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Sustainable Maize and Wheat Systems for the Poor

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Reprint Series 97-02

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Financial support for CIMMYT's research agenda currently comes from many sources, including the governments of Australia, Austria, Belgium, Canada, China, Denmark, France, Germany, India, Iran, Italy, Japan, the Republic of Korea, Mexico, the Netherlands, Norway, the Philippines, Spain, Switzerland, the United Kingdom, and the USA, and from the European Union, the Ford Foundation, the Inter-American Development Bank, the Kellogg Foundation, the OPEC Fund for International Development, the Rockefeller Foundation, the Sasakawa Africa Association, UNDP, and the World Bank.

Responsibility for this publication rests solely with CIMMYT.

Printed in Mexico.

Correct citation: Erenstein, O. 1997. *Conservation Tillage or Residue Conservation?An Evaluation of Residue Management in Mexico.* NRG Reprint Series 97-02. Mexico, D.F.: CIMMYT.

ISSN: 1405-3748
AGROVOC descriptors: Mexico; Conservation tillage; Crop residues; Crop management; Methods; Technology transfer; Innovation adoption; Maize; *Zea mays*
AGRIS category codes: E14 Development Economics and Policies
F07 Soil Cultivation
Dewey decimal classification: 338.162

Conservation Tillage or Residue Conservation? An Evaluation of Residue Management in Mexico

Olaf Erenstein[1]

Abstract

The key to conservation tillage is the use of crop residues as mulch. However, there is some confusion over the term conservation tillage, among other things, because too much emphasis has been placed on tillage. Since tillage is only one of many factors that affect residue availability in the tropics, residue conservation would seem a more appropriate term in those environments. In Mexico, the emphasis of conservation tillage campaigns has been on no burning and no soil inversion (no plowing). In fact, burning and soil inversion are incompatible with retaining enough residue to form an effective mulch. However, it should be noted that all uses of crop residues have to be taken into account to practice effective residue conservation, i.e., not only burning or plowing, but also residue extraction, overall incorporation, and weathering, as well as the amount of residue produced. All alternative uses and total residue production should be factored into the residue balance, which is specific to each locality.

Introduction

In recent years, conservation tillage has received a great deal of attention in Mexico. Several governmental as well as non-governmental organizations have conducted research on it or have promoted the technology throughout the country. All this attention has favored the adoption of conservation tillage by farmers, but has had some disadvantages. For example, the large number of people involved has generated an equally large number of definitions of the technology. To some, conservation tillage simply means not burning, while others view it as zero or reduced tillage (no soil inversion). However, the real key to the technology is retaining a sufficient amount of residue as mulch. Without mulch, practices such as zero tillage may be counterproductive. This confounds the interpretation of the reported conservation tillage experiments, as it is frequently difficult to discern if the mulch was actually present.

How did this confusion in terms originate? As a matter of fact, "a classic problem affiliated with conservation tillage over its years of development has been its definition" (Pierce, 1985). The confusion in terms is due partly to the different interpretations of "conservation" (conservation of what? soil, water, residues?). Another source of confusion is the word "tillage."

There are many different types of tillage methods (involving a wide range of tools and practices). The word "tillage" also places a great deal of emphasis on working the soil. This seems to be most adequate for production systems in the United States, where the technology originated and where incorporating residues through tilling was the major end use of residues. When tillage was reduced, more residues automatically remained as mulch. Nevertheless, in tropical environments, tillage is only one of several factors affecting residue availability. In fact, in some tropical environments no-tillage is already being practiced (e.g., manual labor systems in marginal areas where stick planting is used), but residues are not necessarily retained (they are sometimes grazed or burned). Thus "residue conservation," which emphasizes a crucial rather than a partial component of the technology, seems to be a more appropriate term in tropical systems.

This paper summarizes the implications of residue conservation for crop production systems in Mexico. It focuses mainly on maize-based production systems, given that maize is the most important crop in Mexico. However, before discussing residue management in Mexico, we will discuss the role of crop residues in soil (and water) conservation.

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Published in *Síntesis de resultados experimentales del PRM, 1993-1995*, vol. 5 (1997), pp. 188-197.

