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Planting System on Permanent Beds; A Conservation Agriculture Alternative for Crop Production in the Mexican Plateau

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1. Introduction

Mexico is the world´s twelfth largest country. Almost one-quarter of the population depend on the farming sector for their livelihood. More than half the territory of Mexico is arid or semi-arid, and rainfall is the main factor limiting agricultural production (< 500 mm). Rainfed crops occupy 58 percent of the total sown area that is characterized by a large number of small-scale farmers. This shortage of farmland has resulted, mostly in the central part of the country (the high plateau or Mexican plateau), in an increment of sloping lands cultivated leading to severe soil degradation and erosion. Then, appropriate tillage/planting techniques for crop production have to be studied and promoted to be adopted to mitigate soil erosion and climatic constrains. This work should include the study of maize and small grain cereals like wheat, oat and barley as these are the most common crops in the Mexican plateau.

Indigenous farmers, on the other hand, have used raised-bed cultivation system for centuries for some row crops like corn, beans, and squash. In some states of central Mexico, raised field agriculture is a traditional system that dates back to as early as 300 B.C. (Crews & Gliessman, 1991). Currently, this planting system has been modified and widely adopted in the irrigated areas of northwest Mexico for other crops like wheat (Sayre et al., 2005). Similarly, due to the large potential to be fully adapted in dryland areas of the Mexican plateau, some farmers have started adopting the system. Regrettably, in both cases, considerable use of tillage operations is been applied. Even thought this system offers opportunities to grow crops more efficiently, the use of heavy tillage generally is promoting soil erosion, exacerbating effects of climate change, and increasing production costs. Indeed, Edward Faulkner (1943) with the publication of his classic book, "Plowman's Folly," challenged the conventional wisdom of the day by stating in the very first sentence of the very first page "Briefly, this book sets out to show that the moldboard plow which is in use on farms throughout the civilized world, is the least satisfactory implement for the preparation of crops." He went on to say, "The truth is that no one has ever advanced a scientific reason for plowing." These were revolutionary ideas at the time and met with ridicule and scorn (Triplett & Dick, 2008).

In addition to heavy tillage for seed bed preparation, another constraint for crop production is the climate change which nowadays is clearly evident. This change is most commonly

expressed with higher temperatures and prolonged drought periods. Among the multiple consequences of those changes are the reduction of soil fertility and organic carbon (St. Clair & Lynch, 2010). Fortunately, the reversal can occur as increasing soil organic matter (OM) decreases atmosphere C pools. In this regard, some governments have been initiated efforts to develop markets for crop producers using C-sequestering cultural practices to sell C credits (Wilhelm et al., 2004). Thus, a technological proposal to ameliorate to some degree those ecological and economical constrains, is the application of conservation agriculture. This modern technique has evolved in different ways. One of them is known as the planting system in permanent beds.

This technology applied in the irrigated areas of northwest Mexico, with serious shortage of water in the reservoirs and even though most farmers still use conventional tillage, those that now grow wheat using the planting system on beds obtain 8% higher yield, use approximately 25% less irrigation water, and encounter at least 25% less operational costs compared to those still planting conventional tilled wheat on the flat using flood irrigation (Aquino, 1998).

On the other hand, most of the research work to develop the permanent beds technology has been carried out on wheat and maize crop but the planting system can be applied to many others such as oat, barley, beans, etc. The basic management for this technology consists mainly on leaving crop residues on soil surface as mulch, crop rotation, and bed reformation when needed (Verhulst et al., 2011). Research results have shown that if those practices are applied accordingly, grain yields can be even greater than those from a conventional planting system (Sayre, 2004; Govaerts et al., 2005), in addition to the improvement and conservation of soils (Govaerts et al., 2007). For example, diverse benefits on soil physical, chemical, and biological attributes have been identified from crop rotation and residue management (Torbert et al., 2007).

However, it is has been throughout reported that during the first years at the establishment of the permanent bed planting system, crop yields can be reduced as the net N immobilization is increased (Yadvinder-Singh et al., 2004) by microorganisms to undergo residue decomposition. This phenomenon reduces the N availability to plants to such extent that additional N fertilizer should be applied for several years until disequilibrium comes to an end (Gentile et al., 2010; Govaerts et al., 2006a) and crop yields become stable (Sayre & Hoobs, 2004). After this period, the bed planting increases the N use efficiency compared with conventional planting (Fahong et al., 2004) overall if the appropriate management practices are applied (Limon-Ortega et al., 2000). Nevertheless, there is some inconsistency between studies as other reports indicates that soil water or soil N is conserved when tillage is reduced in some environments, but not in others. The apparent inconsistency between studies suggests that complex interactions between climatic and edaphic factors affect the impact of tillage on soil water and soil N content. Therefore, more research is needed to elucidate why soil water and soil N status are not affected consistently across environments (Carr et al., 2003a; Schillinger, 2005).

This chapter aims on summarizing the dynamics of wheat and maize grain yields over years of research on permanent beds under the dry land conditions of the Mexican plateau. This includes the discussion on the effect of various management factors on the performance of those crops, as well as the advantages of this planting system and their effect on soil attributes.

2. Description of the planting system on permanent beds

Conservation tillage is broadly defined as any tillage system that leaves enough crop residues to adequately protect soil from erosion throughout the year (Reeder, 1992; Scillinger, 2005). Because erosion control is improved with increasing soil cover, systems with 30% or greater soil cover at planting time have been defined as conservation-tillage system (USDA-SCS, 1984). More recently the name of 'conservation agriculture' has been adopted to highlight this sustainable system from the narrowly defined 'conservation tillage' (Govaerts et al., 2009). Zero-tillage (no-till) is one of the primary categories of conservation agriculture, in which the soil is left undisturbed from the harvest of one crop to the seeding of the next one with only slight soil disturbance associated with creating a narrow slot to place the seed/fertilizer (Dickey, 1992).

Similar to zero-tillage, the permanent bed planting system is initiated using conventional tillage to allow the raising of well-formed beds and planting the initial crop. Subsequently, no additional tillage is used except to reshape the beds as required, by passing a winged-shovel in the furrow to maintain the shape of the bed (Morrison et al., 1990). This field operation is usually made before planting each crop but frequency may change depending on crop and/or soil type (Morrison & Gerik, 1983). No tillage is made on the top of the bed except that associated with planting. Since crop residues should be retained, a cutting-disc may need to be placed ahead of the reshaping shovel to allow its free passage through the furrow without clogging with residue during the simple bed-reshaping process. This depends upon the amount of crop residues left that generally vary according to the crop, yield and amount removed for fodder or other purposes. If the amount of crop residues left on the soil surface is the minimum required for a zero-tillage system to adequately protect the soil from erosion, it is likely that the cutting disk may not be needed. Actually this is the case in low- and moderate - rainfall environments of the Mexican plateau where the average grain yield of maize is less than 4 t/ha. The equipment used to reshape beds, with or without cutting-disk, can also be used for mechanical weed control in the furrow areas even in crops like wheat, oat and barley (Sayre, 1998).

