tropics. Can this practice be applied to a wide range of diverse soils as they exist in the tropics? The objective of this report is to assess tillage requirements for different soil conditions and specify soil requirements that suggest success with no-tillage.

SITE FACTORS AND NO-TILLAGE PERFORMANCE

Even on coarse textured soils with adequate quantity of crop residue mulch, crop establishment and performance with no-tillage depends, to a large extent, on the initial soil conditions and previous landuse. Some of the factors that are considered important for temperate regions may not be serious considerations for the tropics. For example, in the tropics, it is generally the lack of an adequate amount of crop residue rather than its excess that is an important factor that determines crop performance. Similarly, soil temperature regimes in the tropics during the seedling stage may be supraoptimal rather than suboptimal as observed in the temperate regions. There may be other factors that are rather specific for a given agroecological region and some that are equally valid in all ecologies. Some important factors for tropical environments are as follows:

A. Soil Compaction

Seedling emergence, crop establishment, and root growth can be seriously affected if the surface horizon is excessively compacted. Although the range of optimum bulk density for different crops and soils may be different for no-tillage compared to conventional tillage, excessively compacted surface horizons can increase losses due to water runoff and adversely affect crop performance. Soils that are easily compacted, such as those that predominate in fine sand and silt fractions, may require periodic ameliorative operations prior to the adoption of no-tillage.

B. Soil Heterogeneity

Micro-relief and an uneven ground surface adversely affect seeding with a no-tillage planter. Many seeds are dropped on the surface (in a depression) resulting in an uneven crop stand. Uneven seeding can also be caused by the presence of stones and gravel in the vicinity of the soil surface. Depressions are also easily waterlogged creating anaerobic environments in the root zone. In addition, uneven distribution of crop residue may also influence micro-climatic environments in the seedling zone and thereby affect crop establishment. Crop residue and shrub growth also harbor birds and rodents that destroy young seedlings and seriously affect crop stand and growth.

C. Topography

It is safer to cultivate steep slopes in no-tillage than conventional tillage provided that the slopes permit mechanized operations. Within the range of slopes that can be managed with mechanized operations, the micro-relief becomes a more important factor than the general topography of the landscape.

CONSIDERATION OF SOIL FACTORS

The adaptability of no-tillage from one soil and agroecological environment to another should be viewed with consideration for soil properties. Soil properties that will favor the application of no-tillage include the following:

(i) coarse textured surface horizons or self-mulching clayey soils with high initial porosity;
(ii) resistance, or less susceptibility, to compaction;
(iii) good internal drainage for upland crops;
(iv) high biological activity of earthworms and other soil animals; and,
(v) friable consistency over a wide range of soil moisture contents.

Soils with these properties respond favorable to no-tillage. Soils that deviate from these characteristics, such as soils with heavy texture (and lack of self-mulching) and massive structure, susceptibility to compaction, plastic or hard consistency, low infiltration rate, and poor internal drainage (for upland crops), do not generally respond favorably to no-tillage. For these soils, an appropriate soil conserving land use system or other suitable tillage operation should be adopted in association with soil conserving practices to minimize soil degradation.

THE CHOICE OF NO-TILL SYSTEM FOR PROBLEM SOILS

No-tillage is naturally suited to those problem soils that are highly susceptible to erosion, have low water holding capacity, and are prone to supraoptimal soil temperature regimes during the seedling stage of crop growth.

A. Soil and Water Conservations

With an adequate quantity of crop residue mulch, no-tillage can effectively control erosion to the tolerable range of soil loss. (Lal, 1976). The range of soil loss tolerance for most Alfisols, Ultisols and Oxisols is rather low because of the shallow effective rooting depth and unfavorable physical, nutritional, and biological properties of the subsoil horizon. It is generally less than 0.5t/ha/annum and mostly below 1.0t/ha/annum.

Soil erosion hazard depends on soil erodibility, rainfall erosivity, slope factor, and land use. Based on these factors, a tentative rating has been proposed for the choice of appropriate tillage systems for a given soil. These ratings in Table 1 (and other tables in this report) are mere guidelines and will perhaps require suitable modifications when more experience, soil data, and climatic records are available for a broad range of environments. A rating of "1" indicates those soil and climatic factors that significantly increase the risk of soil erosion, while a "5" rating denotes those factors that render a soil relatively resistant to water erosion. Soils with high values of the erodibility factor (K) and those in the region of high rainfall erosivity and on steep slopes with shallow surface horizon are more susceptible to erosion and would be assigned a rating of "1."

