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No-till durum wheat yield success probability in semi arid climate: A methodological framework

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ABSTRACT

The aim of this study is to develop a framework for the evaluation of no-till (NT) yield success probability as a decision tool for farmers or decision makers. The effect of soil management on durum wheat yield has been tested on many long-term field experiments. Results of these researches were collected in a unique dataset to evaluate the success of NT management in comparison to conventional tillage (CT) as influenced by the aridity index, crop residue management and cropping system. A total of 519 observations of long-term experiments (> 3years) regarding durum wheat in a number of areas with semi arid climate were included in the present study. The relative ratio of yield under NT and CT was correlated to the aridity index (Ai) for different cropping systems and residue management strategies. No-till performed better with lower values of the Ai. When NT and CT yields were the same, the Ai value was defined as the Ai threshold, and this value resulted as being strongly dependent upon crop management.

The developed framework, in any given site, allows us (i) to know the threshold for different managements tecniques, (ii) to estimate the probability of success in adopting NT and CT soil management techniques; (iii) to predict the best management with reference to Ai variation.

1. Introduction

No-till (NT) soil management quickly evolved in the arable lands of the world, increasing from 45 million ha in 1999 to 155 million ha in 2014 (FAO, 2014). For a farmer, profit is the most important factor when considering the adoption of conservation practices such as NT (Cary and Wilkinson, 1997). The greatest increase in the conservation management area has been observed in the extensive arable land of North and South America, and China, due to the high cost savings in relation to farm size (Cary and Wilkinson, 1997). No-till has been shown to improve farming sustainability in many agricultural environments throughout most of the world and is widely considered the most important conservation agriculture practice as it provides an alternative to conventional ploughing and tillage disturbance, thereby leading to a reduction in the environmental impact (Luo et al., 2010; Ogle et al., 2012).

However, in recent years, this latter aspect has become less evident and hopeful; erosion control, increases in soil organic matter, reduction in CO_2 emissions into the atmosphere, which were considered, until recently, an added value to the practice of NT, have become controversial aspects in the light of new scientific evidence (Barbera et al., 2012; Cary and Wilkinson, 1997; Du et al., 2017; Keesstra et al., 2016; Novara et al., 2016; Powlson et al., 2014; Sun et al., 2015).

As far as the NT yield advantage is concerned, there has been some disagreement in perceived yield benefits of NT farming practices. NT performed better only under rainfed conditions, especially in dry climates, on a wide range of crops (Pittelkow et al., 2015), mainly if carried out together with crop rotation and crop residues (NT system).

Results in Mediterranean environments show the importance of saving soil moisture, through a reduced tillage system, particularly in semi-arid environments characterized by low annual rainfall and high environmental evapotranspiration demand. Superior yield and water-use efficiency occurred with NT when precipitation was < 300 mm during the wheat cycle (November–May) (De Vita et al., 2007). Other studies showed that NT success compared to CT is highly dependent upon the Aridity index (Ai) (UNEP, 1992). The Aridity index was the most important factor influencing the overall yield response to NT (Pittelkow et al., 2015; Ruisi et al., 2014) and generally NT yield was greater than CT at low values of Ai (semi arid environment).

Knowledge of the Ai range determining NT yield success under

Abbreviations: NT, no-till; CT, conventional tillage; CS, cropping system; RM, residue management; M, monocropping; CR, crop rotation; R, residues; noR, no residues; Ai, aridity index; Tai, treschold Ai

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different cropping systems and management, together with the maximum Ai value (threshold) and its statistical distribution, is determinant for the development of tillage practices in drylands.

Given the complexity of the physical and financial aspects surrounding agricultural production systems in general and, more specifically, those concerning dryland systems, there is continual uncertainty as to the profitability of any given production system. Reducing this financial risk is, undoubtedly, an aspect of keen interest to farmers. This uncertainty is largely due to elements which are largely out of our control, such as weather conditions, however, famers do their best to use technological and agronomical innovations in an attempt to limit this risk. This long-term experience has led farmers to think in terms of uncertainties and probabilities. The preliminary requirement for the choice of the best management practice therefore consists in assessing the probability that a certain outcome (e.g., grain yield) will occur under determined pedo–climatic conditions. On this basis, the strategy could be to select a management practice that optimises maximum yield probability or that minimises variability surrounding a targeted goal. In the context of soil management practices, the complexity of decision-making in terms of tillage management is linked to unknown future weather conditions. Since yield must be considered as the main risk factor, quantifing uncertain entities associated with climatic trends is necessary in order to choose the best management practice (Araya et al., 2012; Basso et al., 2012).