The Role of Crop Residues in Soil Conservation

The two major processes of water erosion are the loosening of soil particles by rain splash and the washing away of soil particles by water runoff. The major control mechanisms are maintaining good soil cover (to reduce rain splash) and maximizing soil infiltration (to reduce the amount and speed of runoff) (Shaxson *et al.*, 1989). Crop residues may provide both mechanisms if sufficient quantities are left to form an effective layer of mulch. Mulch serves a double purpose by providing a protective cover for the soil and, at the same time, increasing soil infiltration. The mulch increases infiltration by forming new physical barriers against runoff and improving the physical structure of the soil (and, therefore, its permeability). When 35% of the soil surface is covered with uniformly distributed residues, splash erosion may be reduced up to 85% (compared to exposed soil) (Shaxson *et al.*, 1989). The relationship between relative splash erosion and low-level soil cover is shown in Quadrant I of Figure 1.

Using Quadrant II of Figure 1, it is possible to estimate the amount of maize residues needed to achieved a given level of soil cover. For example, approximately two tons of residue per hectare are necessary to obtain 35% soil cover. Although more than two tons will increase coverage, the gain in terms of diminishing erosion is relatively small. For example, four tons of residues would provide approximately 60% soil cover and a relative erosion of less than 5%. Thus, from a conservation point of view, larger amounts of residues do conserve soil better. However, from an economic standpoint, soil conservation becomes increasingly expensive in terms of the amount of residue required. Two tons per hectare have been established as the minimum amount required for achieving a substantial reduction in relative erosion. To classify as a residue conservation system, this threshold should be satisfied immediately after planting, that is, after crop establishment but before the new crop produces enough vegetative cover.

The idea of using residues as mulch arose from the need to conserve the soil. However, an important aspect of soil degradation is that the damage is cumulative. The effect of soil degradation in a given year may be minor or insignificant, but may accumulate over time (Lal, 1987). Similarly, the benefits of reducing degradation by way of soil conservation practices are cumulative. In contrast, small farmers in tropical environments have problems and needs that require short-term solutions. They are generally not willing to invest large sums in conservation measures. For soil conservation practices to be viable in these environments, additional costs must be limited.

Residue conservation also works as a water conservation measure by decreasing water losses (less runoff, better infiltration, less evaporation) and increasing the amount of water available to the crop. In general, this effect of water conservation is what is first noticed in terms of better yields after the adoption of residue conservation practices. The effect is most evident in areas where there is moisture stress during the cropping cycle. However, it should be emphasized again that this effect of water conservation depends primarily on the use of residues as mulch. In other words, soil and water conservation are a function of residue conservation.

The effect of water conservation may produce short-term benefits and reduce the cost of residue conservation. However, the adoption cost (and, therefore, the potential) of residue conservation depends on several local factors that directly affect residue availability.

In the following section, factors that influence residue availability in Mexico are discussed. Residue production is presented, and then the alternative uses of residues are discussed. Figure 2 shows this information in graphic form.

Residue Production

Agricultural production generally focuses on generating one or more basic outputs (e.g., maize grain). However, the production of basic outputs generates residues (e.g., maize stubble) that are generally considered by-products of farm production. Interest in generating the basic output is reflected, among other things, in the harvest index, which expresses production of the basic output as a fraction of total biomass.

