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Effects of Tillage and Crop Residue Management on Maize Yields and Net Returns in the Central Mexican Highlands Under Drought Conditions*[1]

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ABSTRACT

In the subtropical highlands of Central Mexico, where the main crop is maize (*Zea mays*), the conventional practice (CP) involves tillage, monoculture and residue removal, leading to soil degradation and unsustainable use of natural resources and agricultural inputs. Conservation agriculture (CA) has been proposed as a viable alternative in the region, based on reduction in tillage, retention of adequate levels of crop residues and soil surface cover and use of crop rotation. This study began in 2009 when the highlands of Central Mexico suffered from a prolonged drought during vegetative maize growth in July–August, providing an opportunity for the on-farm comparison of CA with CP under severe drought conditions which 21 climate change models projected to become more frequent. Under dry conditions, CA resulted in higher yields and net returns per hectare as early as the first and second years after adoption by farmers. As an average of 27 plots under farmers' management in 2009, the maize yields were 26% higher under CA (6.3 t ha^{-1}) than under CP (5.0 t ha^{-1}). 2010 was close to a normal year in terms of rainfall so yields were higher than in 2009 for both practices; in addition, the yield difference between the practices was reduced to 19% (6.8 t ha^{-1} for CA *vs.* 5.7 t ha^{-1} for CP). When all the 2009 and 2010 observations were analyzed in a modified stability analysis, CA had an overall positive effect of 3 838 Mexican Pesos ha^{-1} (320 \$US ha^{-1}) on net return and 1.3 t ha^{-1} on yield. After only one to two years of adoption by farmers on their fields, CA had higher yields and net returns under dry conditions that were even drier than those predicted by the analyzed 21 climate change models under a climate change scenario, emission scenario A2.

Key Words: climate change, conservation agriculture, conventional practice, emission scenario, modified stability analysis

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INTRODUCTION

Subtropical highlands of the world have become increasingly densely populated and intensively cropped over recent centuries. Agricultural sustainability problems resulting from soil erosion and fertility decline have arisen throughout these agro-ecological zones due to conventional practices based on mechanical soil disturbance, monoculture and removal of crop residues (Lal, 1993). Soil degradation and lack of soil cover lead to extensive erosion and rain runoff events, making the farmers' production system very vulnerable to dry conditions which happen periodically. Maintaining crop productivity is further complicated by existing and predicted climate change effects, such as rising temperatures, decreasing rainfall and increasing frequency and intensity of dry periods (Carvalho and Jones, 2013). In order to satisfy increasing agricultural output demands, the subtropical highlands around the globe need to produce more crops, with less water, higher temperatures and increasing input costs and with minimal available land that could be converted to agriculture. Cropping systems need to be adapted to face these challenges.

In 1991, the International Maize and Wheat Improvement Center (CIMMYT) established a long-term

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experiment in the highlands of Central Mexico to develop cropping systems that can preserve natural resources, have higher and stable yields and at the same time are more robust against drought and more profitable for the farmer (Govaerts *et al.*, 2005). Among the evaluated practices in the highlands were the conventional practice (CP), based on tillage, monoculture of maize and removal of crop residues for use as animal fodder, grazing or otherwise burned, and the conservation agriculture (CA), based on i) reduction in tillage to zero tillage; ii) retention of adequate levels of crop residues for soil surface cover and iii) use of crop rotation. CA increased physical, chemical and biological soil quality compared to CP (Govaerts *et al.*, 2006a, b, 2007, 2008, 2009). Aggregation and infiltration were higher under CA than CP (Govaerts *et al.*, 2009), resulting in higher soil water content under CA, which allowed for the buffering of short dry periods (Verhulst *et al.*, 2011). Since periodic droughts were an important constraint in rainfed conditions in the highlands, CA had higher and more stable yields than CP (Govaerts *et al.*, 2005; Verhulst *et al.*, 2011). However, there was a lack of information regarding the results of these practices under farmers' conditions and management, and it was questioned if CA cropping systems are an economically sound solution for farmers outside the experimental stations. Moreover, it is important to assess if farmers practicing CA can have positive economic (net returns) results in the short term that can help to quickly overcome the investments of the technological change.

In 2007–2008, an extension program led by CIMMYT started working with farmers in the highlands of Central Mexico to adapt and compare CA-based practices with the conventional farmers' practices, both under the management of the same farmer. Plots were established with farmers in their fields, conceived as a medium- to long-term comparison and as training spots for neighboring farmers for a large-scale adoption strategy. The intense drought in 2009 allowed for the first time in this region a comparison of CA with CP in farmers' fields and under climate conditions predicted to become more common in the whole of Mexico and North America (Carvahlo and Jones, 2013). In 2010, the rainfall was close to the historical long-term average, which also allowed comparison between the CP and CA systems in a scenario similar to an average year.

The objective of this study was to evaluate whether CA results in the short term in higher yields and net returns for farmers in the highlands of Central Mexico under different climatic and production conditions, in a year with extreme drought and a close-to-average rainfall year. A secondary objective was to compare the 2009 drought with the projections of climate change models to assess if the drought was as severe as the projected rainfall patterns for the region under a climate change scenario A2.

MATERIALS AND METHODS

Study area

This study was conducted in the highlands of Central Mexico, in an area that comprises the States of Hidalgo and Mexico, which are located in 18°21′–20°23′ N and 98°35′–100°17′ W. The climate is sub-humid with some variations, and temperatures are semi-hot to temperate (Améndola *et al.*, 2006). A 4–6 month wet season (May to September), with rainfalls on average between 350 and 800 mm, was followed by a dry winter season (Sayre *et al.*, 2001). The dominant soil groups are Andosols, Phaeozems, Vertisols, Regosols and Cambisols (Sotelo-Ruíz *et al.*, 2011). The area has been intensely cropped for many centuries, in particular in high valleys (1 500–3 000 m above sea level). However, soil erosion and decline in soil chemical and physical fertility have led to serious problems of production sustainability. Rainfed agriculture is the most common practice, but irrigation is also applied in a minority of areas. One of the main water sources for irrigation is sewage from the urban centers (Jiménez, 2005). Crops are planted before the start of the main rainfall season. The rains are often intense and short and there can be significant drought periods with crop water stress during the growing season (Sayre *et al.*, 2001). Maize (*Zea Mays*) is the main crop in terms of cultivated area and production volume. Beans (*Phaseolus vulgaris*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and oats (*Avena sativa*) are also grown (Sayre *et al.*, 2001; Fischer *et al.*, 2002). Only one cycle for grain cultivation is possible under rainfed conditions, *i.e.*, during the rainy season, while two grain harvests a year are obtained under irrigation.

In the subtropical highlands of Central Mexico, farmers applying conventional practices (CP) under rainfed conditions leave the soil bare for more than six months each year because almost all crop residues are directly removed for fodder, grazed, and/or burned. Fields are subject to tillage, mainly with small tractor-drawn disc plows/harrows and field cultivators after harvest, during the dry season for weed control and in the weeks before sowing. Sub-soiling to a depth of 60–70 cm is increasingly used by farmers in the region.