The raised bed-planting technology for wheat-based cropping systems was developed in the irrigated areas of northwest Mexico by which a defined number of rows of wheat, or other crops, are planted on the top of beds with furrow irrigation between beds (Wang et al., 2009). Due to the benefits reported by farmers, the bed-planting technology needs to be applied in dryland production areas. The permanent bed planting system applied to irrigated or dryland conditions has various topological variants; bed width and number of seed-rows per bed are probably the most important. (Fig. 1a, b, c, and d). Bed width is mostly determined by user´s preferences to fit individual farm needs and grain yield potential. In general, for the case of small grain cereals, bed-width measured from furrow bottom –to- furrow bottom ranges from 0.75 to 1.6 m and the number of seed-rows per bed from 2 to 6, respectively. As the environment becomes drier and grain yield lowers, beds should be wider (Fig. 1d) and as the environment improves and grain yield increases, beds can be narrowed (Fig. 1b and c) (Sweeney & Sisson, 1988; Iragavarapu & Randall, 1997). In any case, bed width should match machinery to confine wheel traffic to the furrow bottom to maintain the cropping area (bed-top) free from soil compaction (Morrison & Gerik, 1988).

Most farmers that have adopted the bed planting system for dryland wheat, oat and barley production under conventional tillage in the Mexican plateau, plant two or three defined seed rows, regardless of the environment potential, on the top of narrow raised beds (about

80 cm wide) with modified conventional-drills. Analogously, the no-till equipment for small grain cereals to plant multiple rows per bed should be modified as it is not sold commercially. This implies that farmers have to modify no-till equipment so that it can plant through crop residues on beds. This modification requires not only money, but also time and creativity. In fact the machinery problem appears to be greater than any cultural or soil related problem (Morrison, 1985), and this will not be quite solved until machinery designers and agronomist interact to develop models with specific standards for the bed planting system. Those standards should be specific to each region and most common crops. For example, the type of planters should vary according to the amount of crop residues left which in turn depends upon farmer, crop type, and potential environment.

Fig. 1. Planting systems for dryland wheat production in a) conventional planting system on the flat; narrow-raised beds with b) two rows per bed and c) three rows per bed; and wide-raised beds with d) six rows per bed. Farmer´s fields in the Mexican plateau.

3. Benefits on soil attributes

The application of the permanent beds with residue retention as a form of conservation agriculture has several aims. One is to improve soil quality which is a concept based on the premise that management can deteriorate, stabilize, or improve soil ecosystem functions (Franzluebbers, 2002). The annual practice of crop rotation and rational crop residue management as minimum set is crucial to obtain the benefits on chemical, physical and

biological soil attributes which are a function of OM (Chan et al., 2002). However, if those benefits are ultimately to be extended to improve grain yield, those practices should be accompanied with other factors as described in section 5 of this chapter.

3.1 Physical attributes

The primary soil physical characteristic influenced by OM is soil structure through aggregation and aggregate stability (Six et al., 1999). Organic matter improvement is in turn the result of crop residues left or incorporated into the soil. Soil aggregation is the process whereby primary soil particles are bound together into secondary units, usually by natural substances derived from root exudates and microbial activity (Soil Science Society of America, 1997). Reduction of soil crusting on the top of the beds as result of the improvement of soil aggregation (Egball et al., 1996; Fahong et al., 2004) allows a better crop establishment due to a rapid emergence (Guerif et al., 2001). Furthermore, top soil aggregate stability is considered as erodibility factor with strong influence on water run-off and erosion (Barthes et al., 2000). Nevertheless, there is no way universally accepted to measure this parameter (Diaz-Zorita et al., 2002). An approach that has provided an adequate description of aggregate stability is the fractal approach (Guerif et a., 2001). Examples applied to permanent beds can be found in Limon-Ortega et al. (2002) and Limon-Ortega et al. (2006).

For purposes of this chapter a rustic experiment to demonstrate the aggregate stability was carried out using two large clods from the same type of soil; one from a plot under conventional tillage and other from a plot under permanent beds for ten years (Fig. 2a and b, respectively). The experiment consisted on immersing both clods in tab water for about 30 sec. The effect of this immersion on the clod from conventional tillage was to disrupt the initial porosity impeding water infiltration after a rain. The opposite occurred on the clod from permanent beds; porosity was maintained allowing water to infiltrate. In the former case water stagnancy on the surface promotes soil erosion through run-off while in the latter soil erosion is greatly reduced.

Actually, soil erosion due to water run-off is the largest soil degradation process and it is associated to management practices which tend to leave the soil without protection when the rainy season starts. In Mexico, about of 85% of the territory is affected by this sort of degradation (Etchevers et al., 2006) and is frequently caused by the inopportune practice of extensive cattle grazing (Haulon et al., 2007). Regrettably, appropriate management of crop residues from the previous crop is a key to soil structural development and stability (Govaerts et al., 2009).

Relative to grain yield, it has been reported that differences in maize yield between tillage systems are attributed to a better water supply in no-till due to the maintenance of a larger mesopores and a greater hydraulic conductivity (Diaz-Zorita et al., 2004). According to Fig. 2, one might surmise that water supply is greater, and then grain yield, in permanent bed plots (2b) than in conventional tillage plots (2a).

Soil bulk density, another physical attribute, decreases as the soil organic C increases contributing to improve soil quality enhancing the performance of disk-type drills in seed placement in addition to the efficient C sequestration (Halvorson et al., 1999b). However, if a no-till system is practiced on the flat without beds there is a potential increase of bulk density, and thus soil compaction, as machinery circulates randomly (Jones et al., 1989). In the case of permanent beds, this constrain is confined to the furrow bottoms; bed tops remain intact without compaction.
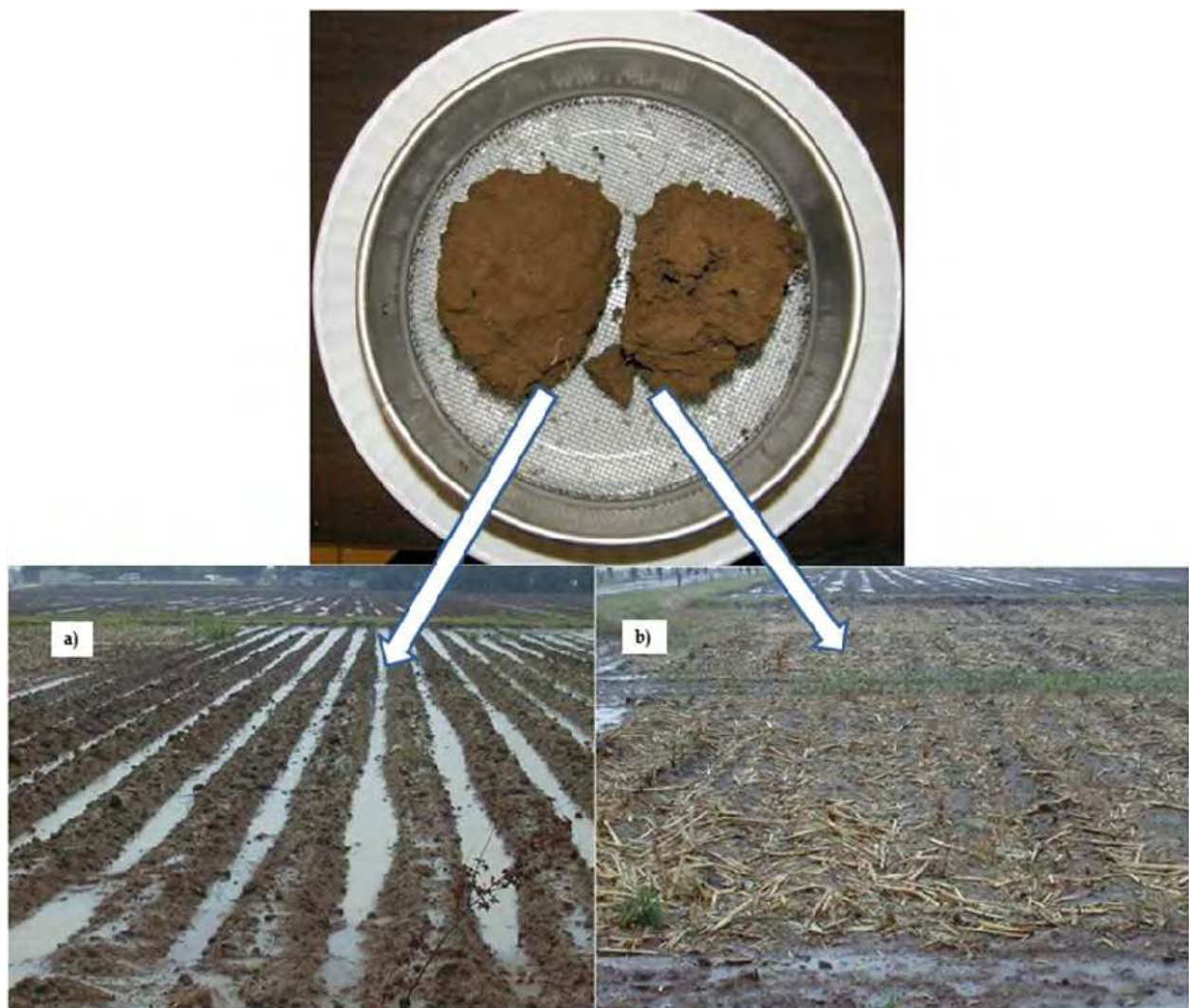
Fig. 2. Stability of two soil aggregates and its effect on water infiltration after a rain storm. Both aggregates from the same type of soil but different till system; a) conventional tillage and b) permanent beds. Arrows indicate the corresponding field plots. Chapingo, Mexico.