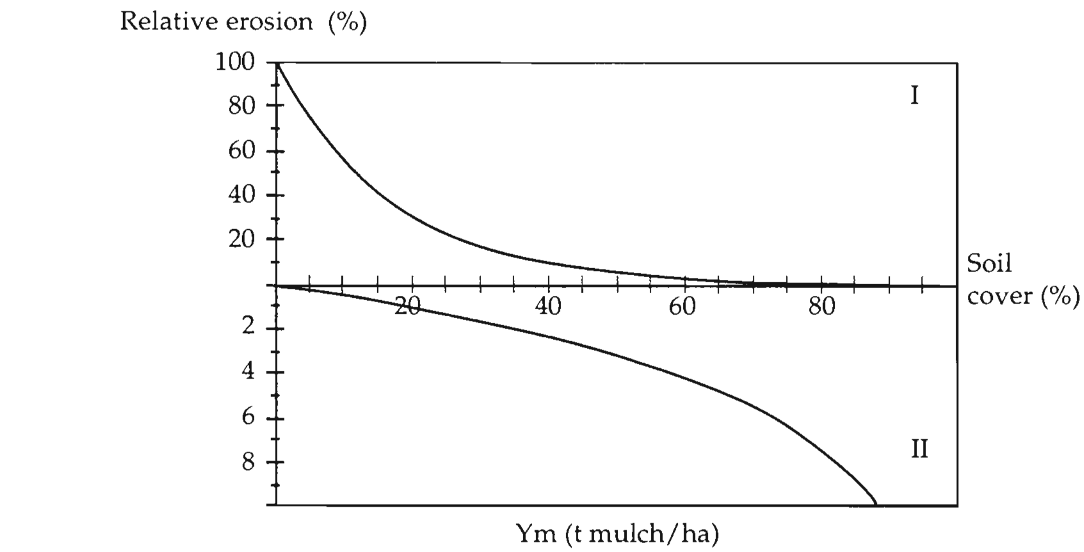

Figure 1. Two-quadrant graph showing the relationship between relative erosion and soil cover in Quadrant I (Shaxson *et al.*, 1989) and soil cover and amount of mulch [Y_m] in Quadrant II (adapted from Tripp and Barreto, 1993, and Kok and Thien, 1994).

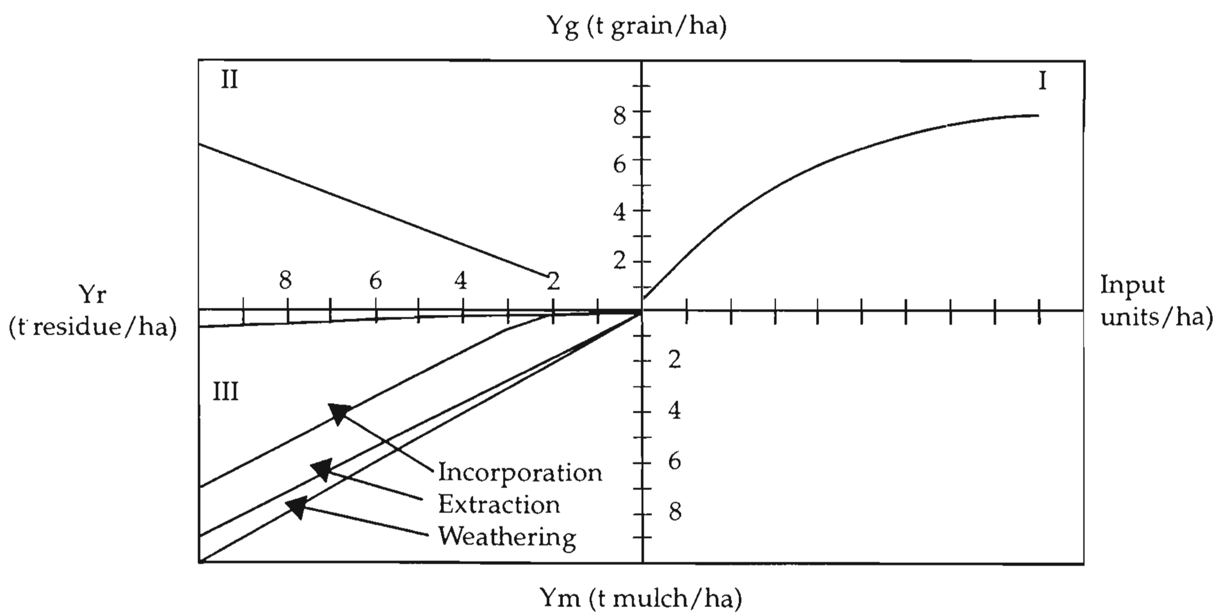

Figure 2. Three-quadrant graph showing the relationship between input and grain yield [Y_g] in Quadrant I; grain yield and residue yield [Y_r] in Quadrant II; and residue yield and amount of mulch [Y_m] in Quadrant III (adapted from Sain, 1996).

In cereals such as maize this relationship may be expressed as:

$$HI = \frac{Y_g}{(Y_g + Y_r)} \quad (1)$$

where:

- HI : harvest index (fraction)
- Y_g : grain yield (t/ha)
- Y_r : residue yield (t/ha)

By reorganizing this relationship, residue production may be calculated as:

$$Y_r = \frac{(1\text{-}HI)^* Y_g}{HI} \quad (2)$$

This relationship shows that residue production is directly linked to production of the basic output. In addition, the harvest index for cereals such as maize is relatively constant for a given variety. Therefore, for these cereals, residue production is a linear function of grain production (see Figure 2, Quadrant II).

