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Resource Conserving Technologies a
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Abstract: This paper summarizes factors affecting the agricultural and environmental potential of conservation tillage in maize-based farming systems in Mexico. The author begins by describing some of the implications of soil conservation in the tropics, including the goals of conservationists and farmers, the defining characteristics of conservation tillage systems, and current perceptions of the potential advantages of conservation tillage in Mexico. Next, the advantages, disadvantages, costs, and benefits of conservation tillage from the farmer's point of view are discussed, followed by an assessment of possible environmental benefits and costs. The author describes four combinations of agricultural and environmental outcomes that could arise from adoption of conservation tillage in the tropics: agriculture lose, environment lose; agriculture win, environment lose; agriculture lose, environment win; and agriculture win, environment win.

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Are Productivity Enhancing, Resource Conserving Technologies a Viable “Win-Win” Approach in the Tropics? The Case of Conservation Tillage in Mexico

Olaf Erenstein¹

Introduction: Productivity and Sustainability

Agricultural development efforts in the tropics initially focused on raising productivity in traditional agricultural systems. Among other results, this has led to the major productive breakthrough known as the Green Revolution. The initial productivity boost was based on the combined use of high yielding varieties and agrochemicals in more favorable tropical environments. However, recent evidence suggests that the initial productivity boost may not be entirely sustainable because of a variety of resource degradation issues.

Widespread sustainability problems in agricultural systems have recently increased interest in an agriculture more oriented toward resource conservation. This has led to renewed attention to low external input agriculture, and is occasionally taken to the point of avoiding synthetic inputs altogether, as in organic agriculture. Although such systems definitely score high on various sustainability indicators, they tend to have low productive potential.

These experiences suggest there is a trade-off between productivity and sustainability. However, in view of a burgeoning population and finite resources, we need to minimize this trade-off while addressing issues of productivity and sustainability. Productivity-enhancing, resource-conserving technologies seem to hold this promise, simultaneously addressing agricultural and environmental issues to achieve sustainable agricultural development. As such, they have a “win-win” potential (Fig. 1).

Conservation tillage is an example of a productivity-enhancing, resource conserving technology currently being promoted in the tropics. The technology has the potential of simultaneously addressing soil conservation and productivity issues. However, although detailed technical and economic information is available on it in industrialized environments, similar information for the tropics still is scarce. Consequently, we do not know its potential in the Mexican tropics. This paper summarizes some factors affecting the

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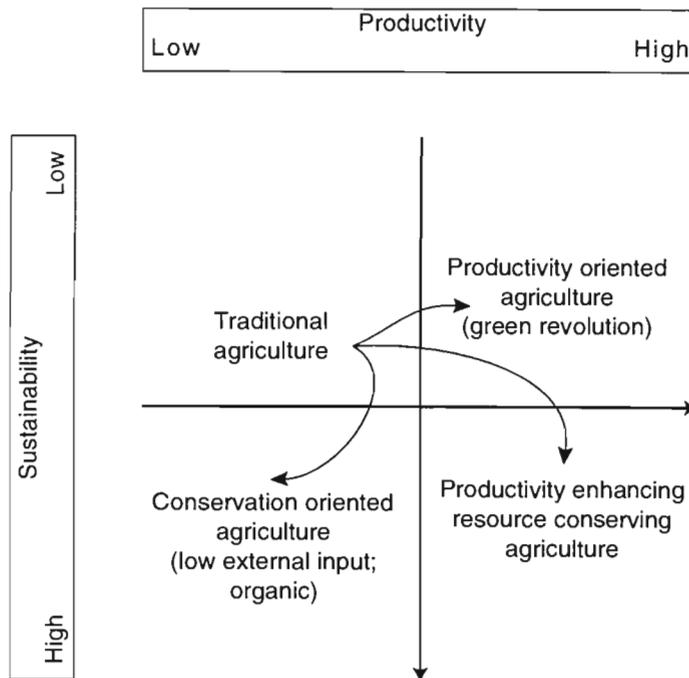


Fig. 1. Relationship between productivity and sustainability in various types of agriculture.

agricultural and environmental potential of conservation tillage in maize-based farming systems in Mexico. However, before doing so, we must look more closely at some implications of soil conservation in the tropics.