3.2 Chemical attributes

The work of Govaerts et al. (2007) in the Mexican plateau reported that sodicity as chemical parameter was highest for conventional-till raised-beds. However, sodium content in permanent beds varies according to the amount of residues left; as the amount is increased, sodicity decreases. The opposite was reported for pH; alkalinity slightly increases.

The decrease in soil salt concentration, on the other hand, resulting from the application of permanent beds may have a tremendous relevance for saline areas (Sayre et al., 2005). However, variations may occur depending upon crop residue management. For example permanent beds with residues burned increases electrical conductivity while the opposite occurs with residue retention (Verhulst et al., 2011). Fig. 3 from a field experiment at Chapingo, Mexico shows how salt concentration is reduced over time with the application of permanent beds with slight variations due to crop rotation.
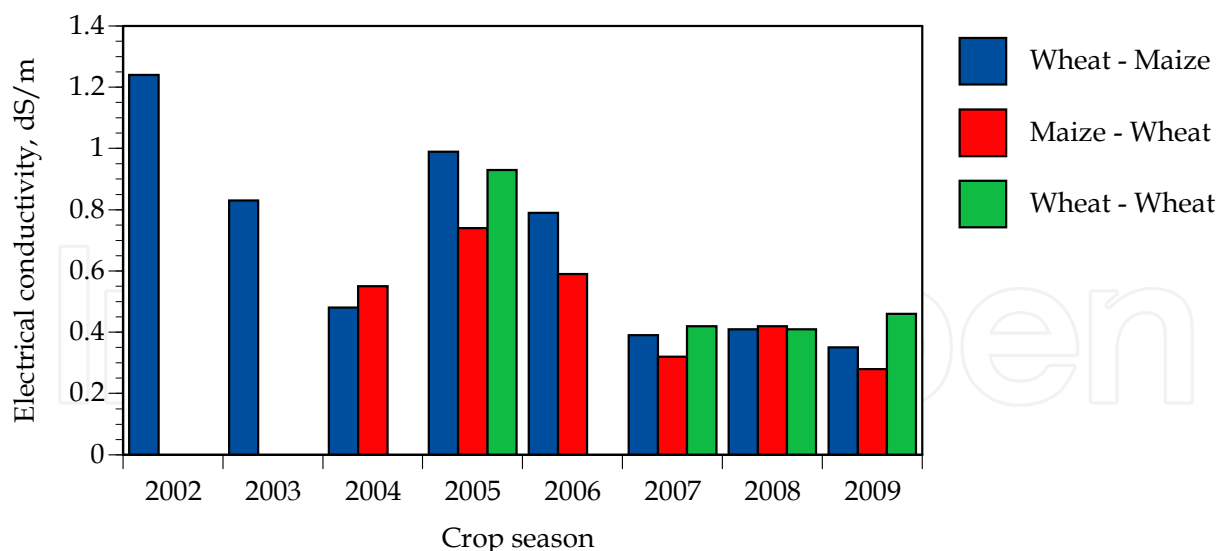
Fig. 3. Soil-salt concentration reduction as result of the use of permanent beds technology under three crop rotations; wheat – maize, maize – wheat, and wheat - wheat. Soil cores were taken from 0 to 30 cm depth. Chapingo, Mexico.

Even thought the initial soil salt concentration in this study was not high enough to be considered as saline soil, it is interesting to see how the electrical conductivity of the soil solution decreases over time from an initial of about 1.2 to 0.5 dS/m after a period of eight cropping cycles. According to this result, the electrical conductivity reduction for the wheat – wheat crop rotation is not as high as showed by the rotation with maize likely due to the higher quantity of crop residues left with this crop. This differential result is attributed to a poor aggregate stability (Verhulst et al., 2011) resulting from an inappropriate crop rotation (Limon-Ortega et al., 2009a).

3.3 Biological attributes

Biological erosion in México is the second largest soil degradation process after water erosion and it represents the rate of organic mater mineralization. Approximately 80% of the territory is affected by some degree of biological degradation (Etchevers et al., 2006). Optionally, the continuous return of crop residues increases the soil OM content. It is estimated that about 11% and 37% of C in corn residues and roots, respectively, ends up as OM indicating that the latter is the major contributor to maintenance of OM in the soil (Barber, 1979). This parameter plays a key role in the soil quality and it is interrelated to physical and chemical properties, far out of proportion to the small quantities present (Kubat et al., 2008). However, the increase in OM is not easily detected by chemical analyses in the short-term. Instead, measurement of soil microbial biomass (SMB) can be used as early indicator of the OM trend (Powlson & Brookes, 1987).

The amount of SMB is an important component of soil quality assessment because of its important roles in nutrient dynamics; decomposition of natural and synthetic organic amendments; and physical stabilization of aggregates. Crop residues, including roots, are a source of nutrients for SMB and plants. Soil microbial biomass is the living component of soil OM and although it comprises less than 5% of OM, it performs various critical functions for plant production in the ecosystem; is a labile source of C, N, P, and S; and is an agent of nutrient transformation (Dalal., 1998). Returning crop residues has a tendency to increase

soil organic C and N (Malhi & Kutcher, 2007) and an example applied to permanent beds can be reviewed in Limon-Ortega et al. (2006).

4. Grain yield variations at the establishment of the permanent bed planting system

The adoption of the permanent bed planting system by farmers faces multiple restrictions, two of them are related to 1) issues of the N cycle and to 2) the visual perspective of wheat fields, i.e. the topological arrangement of plants on beds makes growers hesitate about the appropriateness of the system.

4.1 Variations due to N

Leaving crop residues on the soil surface, among other practices, is critical for the practice of zero tillage to get the benefits on grain yield. Likewise, it can take some time –roughly five years- before the benefits are evident (Govaerts et al., 2005) albeit other authors state that three years are enough (Triplett & Dick, 2008).Other reports indicate that'many' years are required to reach an equilibrium (Motta et al., 2000). This inconsistency leads to think that different effects actually appear due to local conditions, assigning priorities to specific factors and/or processes (Guerif et al., 2001), and offers a great challenge to discern and account for the impact of crop residue on nutrient availability (Schoenau & Campbell, 1996) for plant uptake.

