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Conservation agriculture as a sustainable option for the central Mexican highlands

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ABSTRACT

Tropical highlands of the world are densely populated and intensively cropped. Agricultural sustainability problems resulting from soil erosion and fertility decline have arisen all over this agro-ecological zone. Based on selected soil quality indicators, i.e. time-to-pond, aggregate distribution and stability (expressed as the mean weight diameter (MWD) for dry and wet sieving, respectively) and soil moisture, from a representative long-term sustainability trial initiated in 1991 in Central Mexico (2240 masl; 19.31°N, 98.50°W; Cumulic Phaeozem), some insights into the feasibility of conservation agriculture (CA) as part of a sustainable production system in the tropical highlands are given. Zero tillage plots with crop residue removal showed low aggregate distribution (average MWD = 1.34 mm) and stability (average MWD = 0.99 mm) resulting in top layer slaking, increased erosion and low time-to-pond values. Retaining the residue in the field with zero tillage avoided the above-mentioned negative evolution for both aggregate distribution as stability (average MWD = 2.77 and 1.51 mm, respectively) and even improved the physical conditions of the soil as compared to conventional practice. Throughout the growing season the lowest soil moisture content was found in zero tillage without residue (average over the entire growing season = 20.5% volumetric moisture content), the highest in zero tillage with residue retention (average = 29.7%) while conventional tillage had intermediate soil moisture values (average = 27.4%). Zero tillage without residue retention had most days of soil moisture values under permanent wilting point, while zero tillage with residue retention had the least. Taking into account these results, zero tillage with residue retention can clearly be a part of an integrated watershed management scheme towards sustainable agriculture in the tropical highlands. It is clear that to develop new management practices to improve water use, reduce erosion and enhance human labor/animal power focus must be on the use of conservation agriculture both for rainfed as well as irrigated production systems and be fine tuned for each system.

1. Introduction

The experiences described in this paper are based on an experiment conducted at the International Wheat and Maize Improvement Centre (CIMMYT) experiment station near El Batán, Mexico, approximately 30 km northeast of Mexico City. The climate of El Batán however, makes it representative of many highland areas in the West Asia and North Africa region, the Southern Cone and Andean Highlands of South America, the central highlands of Ethiopia (e.g. Kulumsa), the Mediterranean coastal plains of Turkey (e.g. Izmir) and the highlands of central Mexico. The total area of this region exceeds 8 million hectares (van Ginkel et al., 2002). Each area will of course have its specific conditions and problems, however some overall trends are recognisable. The tropical and subtropical highlands (central Mexico, Ethiopia, . . .) are densely populated and intensively cropped for centuries. Agricultural sustainability problems related to soil erosion and fertility decline have arisen throughout this agro-ecological zone (Scherr and Yadav, 1996). The agricultural system is under stress due to shrinking cultivated area per household, reduced fodder availability and land degradation (Aune et al., 2001). Rainfall is inadequate and unpredictable, hence crop production is threatened by chronic soil moisture stress. Precipitation is usually intensive and short, leading to high runoff and temporal water logging. Qualitative studies describe a trend of decreased soil fertility (Bojö and Cassells, 1995). Cereal grain yields

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are low (<2 t ha^{-1}). Moreover, fields are often weedy and crops are N deficient, soil structure is poor, and sheet and gully erosion are widespread (Nyssen et al., 2000, 2005).

The traditional farming practice involves a series of tillage operations that break up the soil into smaller and smaller chunks to provide weed-free seedbeds at sowing. This system increases erosion as well as the risk of soil structure degradation and results in marked losses of soil moisture (CND, 2002). The productivity of f.e. the Ethiopian livestock system is declining. The large draught requirement for tillage forces farmers to keep a large number of cattle. Such an overstocking of cattle has caused soil erosion, fertility decline, C depletion, compaction, crusting, etc., all resulting in overall land degradation, delayed planting and loss of soil moisture. Most of the biomass/fodder resources are consumed by oxen and other livestock while fodder resources are shrinking due to land degradation (Aune et al., 2001; Gebregziabher et al., 2006). Major changes will thus be needed in land, livestock and water management in line with traditional lifestyles and customs to remedy the agricultural system in the tropical highlands. There is a need to develop technologies and management schemes that can simultaneously enhance production, preserve the natural resource base, decrease costs and reduce poverty. One of the technology packages under consideration to develop new crop establishment and subsequent management practices to improve water use, reduce erosion and enhance human labor/animal power efficiencies is conservation agriculture (CA), both for rainfed as well as irrigated production systems. Conservation agriculture has as key components: (1) minimal soil movement, (2) rational amounts of residue cover, (3) economical viable crop rotations, this all resulting in a reduction in management costs. The name CA has been used over the last 7–8 years to distinguish this more sustainable agriculture from the narrowly defined "conservation tillage"—taking the emphasis off the tillage component and addressing an enhanced concept of the complete agricultural system (Wall, 2006). Reducing tillage combined with crop residue retention on the soil surface, can increase moisture infiltration (Azooz and Arshad, 1996; Elliot and Efetha, 1999; Shaver et al., 2002), greatly reduce erosion and increase water use efficiency (Johnston et al., 2002; McGarry, 2002), compared to conventional tillage. Crop residues accumulated on the soil surface form a barrier to water loss by evaporation and increase the amount of moisture stored in the plant root zone and available to the crop. Field research shows increased moisture levels, decreased soil temperatures and also more stable soil aggregates (i.e. improved soil structure) when less tillage is done (Carter, 1992; Elliot and Efetha, 1999; Limon-Ortega et al., 2002). Crop rotations can break soil pathogen cycles and reduce weed pressure.