Soil Conservation in the Tropics

We can distinguish two viewpoints in relation to soil conservation in the tropics. On one hand, the conservationist emphasizes that soils are being degraded. Although the effects in any one year may be insignificant, they become important as they accumulate over time (Lal, 1987). Therefore, we need to invest now in conservation measures to secure the resource over the longer term. In addition, the conservationist highlights several externalities of soil erosion that harm society at large. Soil conservation can greatly reduce these and thereby generate substantial social gains.

On the other hand, the farmer emphasizes production. Most resource-poor farmers in tropical environments face many uncertainties and short-term needs. As a result, they generally are more concerned with making ends meet today than with securing resources for some distant future. Also, farmers understandably are more interested in the benefits and costs that directly accrue to their farm than in externalities.

In the end, it is the farmer who generally decides land use and therefore the use of soil conservation measures. Thus, for soil conservation measures to be viable and

effective, we need to consider the farmer's concerns. That is, we need to alleviate some productivity concerns before, or in addition to, conservation concerns, with the conservation measures themselves imposing only moderate additional costs on the user.

The relative costs of soil conservation measures vary widely, depending on the measure itself and the environment in which it is applied. For example, physical soil conservation structures require substantial initial investments. These investments generally are prohibitive for resource-poor farmers in the tropics and are unlikely to be profitable (Lutz et al., 1994). Productivity-enhancing, resource-conserving technologies such as conservation tillage have the potential to recover part of the conservation costs in the short run through immediate productivity increases, so that the relative conservation costs are low. However, this potential depends on an array of agroecological and socioeconomic factors, most of which are specific to the farming systems and environmental conditions of the tropics.

Conservation Tillage in the Tropics

Conservation tillage is a widely used term that covers many different practices, but generally relates to a reduction in tillage and the conservation of crop residue for erosion control. As a result of its wide use, various definitions' abound. Here a system will be classified as conservation tillage if it satisfies the following criteria:

- *The reduced tillage criterion:* tillage excludes any soil inversion, but may vary from zero-tillage to a maximum of two superficial cultivations.
- *The mulch criterion:* at least 30% of the soil surface is covered by crop residues immediately after planting. In Mexico, this translates into a threshold of at least 2 tons of maize residue per hectare.

In general, the adoption of conservation tillage seems to require two major changes. On one hand, tillage/soil movement needs to be reduced to satisfy the reduced tillage criterion, which basically means replacing tillage with herbicides. On the other hand, sufficient crop residues need to be left to satisfy the mulch criterion, so that competitive uses and current practices such as the burning of residues must be restricted.

Both the reduced soil movement and the mulch are soil conservation measures. Their conservation effect is achieved partly by protecting the soil better against the erosive impact of the rain, both through the presence of the mulch as a protective layer and through reduced disturbance of the soil's structure. The mulch also reduces erosion by reducing runoff and increasing infiltration by forming physical barriers and by improving the soil's physical structure and thereby its permeability. Both features are especially relevant in tropical regions with erosive rain storms and with erodible soils cultivated on steep slopes. Conservation tillage also conserves water through reduced

runoff, increased infiltration, and reduced evaporation. This increases available soil moisture, which can reduce losses in production during dry spells

Conservation tillage practices have received widespread attention from various agencies throughout Mexico during the past five years. Despite the undoubtedly favorable effect that all the massive attention has had in promoting conservation tillage, the attention also has had its drawbacks. For one, the many different people involved have generated diverse interpretations of what conservation tillage is all about. Some merely interpret it as not burning crop residues, even if they are entirely incorporated or grazed. Others interpret it as any non-inversion tillage. Any subsequent negative experience with such technologies is then erroneously attributed to conservation tillage. However, as discussed previously, conservation tillage must satisfy both the reduced tillage and mulch criteria to achieve its potential benefits.

An additional drawback has been the lack of attention given to assessing the potential of conservation tillage practices in different environments (both agroecological and socioeconomic). Conservation tillage has been promoted as a blanket solution for all Mexican environments. However, it is a complex technology that may not always be appropriate. Its adoption requires changes in several production practices, including field preparation, sowing, mulch management, weed management, and possibly pest and fertilizer management. As a result, it should be promoted carefully, because the required changes could have different implications in different farming systems.