As first instance, the soil N availability declines (Carr et al., 2003a) but the question still remains about how many years of good management it will take before the potential for greater N mineralization will be reflected in situ (Grant et al., 2002). The temporarily N declination is mainly due to organic residues added to the soil surface that should undergo decomposition through the SMB present in soil and/or residues (Cabrera et al., 2005). However, if the amount of N present in the residues is smaller than that required by SMB activity, additional inorganic N will be immobilized from the soil to complete the decomposition process (Corbeels et al., 1999). To offset this temporal deficiency, additional inputs of mineral fertilizer should be applied (Triplet & Dick, 2008) to improve the synchrony between nutrient availability and crop demands (Gentile et al., 2010). Nevertheless, in the long-term the cumulative effects of straw incorporation will play an active role in providing greater amounts of plant-available N from mineralization (Bird et al., 2001) and thus reducing the need of fertilizer inputs. This effect on N will depend upon crop residue quality (Gentile et al., 2010) evaluated as C and N as main parameters (Salinas-Garcia et al., 1997).

Yet, during some seasons and climates, the effect of N immobilization/mineralization at the establishment of a no-till system will inhibit biological activity which may be associated with either production or reduction of plant available nutrients (Schoenau & Campbell, 1996) which will be eventually reflected in grain yields. Fig. 4a and b is an example of what happened to maize and wheat yields, respectively, in a water-limited environment of the Mexican plateau.

Maize yield differences due to N application occurred during the first three years. Lowest yields were obtained with 0 kg N/ha and can be attributed to an initial N immobilization. However, after three years grain yields among N rates were similar (Fig. 4a). This indicates that effect of N immobilization on grain yield occurs only in the absence of N fertilizer suggesting that no additional rates are required to offset immobilization as other factors should be determining final yields.
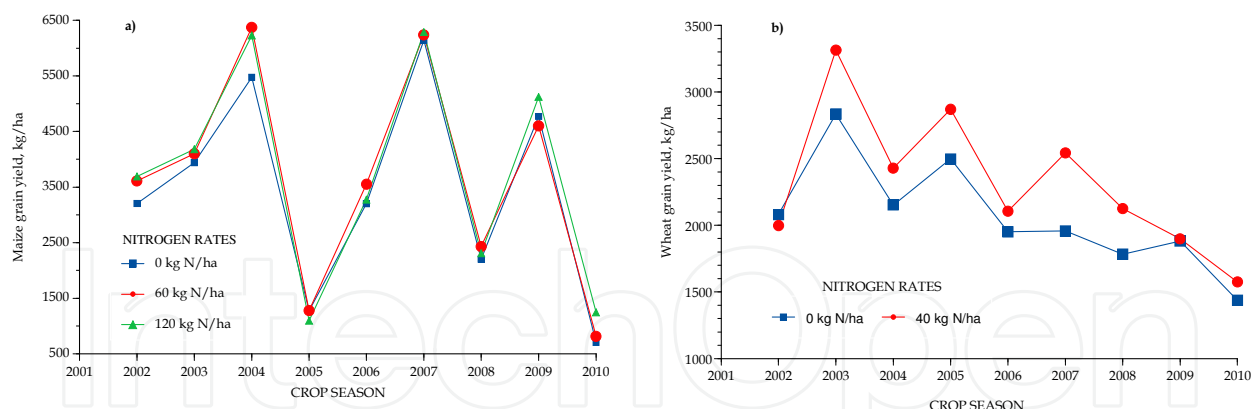
Fig. 4a and b. Maize and wheat yield response to N application and crop season from a trial on permanent beds with residue retention from a trial initiated in 2002 at Chapingo, Mexico.

In contrast, wheat grain yield differences among N rates (Fig. 4b) does not show a clear trend. In average, grain yield differences are clearly lesser than 500 kg/ha, except for the 2007 crop season when the difference was about 600 kg/ha. But from a practical point of view, these differences are minor if the economy of fertilizer acquisition and application is considered. Statistical analysis for this study suggests that wheat grain yields are mostly driven by rainfall amount and distribution albeit there was a slight reduction of soil NO_3 during the first three years.

It is clear that grain yield variations in Fig 4 can not be generalized to other locations as other limiting-factors may be determinants. Indeed, an additional fact in this study is that the application of P and K has been excluded in both crops. Statistical analysis (unpublished data) does not reveal these nutrients as limiting factors. Thus, one may surmise that P is bio-recycled from residues as water-soluble forms and moved with rain to the mineral soil below (Schoenau & Campbell, 1996; Motta el al., 2000). This is of major importance considering the world shortage of mineral P (Cordell, et al 2009).

4.2 Variations due to topological arrangement of small grain cereals

An additional farmers' constrains to adopt the bed planting system even using conventional tillage is the open space in furrows between beds without plants. Generally, they argue that this space is wasted and then grain yields reduced as the seeding rate is too light, or the space between beds too wide for maximum utilization of available resources. However, results from field studies have demonstrated the opposite; grain yields from planting on beds can be even higher than those from conventional planting on the flat. For example, Sweeney & Sisson (1988) reported 15 % wheat grain yield increases in a bed planting system compared to yield obtained in the 'flat' indicating that other factors such as rainfall patterns may be accounting for the differences between systems. The higher yield from beds can be attributed to greater resource utilization through the changes in row spacing and plant density configuration (Chen et al., 2008).

It is well known that wheat plants in narrow-raised beds can compensate, within certain limits, for the lost cropping areas of the open furrows between beds. The exclusion of wheat plants from the furrow bottoms between beds may stimulate tillering, or number of heads, and grain production in location/years with adequate precipitation (Gerik & Morrison, 1985). This increase in tillering can be attributed to more favorable soil moisture and nutritional conditions as well as greater light intensity (Siemens, 1963). Alternatively, if

precipitation is relatively scarce and distribution inadequate, the number of rows per bed should be increased through a wider bed size to compensate for the low number of heads (Sweeney & Sisson, 1988; Iragavarapu & Randall, 1997). And under even harsher conditions, it is likely that a seed row in the furrow bottom may be needed to increase the number of heads but this option in this sort of environment has not been documented al least for the Mexican plateau.

5. Key components for a successful establishment of permanent beds

Most farmers in the Mexican plateau are small, near subsistence producers who practice extensive tillage and mono-cropping combined with direct removal of most crop residues mainly by baling for livestock fodder or by pasturing and/or burning. These traditional practices, which result in bare, exposed fields for most of the year, leads considerable run-off losses of rain water associated with the occasional heavy-afternoon thunder-showers, especially on the extensive sloping fields (Sayre et al., 2001).

Given this scenario, field research has been conducted to provide a sound basis technology to farmers of the Mexican plateau and other regions based on reduced/zero-till, crop rotation, and crop residue retention. One of those technologies is the planting system on permanent beds whose research results are based on long term trials carried out by diverse institutions. Some of the components identified for a successful establishment of this system are discussed below.

5.1 Seeding equipment

Conservation agriculture in its form of permanent beds has many advantages over conventional planting systems; however, crop residues on the soil surface complicate the planting activity (Torbert et al., 2007). Among the commercial equipment developed for direct seeding, there is no one designed specifically for the planting system on permanent beds. Under these circumstances, some agricultural research institutions in the world have developed their own prototypes with varying features among them (Hobbs et al., 2008). This surely has been made based upon how machinery designers conceptualize the planting system and on the particular situation of the farming areas including type of crops, amount of residues, and fertilizer requirements. Consequently, there should be a great variety of local designs ranging from equipments with a forward residue mover to planters with cutting disks. But a common factor is that those designs, including small-scale planters, should be able to penetrate untilled soils to both place and cover the seed, usually through variable amounts of crop residues on the surface (Sayre, 1998).