Table 1

RATINGS FOR FACTORS AFFECTING SOIL EROSION

annual cumulative erosivity (El_{30}, foot-ton)	soil erodibility (K)	soil loss tolerance (t/ha/year)	slope (%)	tenative ratings
>1000	>0.6	<0.5	>10	1
800-1000	0.4-0.6	0.5-2	6-10	2
600-800	0.2-0.4	2-6	4-6	3
400-600	0.1-0.2	6-10	2-4	4
<400	<0.1	>10	<2	5

Although the frequency, amount, and duration of rainfall are also important factors, their effect is built into the erosivity parameter El_{30} as defined in the Universal Soil Loss Equation. Similarly, included in the soil erodibility factor (K) are the permeability, texture, organic matter content, and soil structure. The effective rooting depth and physiochemical and nutritional properties of the subsurface horizon are considered in evaluating the soil loss tolerance. Soil loss tolerance is low for shallow soils and high for deep soils.

B. Hydrothermal Regime

Soil temperature and moisture regimes are affected by particle size distribution, soil structure, and organic matter content. Soil thermal characteristics, including heat capacity, thermal conductivity, and diffusivity, are governed by soil constituents and the moisture regime. Soils in the humid tropics have low available water holding capacity and are drought susceptible. Rapid growth rates favored by high temperatures can be sustained only with a continuous supply of readily available moisture in the root zone. High evaporation rates and low thermal capacity create supra-optimal soil temperatures in the seed environments.

Mulch-based no-tillage is advantageous for those soils with low water holding capacity where supraoptimal soil temperature regimes may adversely affect seedling establishment and growth. The available water holding capacity of the root zone, computed from the in situ measurements of upper and lower limits of available water for the specific crops to be grown, is an important consideration in the choice of an appropriate tillage system. Soil temperatures exceeding 40°C at 5 cm depth from 3 to 6 hours/day during the seedling stage can be injurious to crop growth. Similar to the available water holding capacity, internal drainage and permeability are also affected by the particle size distribution and soil organic matter content. Soils with free drainage are easily adapted to no-tillage for most upland crops.

On the other hand, hydromorphic, poorly drained soils are better suited for rice cultivation, particularly if they are level (to facilitate water management). No-tillage with proper weed control is feasible for lowland rice production. However, a separate section is devoted to rating soil conditions for rice cultivation with no-tillage. Ratings for hydrothermal regimes are given in Table 2. Soils will respond favorably to no-tillage and mulches if the soils have less than 3 cm of available water holding capacity, more than 36°C of soil temperatures at a 5 cm depth from 3 to 6 hours/day during seedling growth, more than 12.5 cm hr^{-1} of permeability, and more than a 60% chance of no rain for more than 10 days during the plowing season.

Table 2

FACTORS AFFECTING HYDROTHERMAL REGIMES AND THEIR RATINGS

available water holding capacity (cm)	maximum soil temperature at 5 cm depth on bare soil (°C)	probability of 10 days or more rainless period (%)	permeability (cm/hr)	tentative rating
<4	>40	>80	>25	1
4-8	36-40	60-80	1.25-25	2
8-12	32-36	40-60	6.25-12.5	3
12-16	28-32	20-40	0.5-6.25	4
16-20	<28	<20	<0.5	5

C. Factors Affecting Soil Compaction

Soil compaction is a more difficult parameter to quantify and characterize in relation to other soil variables. Bulk density and total porosity (or the penetrometer resistance) can be indirectly related to the degree of soil compaction. However, it is difficult to establish a direct functional relationship between soil compaction and any one, or a combination, or parameters because of the confounding effects of variations in soil moisture content. Bulk density and total porosity are significantly influenced by particle size distribution. Furthermore, optimum bulk density requirements are different for different soils and crops. Plant response is related less to the absolute value of bulk density, or total porosity, and more to the rate of its change with time. The drastic change in bulk density and porosity has more edaphological significance. That is why the "specific volume" and "relative compaction" as defined below may be better indices of soil compaction than the bulk density or porosity per se.

Indice A

$$\text{specific volume:} \quad \frac{\text{total volume } (V_t)}{\text{volume of soil solids } (V_s)} = \frac{\text{particle density } (D_p)}{\text{bulk density } (D_b)}$$

$$= (1 + \text{void ratio})$$

Indice B

$$\text{relative compaction ( ) } = \frac{\text{dry bulk density } (D_b)}{\text{maximum dry bulk density } (D_b \text{ poroctor})} \times 100$$

Although both indices are related to bulk density, neither is indicative of the dynamic aspect of the rate of change. Moreover, it is difficult to develop a rating table because relative compaction also depends on the initial level of compaction. Therefore, the ratings presented in Table 3 apply to those soils that are relatively uncompacted initially. This assumption is valid because of the known fact that no-tillage is not successful for compacted soils. Soils that have high relative compaction may be less suitable for no-tillage than those with less relative compaction.