The Agricultural Potential of Conservation Tillage

The agricultural potential of conservation tillage can best be determined by reviewing both its advantages and disadvantages from the farmer's viewpoint and the resulting benefits and costs that farmers face in adopting it. The technology will have little agricultural potential whenever the aggregate on-farm costs exceed or equal the aggregate on-farm benefits. In this section I review some benefits and costs that may influence the agricultural potential of the technology in Mexico.

On-farm benefits of adopting conservation tillage

The benefits of adopting conservation tillage practices generally are twofold: the potential reduction of production costs, and the potential yield increase. The potential reduction of production costs differs between mechanized and manual systems. The reduction in the costs of establishing the crop and controlling weeds can be substantial in mechanized systems. Although herbicide use is increased with conservation tillage, this cost generally is more than offset by the reduced cost of tillage. In manual systems, conservation tillage can save a substantial amount of labor for land preparation and weed control. However, the potential attractiveness to the farmer of replacing labor by herbicides depends on various factors, including the opportunity cost of labor and the cash

cost of herbicides. In addition, conservation tillage has major implications for the cost structure of agricultural production, especially for households that rely primarily on family labor, because it replaces a non-cash (in-kind) input with a cash cost. This can be a special problem in (semi)subsistence systems because of their limited sales, although it may be alleviated by other income sources, such as a cash crop (for example, coffee). Family labor freed by the substitution can either be used to expand the area under cultivation or be diverted to other productive activities. The existence of alternative employment opportunities (agricultural or nonagricultural) can therefore be a decisive factor favoring adoption, because it directly affects the opportunity cost of labor.

Adopting conservation tillage potentially increases yields relative to conventional tillage. However, this yield increase is the aggregate effect of three different causal factors: soil conservation, water conservation, and timeliness of crop establishment.

- *Soil conservation* measures such as conservation tillage reduce the rate of soil degradation and thereby the resultant productivity loss. The magnitude of this gain is therefore directly related to the degradation occurring in the first place. Soil degradation is generally less severe in favorable environments, and consequently the yield increase related to soil conservation may become visible only in the long term. However, in marginal environments such as steeply sloping areas (slopes between 40 and 80%), soil degradation is generally more severe, and the yield increase from soil conservation may already become visible in the medium term.
- *Water conservation* can increase yields in areas where water is a limiting factor. In fact, many rainfed areas in Mexico suffer from a water deficit during the growing season, occasionally in the form of a prolonged mid-season dry spell. Conservation tillage can use the available water more efficiently and thereby reduce water stress during these dry spells. This effect potentially translates into higher average yields and lower production risks.
- *More timely crop establishment* also can increase yields. Conservation tillage can reduce the time required for crop establishment. This can be of special interest in areas where the time available for crop establishment is very limited, as in irrigated systems with two crops per year.

On-farm costs of adopting conservation tillage

The costs of adopting conservation are very diverse. First, conservation tillage requires sufficient crop residue to form an adequate mulch. The cost of these residues is very variable throughout Mexico and can be a decisive factor in determining the potential of the technology. The cost of residues is generally an opportunity cost influenced by alternative competing uses for them. The major competing use in Mexico is as fodder during the dry season, especially through stubble grazing. The amount of

residues used as fodder is variable, depending on the aggregate supply and demand. The demand for fodder is largely determined by livestock pressure and the availability of alternative fodder sources, both on-farm and off-farm. Off-farm factors are important, especially where exclusion possibilities are still limited: communal grazing after the harvest is a common practice in some areas of Mexico and Central America. Under such circumstances, farmers may need to fence their fields to protect their residues; this may present a substantial entry barrier for would-be adopters. In other areas there is a real market for maize residue. In such cases, the costs of residue conservation are clear (the benefits less so), as would-be adopters must forgo the possibility of selling residues. This is an especially important limitation when sales of residues account for a substantial part of the gross margin of maize production, say more than 10%.

Adoption of conservation tillage also presents learning costs to farmers. These costs may be substantial for resource-poor farmers who have only limited experience with the use of agrochemicals. Also, most such farmers have had little or no schooling, and extension services are especially weak in remote and marginal areas.