In general, appropriate field machineries are necessary for successful operation of this crop production system. Fertilizing and seeding machines must effectively interact with varying physical conditions of crop residues and surface soil. They must cut surface residues and soil and perform the desired functions with minimum disturbances of soil and surface residues (Morrison et al., 1990). This fact is critical as suboptimal plant stands may result when tillage is reduced, because crop residue maintained on the surface may interfere with penetration by seed delivery system and contribute to hair-pinning of residue into the bottom of seed furrows (Carr et al., 2003a; Torbert et al., 2007). When this is the case, a suboptimal population will result in lower final grain yield and grain quality (Geleta et al., 2002).

As additional rule of thumb, wheel traffic, not only for planters but cultivators, sprayers, and fertilizer spreaders, should be restricted to furrow bottoms; otherwise, the bed area can be compacted by the tires of the field equipment (Parsons et al., 1984). Similarly, tire width must be preferably minimized to avoid compaction on the edges of the bed area (Morrison, 1985). These principles are particularly important on coarse-textured soils, i.e. sandy loams and silt loams, since they tend to form traffic pans more readily than clayey soils (Mascagny et al., 1995).

The National Institute for Agricultural, Forestry and Livestock Research (INIFAP) of Mexico, developed a planter for this planting system at the 'Valle de Mexico research station' (CEVAMEX). This development has proved to be particularly successful on the basis of its ability to plant wheat and maize through relatively heavy crop residue (Fig. 5). This ability is based on the need to rotate crops as required for the permanent bed planting system.
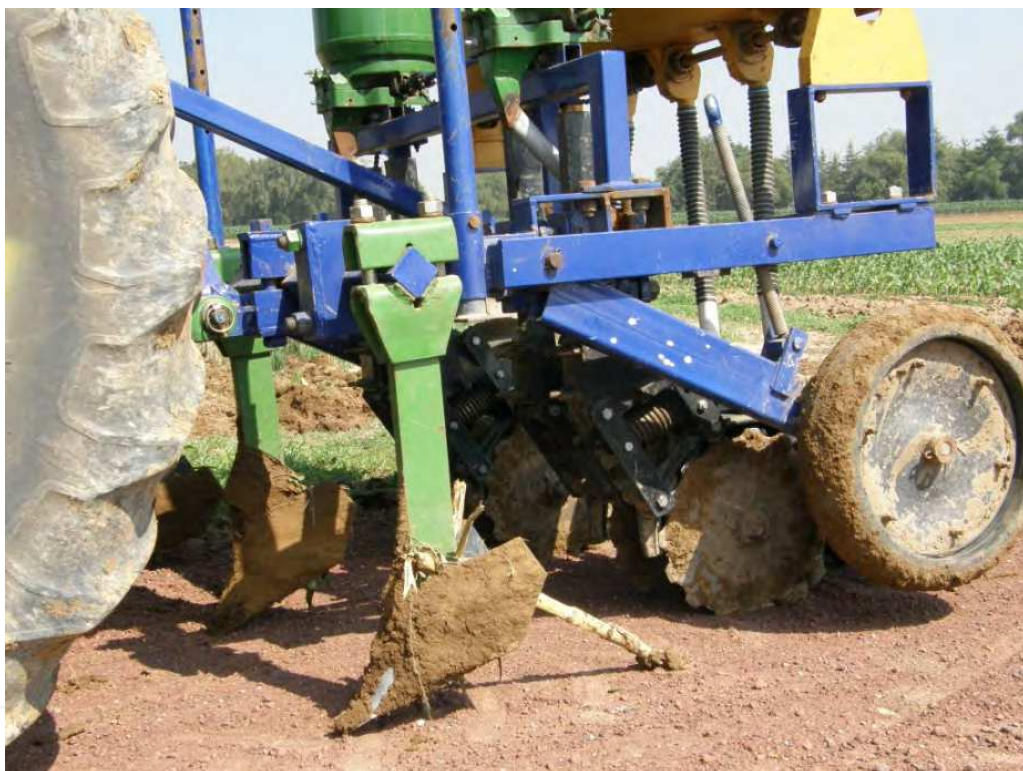

Fig. 5. Prototype of disk-type planter for small-grain cereals and maize developed for the planting system on permanent beds.

This equipment is basically the assembly of commercial seed boxes and disk-type planters into a designed frame. One seed box is to drill small cereals and the other to plant maize. A gear mechanism in the frame permits to select the seed box to operate. The installation of the furrow opener allows planting and reshaping beds simultaneously. This planter has proved to be particularly successful on the basis of its ability to plant through the amount of wheat and maize residues resulting from the yields commonly obtained in the Mexican plateau. A feature of this drill is its paired-row configuration for wheat seeds, whereby rows are planted in pairs spaced 20 to 25 cm apart by means of two heavy-duty double-disk openers per bed. To plant maize only one planter per bed is needed and distance between them

should be adjusted accordingly. Since un-tilled soil does not flow, a small wheel in the back of the disk-type planters pushes the soil to close the slot and cover the seed.

Interestingly, this equipment does not include a hopper to band fertilizer at planting. This apparent 'lack' is partly explained in Fig. 4a and b where crop yield response to N application is negligible. However, it is important to emphasize that this only applies to about 400 mm dryland conditions of the Mexican plateau. Nevertheless, in areas with different conditions the need for fertilizer may be critical. Meanwhile, investment cost of this prototype is low which may promote its copy and then the adoption of the planting system on permanent beds.

5.2 Variety

Research results on bed-planting methods have shown that not all wheat varieties perform adequately on beds. One reason is that during the breeding process genotypes were generally selected in conventional planting systems (Freeman et al., 2007a). Thus a crucial first step in initiating research on bed-planting wheat is to test a wide spectrum of varieties with differing heights, tillering abilities, phonologies and canopy architectures (Sayre, 1998). Close cooperation between breeders and agronomists to jointly identify and understand the proper plant type needed for optimum performance on beds is highly recommended (Freeman et al 2007b).

Work in the Mexican plateau showed that only three out of eight Mexican wheat varieties recommended for rainfed areas performed acceptably on beds (Limon-Ortega et al., 2008). This differential response can be ascribed to plant height (Sweeney & Sisson, 1988), for example, a tall genotype may perform adequately on beds but not in a conventional planting system on the flat. This means that caution should be exercised when making general recommendations on the basis of studies in which only one variety was used (Siemens, 1963). Results from a study with six wheat varieties and seven locations are presented in Fig. 6 using a basic stability analysis.

This figure clearly shows that performance of wheat varieties changes with the environment. In low-grain yield-environments all varieties perform similar to each other, but as environment improves, grain yield differences become greater reaching up to 2 t/ha difference. This result is an indication on the importance to select the adequate variety before planting on beds. In this case, variety Nahuatl F2000 was the most stable across environments probably due to its tillering ability.