In addition to soil constituents (texture and organic matter content), traffic-induced compaction is also related to the amount of crop residue on the soil surface and the antecedent soil moisture content. Soils with high amounts of crop residue and extensive ground cover become less compacted than those with less residue and a bare soil surface. Biological activity of earthworms and other soil fauna also relates to the amount of crop residue on the soil surface.

Soils with less relative compaction, a low rate of change in bulk density, and extensive ground cover at seeding will respond favorably to no-tillage. If seeding is not performed with a proper seed drill that optimizes the environment in the seedling zone, thick crop residue mulch may adversely affect seed germination and seedling establishment. In addition to the effect of insects and other pests, inadequate seed-soil contact, with thick mulch, can curtail germination.

Table 3

RATINGS FOR RELATIVE COMPACTION

percent change in bulk density or macroporosity*	relative compaction	percent ground cover	tentative ratings
----------------------- (%)	-----------------------	-----------------------	
<10	<10	>80	1
10-20	10-20	60-80	2
20-30	20-30	40-60	3
30-40	30-40	20-40	4
>40	>40	<20	5

* from seeding to harvesting

D. Nutritional Properties

Soil acidity and the effective cation exchange capacity are important properties related to nutritional characteristics and should be considered when selecting a tillage system. For example, surface application of lime may not be as effective in neutralizing soil acidity in no-tillage as it is when incorporated into the surface layer with a conventional plowing and harrowing system. Choosing crops (rice, cassava, etc.) may be another alternative.

Cation exchange capacity is influenced by the amount of clay and organic matter content as well as the nature of clay minerals. A majority of soils in the humid and subhumid tropics contain low activity clays with nonexpanding lattice clay minerals and iron and aluminium oxides and, therefore, have low to medium cation exchange capacity. Soils of volcanic origin (Andisols) and Vertisols of the semi-arid region have high cation exchange capacity.

The nature and quantity of the clay fraction is also related to soil consistency, work ability, and trafficability. Clay soils with "self-mulching" properties are more adaptable to no-tillage than those with massive structure and a narrow range of friable consistency. Clayey soils that do not possess natural tilth-forming properties are not readily adaptable to no-tillage. Table 4 ratings consider nutritional and chemical soil properties including those soils with high activity clays. Soils with neutral pH, low clay content, and low activity clays are suited to no-tillage more than those with a greater content of high activity clays.

Table 4

NUTRITIONAL AND CHEMICAL PROPERTIES OF SOIL

soil pH (1:1 in water)	clay content (%)	effective cation exchange capability (meq/100g soil)	tentative rating
6.5-7	<10	<10	1
6.5-5	10-20	10-15	2
5.5-6.0	20-30	15-20	3
5.0-5.5	30-40	20-25	4
4.5-5.0	40-50	>25	5

A PARAMETRIC ASSESSMENT OF SOIL SUITABILITY FOR NO-TILLAGE SYSTEM

Numerical addition of rating factors of all parameters discussed so far can provide some guidelines concerning the adaptability and the success of no-tillage for specific soil conditions. This rating is extremely tenative and can be improved with a more thorough knowledge of ecological factors including soil, crops, and climatic parameters.

For example, the minimum and the maximum rating values range from 14 to 70 for all factors discussed. Tentatively, no-tillage has better chances of success with rating values of less than 30. On the other end of the scale, if cumulative rating factors exceed 45, it is advisable to use some form of mechanical methods of seedbed preparation involving both primary and