It should be noted that the harvest index may vary greatly among crop varieties. For example, a maize landrace may have a harvest index as low as 30%, while in an improved variety it may reach 50%. Thus, at the same grain yield level, residue production will generally be substantially higher with a landrace than with an improved variety.

The direct relationship between grain and residue production implies that all factors influencing grain production also directly influence residue production. Grain production is a function of several factors, including some that are both agroecological and socioeconomic in nature.

Agroecological factors

Ecological factors are the primary determinants of potential biomass production in each environment. The most important factor in tropical environments is water availability, followed by availability of macro- and micronutrients. Availability of these factors is directly related to ecological characteristics such as precipitation, evapotranspiration, soil, temperature, altitude, topography, etc. *Ceteris paribus*, the amount of available biomass (and hence, residue production) is generally much greater in the humid tropics than in the arid tropics; in tropical lowlands than in tropical highlands; under good rainfed conditions than under marginal rainfed conditions (short and/or irregular rainfall), etc. Environmental limitations may be modified by agronomic practices. Water availability may be increased not only through irrigation but also through water conservation practices or by adjusting planting dates. Similarly, nutrient availability may be increased not only through fertilization, but also by altering the physical or chemical soil properties. *Ceteris paribus*, the quantity of biomass available (and hence, residue production) is generally much greater in irrigated systems than in rainfed agriculture; in systems using chemical fertilizers than in those that rely on soil mining; etc.

However, agronomic practices do not only influence the availability of basic factors. To a large extent, the crop itself determines the response (in terms of production) to the availability of production factors. In the first place, the type of crop has major implications. For example, a cereal crop (e.g., maize) potentially produces more biomass than a leguminous crop (e.g., beans). In the second place, the variety itself also plays a role. An improved cereal variety generally responds better to inputs than a landrace. Furthermore, the differences among varieties are reflected in the harvest index (Figure 2, Quadrant II).

The combination of agroecological factors determine the form of the production function, as shown in Quadrant I of Figure 2.

Socioeconomic factors

Agronomic practices can alleviate some of the environmental limitations. However, the use of these practices is directly influenced by socioeconomic factors such as input and output prices and, especially, the ratio between the two. The relative price of an input (relative to the output price) largely determines its level of use.[2] But prices are not the only factors that affect input use. The type of production (commercial or subsistence) largely determines the influence of prices on the use of inputs. However, the availability of resources also influences the use of inputs. For example, applying 100 units of fertilizer per hectare to the crop may be economically sound, but the farmer may sometimes use only 50 units due to a lack of cash.

Socioeconomic factors determine to a large extent where the use of inputs is located in Quadrant I of Figure 2. Therefore, given the production function, socioeconomic factors determine the level of production.

Alternative Uses of Crop Residues

Residue production does not translate simply into its availability as mulch. In tropical regions, residues have several uses (or destinations) that directly affect their availability as mulch. These uses may vary considerably between and even within regions. The different alternative uses of residues affect the relations shown in Quadrant III of Figure 2. We present these uses in greater detail in the following section, and will discuss their implications for retaining residues as mulch in a later section.

Extraction

Although maize residues are generally considered agricultural by-products, they have several productive uses. The most important use is as forage, although residues are also sometimes used as building materials or as an energy source (Choto and Saín, 1993). With regard to their use as forage, a distinction must be made between grazing and harvesting residues for later use. There are several ways of harvesting residues both manually and mechanically (e.g., by packing residues in bales or grinding them). In general, residues are harvested thoroughly, leaving very little in the field. They are usually harvested after the main produce, although there are exceptions, such as the practice of removing the part of the plant above the ear once the grain reaches physiological maturity.