The adoption of conservation tillage practices may require access to certain machinery or equipment. The unavailability of such machinery therefore raises the initial costs of adoption. In the Mexican context two specific types can be distinguished:

- *Crop establishment machinery*: Conservation tillage systems in the industrialized world use direct drills to sow through the mulch under zero-till conditions. However, in Mexico these specialized machines are not readily available, a major limitation for the adoption of mechanized conservation tillage practices. This has forced conservation tillage practices toward reduced tillage systems, which have the disadvantage that they incorporate part of the residues. This is especially disadvantageous in Mexico, where the amount of residue available as mulch is already limited.
- *Herbicide application equipment*: Adoption of conservation tillage practices generally involves replacing tillage with herbicides. This requires access to a backpack sprayer. Not owning a backpack sprayer creates an entry barrier, as the farmer would either need to purchase it (a considerable investment for subsistence systems) or hire it (generally at the going rate for a day laborer).

Another major general limitation is the traditional method of residue disposal. In many areas of Mexico it still is common to burn residues to prepare the field. Farmers burn residues for various reasons. Although not all these reasons may be applicable in current systems, farmers will still need to be convinced about doing otherwise. The major reasons for burning involve the following considerations:

- *Pests and diseases*: Many farmers relate the incidence of various pests directly to the presence of the crop residue as mulch. Although conclusive evidence is

lacking, the potential for increased pest and disease incidence is certainly present, as many rainfed areas in Mexico have continuous maize cropping with one crop a year. Leaving crop residues under conservation tillage practices probably will either raise the costs of pest and disease control or reduce yield through pest damage. In addition, zero-tillage frequently generates problems in controlling perennial weeds. On the other hand, conservation tillage practices can inhibit weed growth if the mulch layer is adequate.

- *Planting problems:* In manual and even in some mechanized systems, sowing is done manually with a dibble. Farmers occasionally still use animal traction for sowing. With conservation tillage, both practices become a little more cumbersome and time consuming.

A farmer will stop burning only if convinced that the benefits of not burning outweigh the costs. However, it may not be enough that a farmer is convinced of the usefulness of not burning the mulch and therefore would not set fire to it. Whenever a neighboring farmer still relies on burning to prepare the land or regenerate a pasture, there is a risk that the dry, flammable mulch will be ignited accidentally. Therefore, a would-be adopter may need to invest substantial additional time in constructing fire-breaks.

The adoption of conservation tillage practices may also be limited by intercropping. Especially in subsistence systems, intercropping maize with beans or pumpkins is common. However, intercrops interfere with the application of herbicides. Furthermore, intercropping generally restricts the possible herbicides to contact herbicides, because the residual effect of some herbicides may harm the intercrop. Conversely, using a wider range of herbicides may limit the possible intercrops.

The Environmental Potential of Conservation Tillage

Technologies that aim to reduce resource degradation seem without question to be environmentally beneficial, with little need for trade-offs among different environmental impacts. Resource-conserving technologies nearly automatically score positively on environmental scorecards.

Similarly, the value of conservation tillage for soil conservation is generally unquestioned, although the size of its conservation benefit depends on the previous level of soil degradation. The soil conservation effect has positive environmental effects both on-site and off-site. On-site, the reduced soil erosion leaves the soil resource less physically, chemically and biologically degraded. Off-site, soil conservation reduces some downstream environmental damage caused by the sediment load in the waterways, such as harm to aquatic life and sedimentation behind dams. In addition, widespread

adoption of conservation tillage practices in watersheds has the potential of smoothing the hydrological cycle and reducing flooding.

Less obvious may be the beneficial effects that conservation tillage has on forest resources. A major environmental benefit of conservation tillage is the potential elimination of burning as a land preparation measure. In Chiapas, for example, burning of residues has been identified as the major cause of forest fires. In fact, protecting forest resources was part of the rationale for a recent law that severely restricts burning as a land preparation measure in the state (Sandoval, 1994).

However, conservation tillage practices also can cause environmental harm. They generally increase the use of agrochemicals, especially herbicides, and therefore increase the risk that some chemicals will leave the farm through leaching or surface runoff. Furthermore, although some farmers may have used herbicides in recent years, knowledge of their properties and application requirements generally is still limited (Tasistro, 1994). Many farmers have learned about the use of agrochemicals by doing, thereby creating a hazard not only to the environment, as when they clean backpack sprayers in streams, but also to themselves. By now, many Mexican farmers have experienced intoxication symptoms (for example, up to 45 % of farmers in the Fraylesca area of Chiapas, according to Nieuwkoop et al., 1994). Also, the presence of the mulch with conservation tillage practices may further increase ammonia volatilization because the fertilizers, including urea and ammonium sulfate, generally are applied on the surface (Tasistro, 1994).