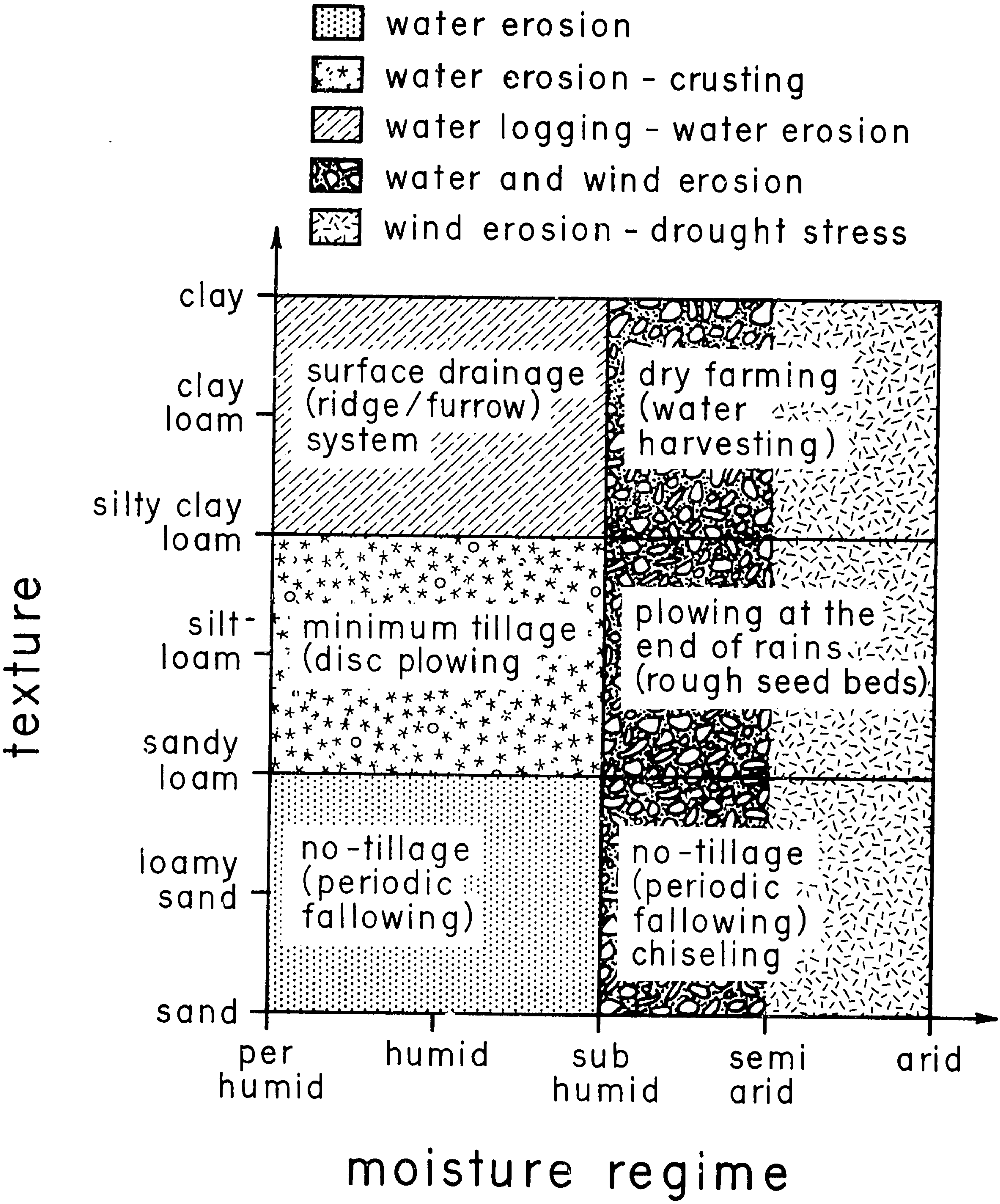

Figure 1. APPROPRIATE TILLAGE SYSTEMS FOR THE TROPICS.

secondary tillage operations. For soils with intermediate rating, some form of minimum tillage or plowing at the end of the rainy season (stale bed technique), or plowing once every two or three years, may be desirable. Appropriate tillage methods for different values of the cumulative rating index are suggested in Table 5.

Table 5

ACCUMULATIVE SOIL RATING INDEX AND APPROPRIATE TILLAGE SYSTEM

accumulative rating index	appropriate tillage system
<30	no-till farming with periodic fallowing
30-35	chiseling in the row zone
35-40	minimum tillage/permanent ridge furrow system
40-45	plowing at the end of the rainy season
>45	both primary and secondary tillage

The index favors conventional tillage methods of mechanical seedbed preparation more than it does no-tillage. This occurs because there is a need to develop an appropriate package of cultural practices for a range of soils and agroecological environments for no-tillage methods to be effective. No-tillage is a system; the agronomic package of practices to support it not only differs from conventional tillage practices, but also varies for different soils and agroclimatic environments. The index rating in Table 5 can be changed in favor of no-tillage as appropriate packages of agronomic practices become available for a broad range of soils and environments.