In Mexico, the use of maize residues as forage during the dry season is very common, especially by grazing. The amount of residue grazed varies, although in general it depends to a large extent on livestock pressure (intensity and duration) and the existence of other forage sources (e.g., summer pasture or forage crops). In general, residues are not very nutritious as animal feed and are used more out of necessity. This is even more apparent when comparing the use of residues in arid and humid areas. In the latter, there are usually other forage alternatives better than residues, and their use is limited. Grazing by livestock is relatively selective, which also reflects the low nutritional value of residues. In general, livestock will eat the tender parts (the leaves and *totomoxtle*, or leaves surrounding the ear) first, leaving the tougher parts (stalks) for last.

Burning

Burning is a traditional way of eliminating residues (commonly called "*basura*", or debris). In many areas of Mexico, it is still one of the first steps in land preparation. Before the crop cycle (which generally coincides with the end of the dry season), fire is set to the dry biomass in the field. This practice originated in migrant slash and burn systems to get rid of large quantities of biomass and improve fertility with the ash. The practice persists in sedentary systems, even though the amount of biomass is much smaller. Farmers continue burning for several reasons, but mainly to clear the field and facilitate other land preparation operations and planting. This is especially the case in systems where manual labor or animal traction is used and the incorporation of residues is minimal, which makes subsequent planting difficult. Further, burning also controls animal pests, diseases, and weeds. In this respect, burning is a double-purpose control method because it directly affects both the organisms and their natural habitat. The latter effect is particularly important in controlling such pests as rodents.

[2] For example, the devaluation of the Mexican peso at the end of 1994 caused an increase in prices of external inputs relative to agricultural and livestock products. The use of the affected inputs was substantially lower during the 95 spring/summer cycle than in previous years.

In general, burning is very effective for disposing of residues. However, it may be less efficient when there are small quantities of residues and the farmer does not group these.

Incorporation

In arable systems, land preparation traditionally implies tillage before planting. The main purpose of this operation is to create a clean, uniform seedbed that facilitates planting and crop establishment. To achieve this, the top soil is turned over, incorporating residues remaining on the soil surface. In mechanized systems, incorporation may be substantial, depending largely on the tillage method used. Of special importance are the type of implements used, the number of passes, and the depth and speed of the cultivations (ACC and CTIC, 1994). There is generally a certain degree of residue incorporation in animal traction systems, although less than in mechanized systems. In manual labor systems with zero tillage, the level of residue incorporation is not significant.

In arable systems in Mexico, disk plowing and harrowing are common. Plowing is especially effective for incorporating residues (80-90% according to ACC and CTIC, 1994), although several passes with the harrow are also effective for incorporating large amounts of residues.

Weathering

Even if not used for any specific purpose, the amount of residues diminishes over time due to the weathering process, consisting mainly of residue decomposition, which is a function of time,[3] and several agroecological factors such as moisture, temperature, and biological activity in the soil. The nature and status (fragility) of the residues are additional factors that facilitate/speed up decomposition. Besides decomposition, weathering may include wind and water erosion of residues, which may be important in areas with steep slopes and/or strong winds.

In warm, humid environments, residue weathering between cycles may be substantial. However, weathering is relatively limited in many Mexican environments due to a combination of factors. The unimodal rainfall distribution in most environments implies a long, intense dry season, sometimes lasting more than six months. During this season, weathering is limited by the lack of water. In more humid areas where there is a second crop (e.g., relay cropping), the period between crop cycles is shorter. In addition, the main crop in Mexico is maize, and maize residues are not very fragile, especially if harvested manually.

The Residue Balance

In general, the sum of all possible uses or destinations of residues should not exceed production. Although in theory there is the option of importing residues into the field to form an effective mulch, in general it is not economically feasible on a production scale (Lal, 1989). It is also worth noting that residue uses (with the exception of mulch) are irreversible, though several can coexist. For example, part of the residue may be used for grazing (productive extraction) and the rest may be incorporated during land preparation. Thus the residue balance may be expressed as:

$$P = U_E + U_B + U_I + U_W + U_M \qquad (3)$$

where:

P : production
U_E : extraction
U_Q : burning
U_I : incorporation
U_D : weathering
U_M : mulch

The residue balance is site specific because both production and use are determined by local factors. A complication when determining the residue balance is that, in many uses, residues are not usually harvested or measured. It is thus sometimes difficult to gather the above information quickly. Nevertheless, there are several techniques that facilitate measuring the amount of residues. Two methods based on field observations are the use of photographs with predetermined amounts of

[3] Relevant for residue conservation is the interval between harvest and the establishment of the subsequent crop.

residues as reference (e.g., Tripp and Barreto, 1993) and the transect line methodology (e.g., Shelton *et al.*, 1994).

