Europ. J. Agronomy 77 (2016) 188–198

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Effects of crop residue management on winter durum wheat productivity in a long term experiment in Southern Italy

Domenico Ventrella*, Anna Maria Stellacci, Annamaria Castrignanò, Monia Charfeddine, Mirko Castellini

Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA)—Unità di ricerca per i sistemi colturali degli ambienti caldo-aridi (CREA-SCA), Via Celso Ulpiani 5, 70125 Bari, Italy

ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form 5 February 2016
Accepted 23 February 2016
Available online 7 March 2016

Keywords:
Crop residue incorporation
Crop residue burning
Residual autocorrelation
Mixed models

ABSTRACT

A long-term experiment comparing different crop residue (CR) managements was established in 1977 in Foggia (Apulia region, southern Italy). The objective of this study was to investigate the long-term effects of different types of crop residue management on main yield response parameters in a continuous cropping system of winter durum wheat. In order to correctly interpret the results, models accounting for spatial error autocorrelation were used and compared with ordinary least square models.

Eight crop residue management treatments, based on burning of wheat straw and stubble or their incorporation with or without N fertilization and irrigation, were compared. The experimental design was a complete randomized block with five replicates.

Results indicated that the dynamics of yield, grain protein content and hectolitric weight of winter durum wheat did not show any decline as usually expected when a monoculture is carried out for a long time. In addition, the temporal variability of productivity was more affected by meteorological factors, such as air temperature and rainfall, than CR management treatments. Higher wheat grain yields and hectolitric weights quite frequently occurred after burning of wheat straw compared with straw incorporation without nitrogen fertilization and autumn irrigation and this was attributed to temporary mineral N immobilization in the soil. The rate of 50 kg ha^{-1} of N seemed to counterbalance this negative effect when good condition of soil moisture occurred in the autumn period, so yielding the same productive level of straw burning treatment.

1. Introduction

Winter durum wheat (*Triticum durum*, Desf.) is the main cereal crop in Italy with more than 1.25 Mha cultivated in 2013 and with mean yield of 3.2 t ha^{-1}. Almost 70% of the cultivation is concentrated in southern Italy, where meteorological factors, such as rainfall and air temperature during the growing season, strongly influence crop yield. In the past continuous wheat and two-year wheat-fallow rotation have been the cropping systems extensively used in rainfed farming systems. Recently, as in the district of Foggia (in the northern part of Apulia region), durum wheat is frequently rotated with tomato in two- or three-year rotations (two years of winter wheat and one of tomato) and/or with irrigated and profitable catch crops such as cabbage.

Traditional agronomic practices involve the use of moldboard plowing as primary tillage, followed by repeated secondary shallow tillage. With the main plowing, straw and stubble, after being chopped, are buried into the soil or, alternatively, are burned in early September before carrying out soil tillage.

Stubble and straw burning is a common practice in areas where cereals are traditionally cultivated and it ensures quick seedbed preparation and residue clearance without machinery utilization. Moreover, burning is mainly performed in areas characterized by irregularity or steepness of land or where there is less need for straw due to reduction in heads of cattle. On the other hand, it can also be considered as a cheap way to limit the spread of several pathogens present in the residues of the previous crop and to reduce the number of germinable weed seeds. However, this practice has been prohibited by law owing to several drawbacks in many countries including Italy, even though in some Italian regions it is allowed, but in narrow time windows and with agronomic practice such

* Corresponding author. Fax: +39 080 5475023.
E-mail addresses: domenico.ventrella@entecra.it (D. Ventrella), annamaria.stellacci@entecra.it (A.M. Stellacci), annamaria.castrignano@entecra.it (A. Castrignanò), monia.charfeddine@entecra.it (M. Charfeddine), mirko.castellini@entecra.it (M. Castellini).

http://dx.doi.org/10.1016/j.eja.2016.02.010
1161-0301/

as “precesa”. It consists of buffer strips of at least 10 meter wide, along the field border cultivated with cereals, which are prepared immediately after harvest.

In several studies crop residue (CR) burning has been reported as beneficial for yield increase, but it should be avoided since it reduces organic matter input in the soil with consequent negative effects on environment and soil quality (Limon-Ortega et al., 2009). In fact according to these studies, burning reduces the amount of organic matter incorporated in soil, soil organic carbon and carbon substrates for soil microorganisms (Hamman et al., 2007). This causes a dramatic reduction in microbial biomass, number of bacteria and basal respiration (Glaser et al., 2002), so affecting CO_2 and N emissions from soil.

A number of studies has demonstrated that burning residues over a period of twenty years did not result in any significant reduction in grain yield or soil organic matter; a reduction in microbic activity was then noted with increase of the loss of soil organic carbon (Rasmussen and Collins, 1991). Straw and stubble burning does not determine rapid loss of soil carbon but significantly affects important physical properties, such as soil colour, aggregate stability and water infiltration rate (Rasmussen et al., 1980).

As reported in the exhaustive review by Kumar and Goh (2000), several scientists have examined the effect of CR management on yield of the following crop; however, the results from these experiments are conflicting because of a number of factors involved, such as residue quality, edaphic factors, health status of the previous crop, and their interactions with management practices.