APPROPRIATE TILLAGE SYSTEMS FOR DIFFERENT SOILS AND ENVIRONMENTS

Based on the available information for soil management problems and climatic constraints for different soils and agroecological environments in the tropics, general guidelines for appropriate tillage systems are depicted in Fig. 1. This diagram is very tentative and no claim is made for its application to very diverse soils and agroecological environments as they exist in the tropics. It is evident that in the humid and subhumid tropics, with soils of coarse texture in the surface horizon, no-tillage can be successfully applied for upland row crops. In the semi-arid region, and with heavy textured soils, some type of mechanical seedbed preparation is necessary. The frequency and type of mechanical operation desired depends on soil characteristics and the crops to be grown.

Several examples of the application of this system are available in the literature. No-tillage has been shown to be effective for production of grain crops on Alfisols in the sub-humid environments (Lal, 1979). A semi-permanent ridge furrow system with graded contour furrows is recommended for vertisols in the semi-arid region (Kampen, et al., 1981), and both primary and secondary tillage for easily compactable sandy and loess soils in the Sahel (Nicou and Chopart, 1979). Considerable flexibility exists within each ecological zone depending on the local variation in soil conditions and predominant farming systems.

TILLAGE SYSTEMS FOR RICE

Upland rice is not economical for those soils with available water holding capacity of less than 15 cm in the root zone and where annual precipitation is less than 1500 mm. For these soils and environments, rice can be successfully grown in periodically inundated valley bottom soils, provided a system of drainage can be developed for water management. The best conditions for rice production in these regions are flooded paddys with controlled irrigation and proper drainage. Under paddy conditions, no-tillage can be successfully adopted, both for direct seeded and transplanted rice, for soils of heavy texture (Brown and Quantrill, 1973; Elias, 1973; Maurya and Lal, 1979; Rodriguez and Lal, 1979).

Perhaps once every five to six years (after 10 or 12 rice crops), plowing may be necessary during the dry season to ameliorate the soil of any harmful effects of the anaerobic conditions that may prevail. Ideally, a rotation with an upland crop, such as soybeans, grown during the dry season, should provide an opportunity to perform any disease and pest control.

Tillage requirements for paddy with sandy permeable soils are different than for soils of heavy texture. Leaching losses of fertilizer, and especially that of nitrogen, are generally high under unpuddled conditions. This implies additional nitrogen requirements for no-tillage. Although nutrient imbalances and toxicities cannot be entirely ruled out, a sizeable portion of yield reduction with no-tillage may be attributed to leaching losses of applied fertilizer.

Whereas soil and water conservation and weed control are the main objectives of an appropriate tillage system under upland conditions, savings in time, cost of land preparation, and a possibility of growing an upland crop that prefers aerobic environments in the root zone with good soil structure during the dry season are the principal benefits of reduced tillage system for lowland rice.

With adequate chemical weed control, upland rice can be grown in a wide range of soils in the humid and perhumid tropics with annual rainfall exceeding 2000 mm. Under these ample rainfall conditions, rice can be grown under upland conditions even if the available water holding capacity of the root zone is only 5 to 10 cm.

TILLAGE SYSTEMS FOR TROPICAL ROOT CROPS

Tuberous roots develop in, and interact with, the soils differently than fibrous roots of grain crops. Not only is voluminous "root room" required for their development, ease of harvesting them should also be considered. For sandy, deep soils of at least 30 cm effective rooting depth, no-tillage is a feasible system for root crops such as sweet potato and cassava. In any case, for conventional tillage the economic benefits obtained may not justify the additional cost required for seedbed preparation. Harvesting also may not be a serious hazard for coarse textured soils of loose and friable consistency. For shallow soils, on the other hand, and those with heavy texture, hard consistency, and a narrow range of moisture content for friable tilth, some mechanical means of seedbed preparation may be inevitable. Under these conditions, yam cultivation may be better with a conventional plowing system followed by ridging, compared to planting on a flat, untilled seedbed. For very shallow and gravelly soils, yams are customarily planted in a vertical hole dug about 15 to 20 cm deep and filled with loose surface soil and organic matter.

CONCLUSION

Research experiments aimed at determining the applicability of no-tillage have been conducted for only a few of the diverse soil and agroecological environments of the tropics. In spite of management problems encountered with its application, the superiority of no-tillage in preventing soil erosion on highly erodible soils and in erosive environments justifies the exploration of its potential for other soils, crops, and agroecological regions. No-tillage is not a panacea for all soil management problems, and it is not applicable for all soils and crops. However, its benefits and adaptability can be broadened for other soils and environments by developing appropriate packages of cultural practices that are specific for no-tillage.

A rating method has been suggested in an attempt to assess tillage requirements for diverse soil conditions in the tropics. These ratings are tentative and are mere guidelines that should be evaluated for local soils and environments. Rating evaluations can be improved as additional information becomes available on soils, crops, cropping systems, and agroclimatic environments.

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