Yield components that determine wheat grain yield are heads per m^2, heads per plant, kernels per head and kernel weight and there are compensatory relations among them in response to the changes of environmental conditions and agronomic practices, such as row spacing and seeding rate (Chen et al., 2008). Research work has shown a consistent relationship between grain yield and number of heads; the former increases as the latter improves (Zhang et al., 2007; Chen et al., 2008). This suggests that factors constraining tiller survival should be considered to improve production under such planting systems (Pierce & Lizaso, 1993) regardless of the ability of wheat plants to adjust one yield component when another one is reduced due to environment or other factors (Carr et al., 2003b). In this scenario, if the environment is conductive, genotypes may have the ability to compensate under relatively lower seeding rates to establish good stands with many tillers, larger heads, or more kernels, resulting in higher grain yield (Geleta et al., 2002). According to Schillinger (2005), the number of heads is generally the most important yield component and is

primarily affected by management practices such as seeding rates and N inputs (Zhang et al., 2007). One way to optimize tillering and yield component formation is through the timing of N application (Weisz et al., 2001; Limon-Ortega & Villaseñor-Mir, 2006). A regression analysis with grain yield suggests that attaining 350 heads/m^2 is key to achieving about 3500 kg/ha of wheat in the Mexican Plateau (Limon_ortega, 2011). Assuming that spring wheat has a tiller survival rate of 70-75% (Zhang *et al.*, 2007), it is then estimated that 500 – 466 tillers/m^2 should be targeted to attain an optimum grain yield in this region.
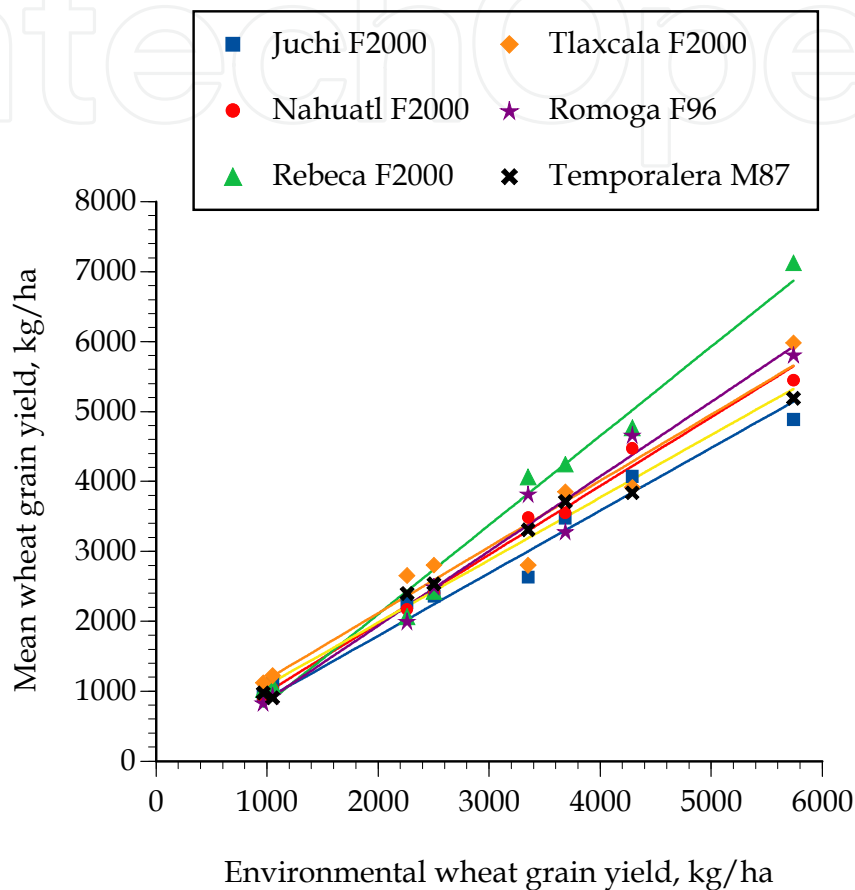

Fig. 6. Stability analysis of eight wheat varieties planted on narrow-raised beds in seven environments of the Mexican plateau (Courtesy, Dr. E. Villaseñor-Mir, 2005).

5.3 Crop rotation

Several researchers have suggested that phytotoxins from residues on the surface in a mono crop system may inhibit plant growth. The potential phytotoxic effect can not be reverted unless the period between successive crops provides sufficient time for residues to decompose and potential phytotoxic compounds be broken down or leached away (Carr et al., 2003b). Alternatively, diversifying crop rotations with different water use patterns and requirements can increase yield potential by influencing plant diseases and weeds (Campbell et al., 1990). The total crop yield increase and nutrient removal will depend upon the root depth of each crop (Grant et al., 2002). However, some crops in the rotation may cause reductions in subsequent wheat yields by decreasing the number of heads but they provide diversification and may prove beneficial when the yield and economics of the whole cropping system is considered (Norwood, 2000).

For the specific case of the Mexican plateau, it has been reported that maize-wheat as crop rotation is adequate. Otherwise, wheat grown in a mono-crop system tends to produce lower grain yields (Fig. 7). Data points in this figure are the average of four N rates (0, 40, 80 and 120 kg/ha).
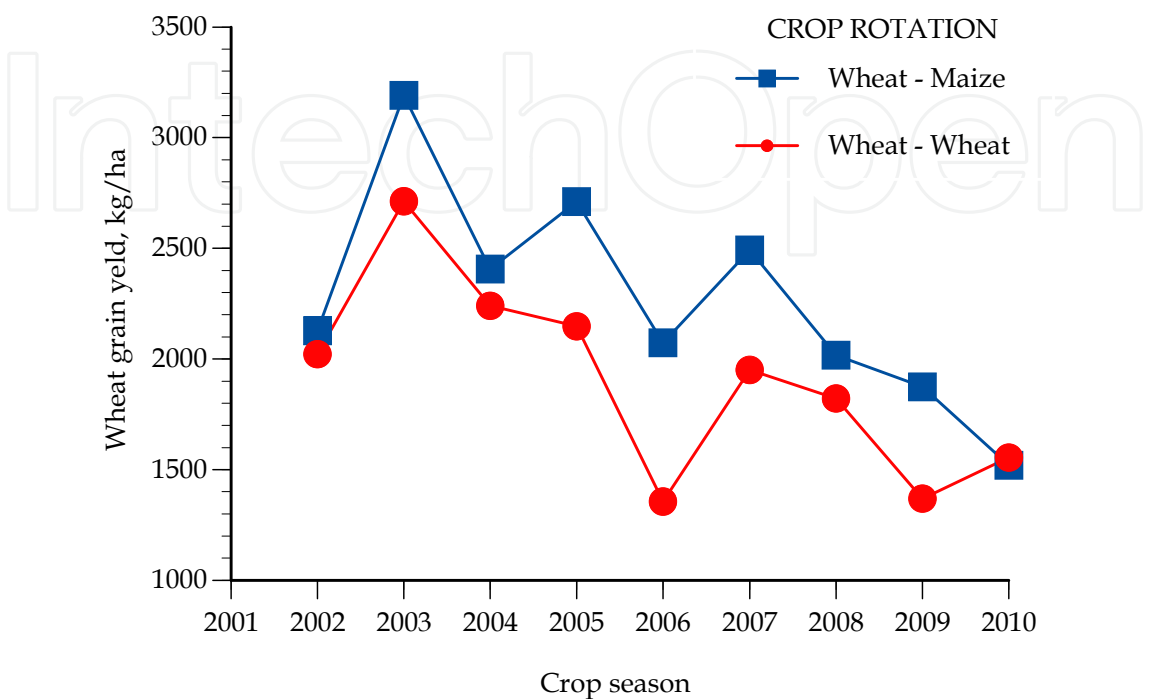

Fig. 7. Wheat grain yield variations when grown in rotation with maize and a mono crop. Chapingo, Mexico.