In 1991, an experiment was started to investigate the long-term effects of tillage/seeding practices, crop rotations and crop residue management on the performance of maize and wheat grown under rainfed conditions in the tropical highlands. The determination of some selected soil quality indicators (Govaerts et al., 2006), i.e. time-to-pond, aggregate distribution and soil moisture, for the different treatments (zero tillage (ZT) versus conventional tillage, crop residue removal versus retention and crop rotation versus monocultivo) of this representative long-term sustainability trial in Central Mexico give some insights into the feasibility of CA as part of a sustainable production system for the target area.

2. Materials and methods

2.1. El Batán experiment station

El Batán, located near the ancient Lake Texcoco in the State of Mexico, is situated in the semi-arid, subtropical highlands of Central Mexico (2240 masl; 19.31°N, 98.50°W), with monthly average temperatures between 12.5 and 17.5 °C, and 600 mm average annual rainfall, 520 mm of which falls during the growing season (May–October). Short, intense rain showers followed by dry spells typify the rainy season, and total annual, potential evapotranspiration is 1900 mm. The average growing period (FAO, 1978) is 152 days long. The soil is a fine, mixed, thermic Cumulic Haplustoll, according to the USDA Soil Taxonomy system (Soil Survey Staff, 1998), or a Cumulic Phaeozem, according to the world reference base (IUSS Working Group WRB, 2006); its chemical and physical properties make it adequate for farming. The major limitations are periodic drought, occasional excessive rainfall, and wind and water erosion.

2.2. The long-term trial

The study described here was conducted as part of a long-term trial begun in 1991. In 1990 the entire experimental plot was treated with a broad-spectrum contact herbicide 1 month after the rainy season began, then seeded with barley in late July (Fischer et al., 2002). Individual plots measured 7.5 m $\times$ 22 m. Maize was planted at 60,000 plants ha^{-1} in rows 75 cm apart and wheat in 20-cm rows at 100 kg seed ha^{-1}. Both crops were fertilized at a rate of 120 kg N ha^{-1}, with all N applied to wheat (broadcast) at the 1st node growth stage and to maize (surface-banded) at the 5- or 6-leaf stage. Appropriate herbicides were used to control weeds as needed, and no disease or insect pest controls were utilized. The planting of both maize and wheat depended on the onset of summer rains but was usually done between 5 and 15 June. The experimental design consisted of a randomized complete block with two replications. The 32 treatments combined different wheat–maize rotations, tillage/planting methods, and residue management practices, but only 16 were considered in this research (Table 1). Crop treatments included continuous wheat (WW), continuous maize (MM), and wheat and maize rotations (MW, WM). Residue was either kept on the field (K) or removed for fodder (R). Retained residues were incorporated under the conventional tillage treatment (CT) or left on the flat if zero tillage was done.

2.3. Aggregate stability and distribution

A composite of seven sub-samples, with a total weight of 500 g, was taken randomly from the 0 to 5 cm and 5 to 20 cm soil layer during the 2004 and 2005 crop cycle. To avoid breakdown of the aggregates, sampling was done with a small shovel. Samples were air-dried for a few hours and big clods (>5 cm) were gently crumbled, then air-dried further for 2 weeks at which time

Table 1
Schematic outline of treatments in CIMMYT's long-term sustainability trial, El Batán, Mexico

Tillage management			
Zero tillage (ZT)		Conventional tillage (CT)	
Keep residue (K)[a]	Remove residue (R)[a]	Keep residue (K)[a]	Remove residue (R)[a]
Crop sequence[b]			
WW	WW	WW	WW
WM	WM	WM	WM
MM	MM	MM	MM
MW	MW	MW	MW

[a] Residue management.
[b] MM, continuous maize; WW, continuous wheat; MW, yearly maize and wheat rotation; WM, yearly wheat and maize rotation.