Conclusion

From the above discussion it should be clear that many factors affect the agricultural potential of conservation tillage in the Mexican tropics. The technology seems viable from the farmer's point of view only in cases where the on-farm benefits outweigh the on-farm costs. On the other hand, resource-conserving technologies as such would generally have overwhelmingly positive environmental effects. However, under certain circumstances the promotion of conservation tillage practices also can have detrimental environmental effects. As a result, we can distinguish different combinations of agricultural and environmental outcomes (Fig. 2):

1. *Agriculture lose - environment lose*: Adopting zero- or reduced tillage practices without adequate residue conservation is harmful both agriculturally and environmentally. Experimental evidence repeatedly has shown that without the protective mulch, reduced tillage actually backfires, causing lower yields because of soil sealing, compaction, runoff and other problems. Furthermore, without the protective mulch, reduced tillage also loses most of its soil conservation effect. There is little point in promoting such practices, and care should be taken so that they are not mistaken for true conservation tillage.

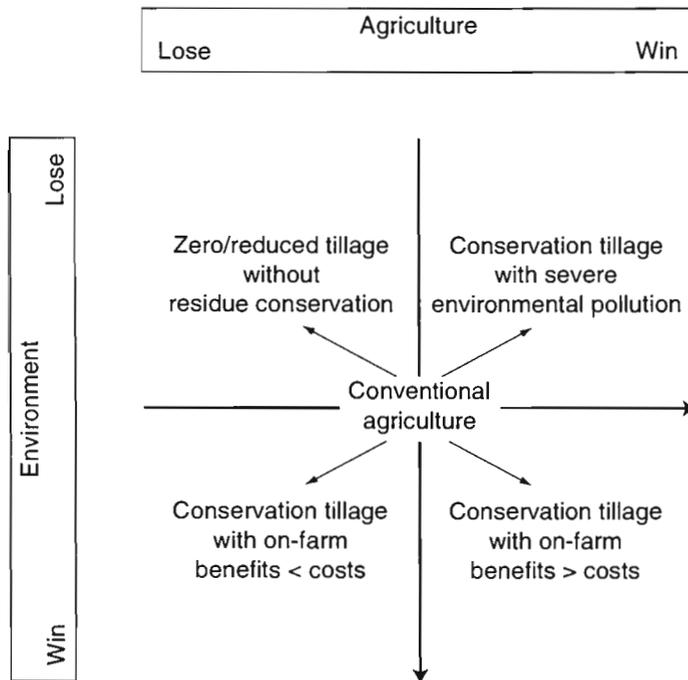


Fig . 2. Potential win-lose relationships between agriculture and environment from adopting conservation tillage.

2. *Agriculture win - environment lose*: Adopting conservation tillage practices under profitable on-farm circumstances would generally lead to a win for agriculture. However, excessive or inappropriate agrochemical use may cause severe environmental pollution, which in extreme cases may offset the soil conservation effects. In such cases, the environmental degradation could be alleviated through corrective measures such as education and price policy.
3. *Agriculture lose - environment win*: Adopting conservation tillage practices would generally reduce the environmental degradation occurring under conventional agricultural practices. However, the on-farm costs of adopting conservation tillage may outweigh the benefits, as in some of Mexico's semiarid regions that have an important livestock sector. In such environments, the opportunity cost of the residues may be so high that it is impossible to offset them through increased productivity. The technology thus offers limited scope unless part of the on-farm costs can be alleviated, such as by better alternative fodder sources and management practices.

4. *Agriculture win - environment win.* Adopting conservation tillage practices is most feasible in areas where the on-farm benefits outweigh the on-farm costs and the environmental benefits outweigh environmental costs. Generalizations of this win-win potential are dangerous in view of the many factors that contribute to the benefits and costs. However, the technology especially seems to have potential where the opportunity cost of residues is low, such as in humid areas where there are abundant and better supplies of fodder. Also, the productivity-enhancing feature of the technology becomes especially obvious in areas with a water deficit during the growing season or in areas that are particularly prone to severe soil degradation, such as steep hillsides. Only in such win-win cases does the technology seem to offer a viable productivity-enhancing, resource-conserving alternative.

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