In general, wheat grain yield was greater for the rotation with maize compared to wheat – wheat rotation. One reason for this result is related to the development of root and foliar diseases as residues from the same crop serve as source of infection (section 6.1 of this chapter). Other relates to soil deterioration, mainly soil aggregate stability and its concomitant effects on numerous quality parameters. In general, wheat – wheat rotation produces less crop residue biomass compared to wheat – maize crop rotation. This results in a greater soil surface exposure to environment and thus deteriorating its aggregate stability.

5.4 Crop residues management

There are several constrains associated with crop residue management that may inhibit the farmer adoption of conservation agriculture. Currently many farmers in the Mexican plateau remove crop residues by baling to get an extra income. Farmers who convert to conservation agriculture, but continue to remove crop residues by any means, will usually produce lower yields than with conventional tillage practices. A good rule of thumb is that conservation agriculture should probably not implemented if it is not possible to maintain sufficient residues for adequate ground cover, especially under erosion-prone, low-but intense-rainfall dryland conditions (Sayre, 1998). When only certain amount of residue can be removed, the recommendation for removal rates must be based on regional yield, climatic conditions, and cultural practices. In this regard, agronomists are challenged to develop a procedure (tool) for recommending maximum permissible removal rates that

ensure sustained soil productivity (Wilhelm et al., 2004). Since there is intense competition to use residue in many rainfed areas, especially by small- and medium- scale farmers, it is allowed to remove 50 -70 % of the residues as remaining portion will provide adequate benefit to the soil (Sayre et al., 2005). Similarly, more (or improved) knowledge about residue decomposition dynamics is essential for developing effective management strategies as no single residue management practice is superior under all conditions (Kumar & Goh, 2000).

The nature of crop residues and their management has a profound influence on soils over the short – and long -term (Schoenau & Campbell, 1996). Albeit chopping and incorporating crop residues is an acceptable practice for soil improvement, the planting system on permanent beds as conservation agriculture requires crop residues chopped and distributed uniformly over the soil surface, preferably during harvesting with the combine's chopper. But depending on the local conditions, sometimes is better to chop residues after harvesting when the season of winds is over. For example, winds of January and February in the Mexican plateau have the potential to blow off chopped crop residues. It is also important to point out that the initial location of crop residues at the soil surface, the clustering, and the spreading of fragments modify many soil physical factors (Guerif et al., 2001).

Residues, on the other hand, can enhance the loss of N fertilizer by volatilization from broadcast urea because urease enzyme present in the residues can increase the rate of NH_3 release (McInnes et al., 1986). Therefore, in a planting system like permanent beds with crop residues on soil surface is crucial the separation of fertilizer from the residues by placing fertilizers below the soil surface to increase fertilizer use efficiency. In irrigated conditions the incorporation can be accomplished by watering immediately after the fertilizer application (Limon-Ortega et al., 2000), while in rainfed areas this should necessary be done by mechanical means below the soil. Alternatively, fertilizer application can be scheduled to coincide with favorable conditions as predicted by short-term (48 – 72 h) weather forecast (Limon-Ortega, 2009b; Nielsen et al., 2005). Furthermore, guidelines routinely used for seed-banded N fertilization that only consider N application rate, should be modified to also consider N source and soil moisture (Mahler et al., 1989).

5.5 Bed formation and maintenance

Certain guidelines to begin the permanent beds should be followed (Griffith et al., 1990); 1) on nearly level soils with poor internal drainage, beds should not interfere with natural drainage-ways as ponded water in furrows may result, 2) on slopes of more than 6%, even with all crop residues left, beds should be oriented across the slope, 3) careful driving is needed to maintain proper furrow spacing between adjacent passes when raising beds the first time, any mistake made initially will be carried over from year to year, 4) a cultivator and planter with the same number of rows should be used as none drives straight all the time, 5) bed spacing from center –to- center must be exactly the same as spacing of planter rows, improperly adjusted winged-shovels may not move soil equally to both sides of the ridge, 6) to minimize potential planter centering and control problems, no attempt should be made rising beds too tall or 'peaked' (crowned) on top. Interestingly, harvesting individual rows on crowned beds, grain yield increases from furrow rows to center of the bed, while on flat beds, grain yield can be about the same on the top of the bed (Mascagni et al., 1995).

Furrow bottoms, on the other hand, should be periodically reformed to maintain the shape of the bed to provide surface drainage in situations of waterlogin (Morrison et al., 1990), and

to restore the macroporosity to promote water infiltration into the soil and gas exchange. An additional benefit in certain production systems from re-shaping beds can be obtained in soils that tend to develop compaction constrains (Mascagni & Sabbe, 1990) that in other cropping systems occur from the wheel traffic of cultural practices applied at random over the field (Gerik et al., 1985).

6. Advantages and disadvantages of the permanent beds

The planting system on permanent beds as conservation agriculture for crop production offers many advantages and disadvantages to users. Both are mostly described by the key components for a successful establishment of the permanent beds in section 5 of this chapter. However, there is not a clear-cut to identify a component as absolutely advantageous as occasionally it might be beyond the farmer's control. Crop rotation, for example, is fundamental but not always feasible. This depends on the onset of the rainy season or expected market in a given year. If the onset of the season is delayed and the following crop in the rotation is maize, farmers should change the cropping plan to wheat or even oat depending upon the time the rain season is established. Regardless of this, other points to take into account about the planting system on beds are described below.

6.1 Foliar and root diseases

Direct seeding methods like permanent beds with crop residues left on surface have proved to promote the development of both foliar and root diseases and become yield-limiting factors if crops are grown without adequate rotation (Cook et al., 2000). For example, seedlings which encounter buried residues may be injured if the residues have not had enough time and moisture to lose their pathogenicity (Wuest et al., 2000). Thus, appropriate management techniques are needed to reduce the effects of these factors. Nitrogen fertilizer, on the other hand, has been identified as management factor affecting the incidence of diseases; in general, adequate N rates tend to reduce incidence but this varies according to moisture conditions (Halvorson et al., 1999a).

Foliar diseases, namely Yellow leaf spot (*Helminthosporium tritici-repentis*), and Septoria (*Septoria tritici*) and root diseases, namely take-all (*Gaeumannomyces graminis*), Rhizoctonia root rot (*Rhizoctonia solani*), and Pythium root rot (*Pythium spp*), become yield-limiting to wheat when grown without adequate rotation, especially in no-till plant systems. Nevertheless, the degree of incidence is influenced by the microenvironment formed by the configuration of the plant rows (Cook et al., 2000). For the case of planting on beds, there is a skipped furrow without plants that results in a more open space that affects disease incidence due to the microclimate from the row orientation (English et al., 1989). Foliar diseases that have been found to be suppressed by the planting system on beds include the sharp eye spot disease caused by *Pseudocercosporella herpotrichoides* and powdery mildew caused by *Erysiphe graminis* (Fahong et al., 2004; Sayre et al., 2005).