In this study we focused on the impact of tillage practices on rainfed durum wheat. This crop is cultivated on 16 million ha globally between longitude 30° and 45° on both hemispheres. The aim of this study was to:

i investigate the relative yield of NT in comparison to conventional tillage in relation to crop rotation and residue management considering the high variability and uncertainty of the climatic conditions characterizing the Mediterranean environment;
ii determine Aridity index (Ai) threshold (breakpoint) of conventional tillage in comparison to NT;
iii suggest a specific framework for a NT success probability approach.

2. Material and methods

2.1. Dataset selection and data analysis

A dataset comparing crop yields under no-till (NT) and conventional tillage (CT) soil management was compiled with data from the meta-analysis of Pittelkow et al. (2015),updating the dataset to 2016. In total, 519 observations (which include results of different years for each trial) from 85 studies on rainfed durum wheat systems with a trial duration of more than 3 years were collected (see supplementary material).

The selection criteria of the dataset were:

- Data derived from comparative trials during which CT and NT management was carried out while other cultivation factors (fertilization, weeds control, etc) were mantained constant.
- Cropping system (CS) and residue management (RM) were considered as management aspects that could strongly influence durum wheat yield together with the Aridity index (Ai) and soil characteristics.
- Cropping systems included Durum Wheat monocropping (M) and Durum Wheat crop rotation (CR); RM comprised two management strategies: Residue completely removed (noR) and residue left into the soil (R).
- Only field experiments carried out between 30° and 45 °North and South latitude were included. Other small areas of durum wheat cultivation, outside the considered range of latitude, were not included to avoid a bias in the dataset that could stress the importance of climate (Fig. 1).

For each long-term durum wheat experiment included in the dataset, the aridity index (Ai) (UNEP, 1992) was calculated as follows:

$$Ai = P / PET \tag{1}$$

where P is the mean annual precipitation and PET is the mean annual potential evapotranspiration. Ai data were derived from the global map of Ai of the CGIAR-CSI Consortium for Spatial Information with the support of the International Center for Tropical Agricultural (CIAT) based on modelling and analyses by Trabucco et al., (2008).

Basic soil information such as texture were classified according to the USDA texture classification system and three classes were considered: (i) loam including loam soils; (ii) clay including clay and silt clay soils, clay loam; (iii) sand including sand, loamy sand and sandy loam soils.

Using the whole dataset, differences between NT and CT were expressed as the natural logarithm of yield relative ratio (LnRR):

$$LnRR = ln\left(\frac{Yield_{NT}}{Yield_{CT}}\right) \tag{2}$$

The relative ratio (RR) and its logaritm (LnRR) can be successfully used to highlight the effectiveness of soil management practice on yield, standardizing yield differences due to specific environment potential (Hedges et al., 1999). The absolute yield values, in fact, cannot be used because they are conditioned by the specific environmental potential. LnRR is 0 when the CT yield is equal to NT yield. The corresponding Ai value, when LnRR is 0, was considered to be the Ai threshold (TAi). For Ai values higher than TAi, the NT yield is lower than CT.

The adopted stepwise regression (mixed procedure) using STATA software (STATA Corp, 2015) was used to stress the factors affecting LnRR. The LnRR was mainly affected by RM and Ai, according to the following equation indipendently for the two cropping systems (M and CR):

$$LnRR = \alpha + \beta_{RM}RM - \beta_{AI}Ai \tag{3}$$

where LnRR is the logarithm of relative ratio; α is the estimated coefficient; RM is crop residue management factors (dichotomous varaibile, 1 = residues retained and 0 = residues removed); Ai is the aridity index (continuous variable). In the stepwise procedure, LnRR values were not affected by soil texture. As mentioned above, the LnRR is 0 at thresholds Ai (TAi), therefore TAi can be calculated solving the Eq. (3) for Ai, assuming LnRR = 0:

$$TAi = \frac{\alpha + \beta_{RM}RM}{\beta_{AI}} \tag{4}$$

2.2. Framework of NT yield success probability

In order to assess the probability of NT management yielding more than CT management for each specific environment, a conceptual framework was developed.

This framework allows us to predict the probability of a better yield under NT practice in comparison to CT, taking into account both the environment (Aridity index) and different management practices (CS and RM). The first step of the framework is to estimate the probability of success in NT compared to CT in order to determine TAi. A general logit equation model was specified to evaluate NT success in relation to Ai and RM, using the 519 values of dataset separately for each cropping system (M and CR), as follows:

$$\mathrm{logitNT} = \alpha + \beta_{\mathrm{RM}}\mathrm{RM} - \beta_{\mathrm{AI}}\mathrm{Ai} \tag{5}$$

where:

logitNT indicates the success of NT (logitNT = 0 when CT yields more than NT, logitNT = 1 when CT yields less than NT); RM indicates residue management and it is a dichotomous variable (1 = R, 0 = noR); Ai is a continuous variable.

Logit regression is a statistical tool that relates a binary dependent