It is worth emphasizing that the use of residues as mulch will always be residual, i.e., other uses generally determine how much residue is left over for use as mulch. Earlier we saw that at least two tons of residues per hectare are needed for an effective mulch. We can thus reorganize the relation (3) to establish the following condition for residue conservation:

$$P - (U_E + U_B + U_I + U_W) \geq 2 \qquad (4)$$

If this condition is satisfied, sufficient residues have been retained to form an effective mulch. If it is not, either residue production (P) will have to increase or its alternative uses (sum of U) have to decrease in order to form an effective mulch. In the following section, we discuss these options in general terms, taking into account the potential costs for the farmer. The higher the costs, the higher the opportunity cost of residues as mulch and the less attractive the adoption of the technology. Nevertheless, it should be emphasized that these costs are site specific.

Increasing production

Increasing residue production may at first glance seem an option that satisfies the condition of residue conservation (4). However, many uses such as burning, incorporation, and weathering are directly related to the total amount of residues. *Ceteris paribus*, this implies that an increase in production would result in an increase in such uses. Only in cases where extraction is important and at a more or less fixed level (e.g., grazing) would residue availability be substantially alleviated by increasing production. Reducing uses such as burning and incorporation would thus seem to be a higher priority.

Reducing incorporation

Campaigns promoting conservation tillage in arable systems have focused on reducing residue incorporation. Hence the emphasis on minimum and zero tillage, which substantially reduce residue incorporation compared with more intensive tillage systems. One of the first goals in promoting conservation tillage in arable systems is to eliminate the practice of plowing.

Reducing tillage greatly decreases residue incorporation and may also generate substantial savings in land preparation costs. This is one of the technology's most attractive features in the short term. However, reduced tillage also means a more irregular seedbed covered with more residues. The presence of residues makes planting difficult and more time consuming, whether it is done manually, with animal traction, or mechanically, with a conventional seed drill. A direct seed drill solves this problem by planting the seed through the residues in unprepared (but arable) soil. However, up to now this type of machinery has been relatively unavailable in Mexico, among other reasons, because of its high cost. Therefore, the adoption of conservation tillage in arable systems in Mexico has been geared toward minimum tillage systems. The disadvantage is that these minimum tillage systems still incorporate a substantial portion of the residues (e.g., two passes with a disk harrow will incorporate half the residue present; ACC and CTIC, 1994). This is a problem, especially in areas where residue availability is already limited.

Furthermore, it is not only planting that is made more difficult. Some crops simply cannot emerge from under a cover of residues from the previous crop (e.g., chickpea after maize in Jalisco; Mendoza *et al.*, 1992), so the cropping pattern may limit the possibility of decreasing residue incorporation. The lack of tillage may also generate problems of perennial weeds in zero tillage systems, though it also can actually restrict weed growth if the layer of mulch is thick enough.

No burning

Efforts aimed at promoting conservation tillage in zero tillage systems have focused on eliminating the burning of crop residues. Burning is incompatible with conservation tillage because it is so efficient at getting rid of residues that it does not leave enough for mulch. However, many farmers associate the incidence of several maize pests, including soil pests such as white grubs (*Phyllophaga* spp.), leaf pests such as fall armyworm (*Spodoptera frugiperda*), and rodents, with the practice of not burning maize residues. There is potential for higher incidence of pests and diseases, given that most rainfed areas in Mexico have a pattern of continuous maize-maize cultivation with one crop cycle per year. However, residue conservation favors not only harmful pests and diseases, but also their natural enemies, which helps to establish a new equilibrium. In fact, several studies have reported equal or lower incidence of some pests (for example, fall armyworms; Violic *et al.*, 1989), but others have increased. Therefore, it is still unclear how using residues as mulch may affect the costs of controlling pests and diseases or the damage they may cause.

Some conservation tillage programs have focused on convincing farmers not to burn by giving them incentives and disincentives. For example, the government of the State of Chiapas has been distributing backpack sprayers, inputs, and credits as an incentive to adopt the practice of not burning. It has also passed a law banning the use of burning for land preparation (Cadena, 1995).