Visual scores taken from tillering to grain filling stage on the foliar diseases complex using a 0 to 10 scale, allowed to estimate the amount of initial disease and the exponential rate of disease increase (Fry, 1982) for each plot in a field study on permanent beds at Chapingo, Mex. Results showed that only the amount of initial disease was related to final wheat grain yield. Fig. 8 indicates that for every unit increase in the scale, grain yield will be reduced by 246 kg/ha (equation not showed). According to this figure, the wheat – wheat rotation has

the largest visual scores and consequently the largest grain yield reductions. In contrast, the annual wheat – maize rotation showed less incidence of foliar diseases which resulted in greater grain yield.
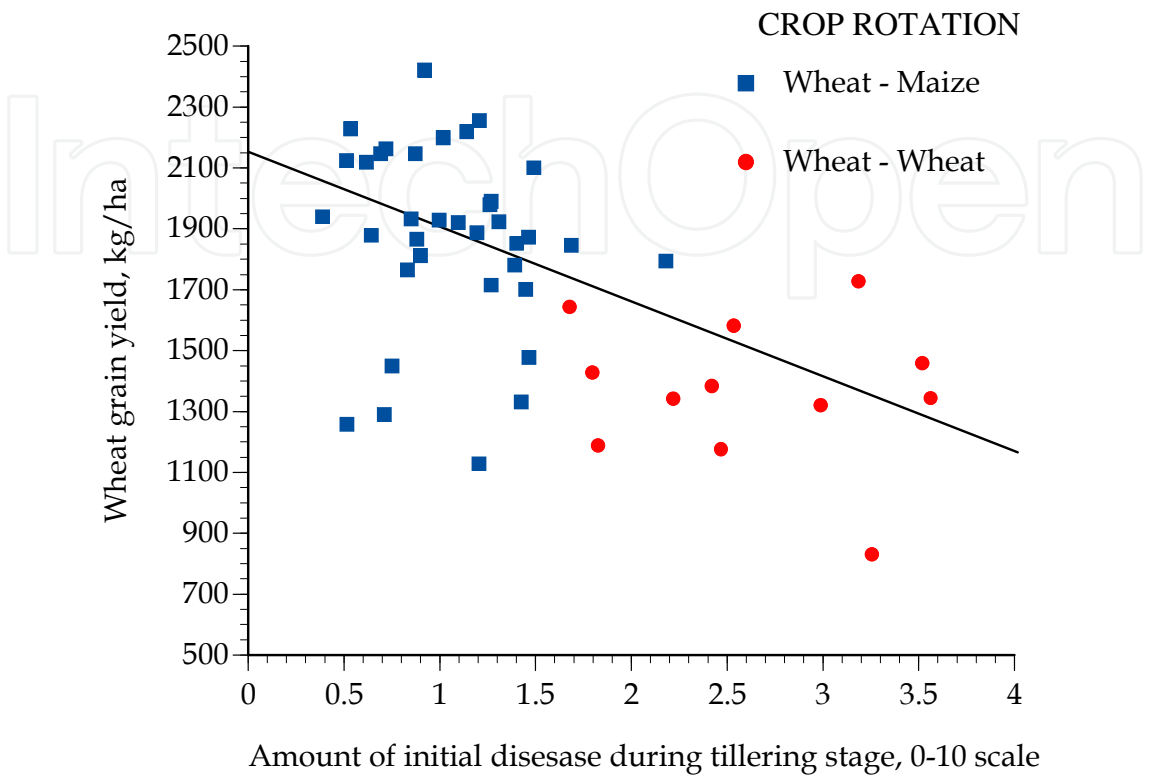

Fig. 8. Relationship foliar disease score - wheat grain yield in 2009 crop season. Chapingo, Mexico.

The work on root disease incidence on permanent beds in the Mexican plateau, on the other hand, has also shown the effect of crop rotation. For wheat – maize rotation with full residue retention, the root rot incidence in wheat was intermediate while for maize was even lower. However, in contrast to foliar diseases, the root rot incidence in both crops had minor influence on final grain yield as other factors such as water availability and nutrient status were more critical (Govaerts et al., 2006b).

6.2 Diking

Water is often the most limiting factor to dryland agricultural production. Practices that conserve water received as rainfall can greatly improve the potential for success of cropping systems (McFarland et al., 1991). One of those practices should include the bed planting system joined with furrow diking.

Furrow dikes are small dams formed periodically between the beds along the furrow bottoms. The furrow diking practice is known by many names, including tied-ridges; furrow damming; basin tillage; basin listing; and microbasin tillage. Furrow diking is a soil and water conservation practice that is very well adaptable to dryland crop production. It is most often used on gently sloping terrain in arid and semiarid areas where crops are grown under water deficit conditions (Jones & Baumhardt, 2003). Furrow diking in the Mexican

plateau for wheat production on conventional-till raised-beds was first used in 2000 by Mr Emigdio Taboada, a wheat farmer at Nanacamilpa, Tlaxcala state. This farmer modified his conventional drill removing three planters and replacing them by three small furrow openers connected to an eccentric wheel which causes a trip movement to form small dikes. As immediate result wheat grain yields were improved, the amount of water runoff was substantially reduced, and water infiltration through the soil profile increased. Similar results have been reported for other places and crops (Jones & Baumhardt, 2003) indicating a strong correlation between grain yield and amount of rain during critical growth stages (Tewolde et al., 1993).

The application of furrow diking technology in a bed planting system is of particular importance in many semi-arid regions where rainfall is often of high intensity and short duration (Lyle & Dixon, 1997). This rainfall pattern is characteristic of many developing countries (Clair & Linch, 2010) including the Mexican plateau and will be surely extended to other areas of the world as the climate change will continue. For example, precipitation intensity in terms of the number of days with precipitation above 25 mm, shows a statistical significant increase in many areas of the globe (Porter & Semenov, 2005). Those changes in rainfall distribution can be parameterized by means of standard deviation (Monti & Venturi, 2007). The effect of furrow diking on water retention in conventional-till raised-beds appears to offset those climatic changes as shown in Fig. 9. Nevertheless, the implementation of tied ridges has no effect on soil parameters (Govaerts et al., 2007).

However, care should be taken in permanent beds as research has shown that furrow diking in every furrow may not be desirable as wheat grain yield can be slightly reduced (Saye et al., 2005). Alternatively, to improve yields furrow diking should be applied in alternate furrows (Limon-Ortega, 2011). This differential effects of furrow diking options on grain yield can be ascribed to an excessive amount of rain water accumulated in the soil profile due to the improvement of soil structure stability and suggests that there should be a balance between water conservation and drainage .

Fig. 9. Rainfall water retention with furrow diking in conventional-till raised-beds applied to wheat.

Apparently the added water through the sole use of conservation practices compared with more intensive conventional tillage, is enough to take full advantage of the often low and erratic growing-season precipitation (Grant et al., 2002). But care should be taken as contrasting results have been reported for crops like maize from wetter areas with rain amounts exceeding 900 mm where diking had little effect on grain yields (McFerland et al., 1991). The inconsistency of furrow diking in increasing grain yields can also be attributed to size of rain events –rainfall distribution. For example, small rain events (< 20 mm) can be lost to evaporation and then no-till with crop residues can be more effective than furrow dikes in improving water conservation in semiarid regions (Nielsen et al., 2005).

7. Conclusion

Given the large number of advantages of the planting system on permanent beds over the conventional planting for wheat and maize production, researchers have to joint efforts to accomplish two basic requirements. One is the work of agronomists with machinery designers to develop prototypes of planters that can be copied by small-scale farmers and be easily reproduced in local shops. Other is the joint work with breeders to identify and select the appropriate wheat and maize genotypes for the bed planting system. Furthermore, local governments should provide subsidies to allow those farmers to acquire planters and simultaneously provide some incentive to trigger the adoption of the system.

The stabilization period required to obtain the benefits of the permanent beds appears not to have a pronounced effect on wheat and maize yields under the rainfed (about 400 mm rainfall) conditions of the Mexican plateau. The adoption of this planting system as conservation agriculture and its effects on the improvement on soil attributes has the potential to reduce substantially the degree of soil erosion, as well as to improve the farmer's income by increasing grain yields and reducing production costs.

8. Acknowledgment

9. References

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Soil Erosion Issues in Agriculture

Edited by Dr. Danilo Godone

The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.

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