Kumar and Goh (2000) assert that “under conditions of optimum fertility, adequate soil water supply and absence of pests and diseases, grain yields are largely unaffected by management ” whereas pollution and sustainability are the major concerns.

Under environmentally constrained conditions, CR management practices may affect grain yield trends significantly. For example, under low soil moisture conditions no-tillage and surface mulch treatment provided higher crop yields because of greater water conservation and evaporation reduction (Hatfield and Prueger, 1996; Prihar et al., 1996).

Under high soil fertility conditions or where long-term additions of CR have increased the amount of available N, yield generally increases (Tian et al., 1993; Dick and Christ, 1995), especially when crop demand and nutrient availability from residue decomposition are synchronized (Becker and Ladha, 1997).

CR incorporation after harvest might determine lower yields due to microbial N immobilization compared to fields where the residues are burned or removed (Limon-Ortega et al., 2000). It implies the need to apply higher N rates to compensate crop for a potential N deficiency and maintain constant yield levels. However, the efficiency of this action depends also on the date, rate and type of N fertilizer.

In a recent detailed literature review, Lehtinen et al. (2014) quantified the effects of CR incorporation on soil organic carbon and greenhouse gas emission across Europe by evaluating to what extent they are influenced by environmental zone, clay content of soil, duration of experiment, experimental setup and kind of CRs. The study indicated that the impact of CR incorporation on soil organic carbon sequestration is positive, but not for CO_2 and N_2O emissions that are expected to increase compared with CR removal. They also showed that long-term CR incorporation may increase crop yields but over a very long term (>20 years) and under continental climate. In fact, the Authors, reporting also the partial results of the long term experiment (LTE) described in this paper and of another similar experiment located at the same farm of Foggia, asserted that the incorporation of CRs lowered yield because of the poor mineralization and strong N immobilization caused by arid climate and low soil N content (Maiorana, 1998).

When a crop is continuously grown, a decrease in yield may be observed. In particular, yield losses in continuous cropping can be attributed to various mechanisms, such as reduction of soil water reservoir and nutrient availability, increase of weed populations, proliferation of certain pathogens, reduced transformation of nutrients owing to lower activity of soil microorganisms. Such processes can have significant impact on nutrient and water use efficiency (Nielsen et al., 2002; among others).

Several studies reported by Lithourgidis et al. (2006) showed yield reduction after continuous wheat cropping. Wheat grain yields were decreased considerably in the third year of continuous cropping in Iran, due to the adverse effects of continuous cropping and weeds (Bahrani et al., 2002). Twenty-five years of continuous wheat cultivated in India reduced wheat grain yields to almost zero (Sharma and Subehia, 2003).

On the other hand, other studies have shown that continuous cropping can be carried out in cereal production without significant yield losses. Jones and Singh (2000) found that in the medium term continuous barley cultivation was a sustainable cropping system provided that adequate annual fertilization was maintained. Procházková et al. (2003) found that wheat yield was not affected significantly by continuous cropping.

In evaluating the effect of different cropping systems on yield response, statistical analysis plays a crucial role. To assess long-term effects of agronomic management on yield response parameters, ordinary least squares (OLS) regression models are commonly employed. Their use requires assumptions of normality, independence and homoscedasticity of residuals. However, residuals are often spatially correlated (Lark, 2000; Kissling and Carl, 2007) and, if the test statistic does not account for spatial dependence it will be too large and consequently type I error, i.e. the incorrect rejection of the null hypothesis, will tend to increase (Rodrigues et al., 2013; Schabenberger and Gotway, 2005). Failure to account for spatial dependence can then result in erroneous conclusions (Littell et al., 2006) and lead to critical misinterpretation errors and improper management decisions.

Linear mixed effect models (LME) allow spatial correlation components to be assessed and filtered from the total residual term of the model so improving the protection of statistical tests (Rodrigues et al., 2013). Some studies have pointed out that mixed effects models, which incorporate spatial variability, can improve the understanding of factors affecting crop yield and plant response, and are then crucial in ecological and environmental studies (Lambert et al., 2004; Rodrigues et al., 2013; Kissling and Carl, 2007).

A long-term experiment, comparing different CR managements, was established in 1977 in Foggia (Apulia region, southern Italy) and is still ongoing. The objective of this study is to investigate the long-term effects of different types of CR management on the main yield response parameters in a continuous cropping system of winter durum wheat. In order to correctly interpret the results, models accounting for spatial error autocorrelation were used and compared with ordinary least square models.

2. Material and methods

2.1. Experimental layout and agronomic practices

The field experiment was established in 1977 at the experimental farm “Podere 124” of CRA-SCA located in Foggia (41°27′ latitude N, 15°36′ longitude E, 90 m above sea level) on a soil with clay-loam texture of alluvial origin, classified by Soil Taxonomy-USDA as fine, mesic, Typic Chromoxerert (Soil Survey Staff, 1992). The soil has a good availability of total nitrogen (0.12 g 100 g^{-1}) and organic matter (2.07 g 100 g^{-1}) and a content of 41 of available phospho-