It is worth noting that a farmer will stop burning only if he believes the benefits of not burning are greater than the costs. However, it is not enough that an individual farmer stop burning his residues because he is convinced of the advantages of not burning. As long as one of his neighbors continues burning to prepare the land or regenerate pastures, there is the risk that his mulch will accidentally catch fire (in Mexico it is common to hear that a farmer did not burn, but that the "the fire crossed over" into his fields). To be sure that his residues will not burn, the farmer would need to make additional investments in terms of time and energy to build a fire barrier.

Reducing extraction

Reducing the extraction of residues is feasible only if the farmer believes the benefits of not extracting them are greater than the costs. It should be noted that as it is a matter of productive extraction in general there are true visible costs in retaining residues. Furthermore, several scenarios are possible. The farmer may extract the residues for his own benefit. In this case, if he reduces extraction, he will need to seek alternative sources of forage or reduce the size of his herd. At first glance, this does not seem to be a very attractive option.

It may also be that other farmers extract his residues. In that case, the cost of reducing extraction depends considerably on whether users pay for the residues. Extraction might be free—for example, through communal grazing after harvest, a practice common in Mexico and Central America. If socially acceptable, the farmer may consider restricting the access of livestock to his fields by fencing them off, for example. However, in this case the need to protect his residues may represent a substantial entry barrier in terms of costs.

In other places where there is already a market for crop residues, the residue is generally sold standing. Arrangements and prices vary, depending on the region (e.g., demand for and production of residue as forage) and on plot specific factors (e.g., location, fencing, water availability, amount of residue). In these cases, the costs of reducing residue extraction are very evident, given that farmers will have to stop selling residues. This limitation is particularly severe if the benefits from the sale of residues constitute a substantial part of the farmer's gross income (e.g., > 10%), which is the case in some semiarid areas of Mexico (e.g., the Mixteca region in the State of Oaxaca, Bravo *et al.*, 1992).

It should be mentioned that land tenure agreements in Mexico generally contain provisions regarding the use of residues. If the decision is completely up to the owner, it may be impossible for a tenant to reduce residue extraction.

Reducing weathering

Weathering is difficult to reduce given that it is an autonomous process and a direct result of the forces of nature. However, the farmer may influence the weathering process somewhat by: 1) selecting a crop with non-fragile residues, 2) using an appropriate harvesting method, and 3) deciding how long residues are exposed to weathering (e.g., planting date). However, this option does not seem to offer great opportunities for residue conservation.

In summary, the most realistic options for satisfying the condition of residue conservation seem to be to eliminate burning and to reduce residue incorporation (especially plowing in mechanized systems). Both practices are very efficient in getting rid of residues and therefore incompatible with residue conservation. In Mexico, efforts aimed at disseminating conservation tillage have emphasized these two factors. However, even with no burning and reduced tillage, there may still not be enough residues to form an effective mulch. In that case, the extraction of residues would have to be reduced, which seems to be the most costly option, and the potential of the technology would depend largely on the opportunity cost of residues as forage. The other two alternatives, increasing residue production or reducing weathering, seem less promising.

Conclusion

The key to conservation tillage is the use of residues as mulch. However, there is much confusion over the term conservation tillage—among other reasons, because it over-emphasizes tillage. Tillage is only one of the factors that affect the availability of residues in tropical areas. Therefore, residue conservation seems to be a more appropriate term in tropical environments.

In Mexico, efforts promoting conservation tillage to date have emphasized no burning and no soil inversion (no plowing). Though burning and plowing are incompatible with retaining enough residue to form an effective mulch, it should be emphasized that to retain residue it is necessary to consider all alternative uses, that is to say, not only burning and plowing, but also extraction, aggregate incorporation, and weathering, as well as residue production. The whole range of alternative uses and production are included in the residue balance. Since this balance is site specific, it is unwise to make generalizations. However, in the Mexican context, the residue balance does not generally facilitate residue conservation in semiarid areas where residues are an important source of forage during the dry season. For example, in the semiarid Mixteca region (State of Oaxaca), Bravo *et al.* (1992) found that the importance of residues as forage and their resulting high price present a serious limitation for residue conservation.

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ISSN: 1405-3748

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