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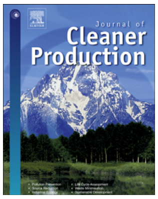

# Effect of different crop management systems on rainfed durum wheat greenhouse gas emissions and carbon footprint under Mediterranean conditions

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## ABSTRACT

The impact of management practices and input intensities on the greenhouse gas (GHG) emissions and carbon footprint (CF) of Italian durum wheat is not well documented. A field experiment was established in 2009 to gain insight into the effects of different crop management systems on total GHG emissions of faba bean–wheat rotations per unit area over five years. The aim was to estimate the emission intensity generated from the production of 1 kg of durum wheat in a typical wheat cultivation area of southern Italy. We proposed different crop management systems to reduce GHG emissions and enhance crop productivity. The proposed management practices consisted of three levels of soil disturbance – conventional (CT), reduced (RT) and no-tillage (NT) – and different nitrogen (N) fertilizer rates. These were applied and tested in order to validate their workability in the area. Results showed relatively higher emissions resulting from the pre-farm phase, whereas the cultivation phase was responsible for 49%, most of which was due to soil emissions (37.4%). In average, our wheat system was responsible for the emission of 1481.1 kg $CO_2$eq $ha^{-1}$ and 0.295 kg $CO_2$eq $Kg^{-1}$ of grain, which varied significantly between the proposed management systems. The tillage system had a significant impact on the total emissions. In general, NT and RT resulted in lower emissions than CT, although there were some exceptions in terms of GHG emissions per kilogram of grain due to the lower productivity of RT compared to CT and NT. On a hectare basis, NT reduced the emissions by 22% and by 35% on a kilogram basis compared to the highest emissions in CT in RT, respectively. N fertilizer, however, had both strong direct and indirect effects on total emissions resulted in increase by 60% when the highest N rate was applied. This positive correlation was reflected in CF data where a minimum of 0.155 kg $CO_2$eq $kg^{-1}$ of grain was obtained when the lowest N fertilizer rate was applied with a reduction of 65%. This was very much linked to the grain yield, thus, a low grain yield together with a high N fertilizer rate led to higher emissions and, therefore, a higher carbon footprint. The effect of the cropping system was clear, as the grain yield increased compared to the base year, with a consequent 31% reduction in CF at the end of the study period.

This is the first study in Italy to focus on the emission intensities associated with the production of durum wheat using different input intensities. Our findings indicate that achieving synchrony between minimum input requirements and crop demand without excess or deficiency is the key for optimizing a trade-off between yield and environmental protection.

## 1. Introduction

It is widely accepted that human activities, including agriculture, are causing significant changes to the global climate due to the increasing emissions of anthropogenic greenhouse gases (FAO, 2002; Ruddiman, 2003; Solomon et al., 2007 and Smith et al., 2008). Globally, agricultural activities and related farming practices are responsible for 10% of GHG emissions (IPCC, 2007). The largest contributors in agricultural are inorganic fertilizers, plant residues, as well as various biological and soil processes. In rainfed field crops, Robertson et al. (2000) and Johnson et al. (2007) found that fossil fuel use, N fertilizer application and soil disturbance were the main factors affecting GHG production. However, despite the impact of agriculture on climate change, an alteration in

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agriculture practices is thought to have a mitigating role if the right management is applied. Gan et al. (2014) concluded that wheat can convert more $CO_2$ from the atmosphere into soil carbon than is actually emitted during its production if various key farming practices are integrated together systematically. To be effective, the Intergovernmental Panel on Climate Change (IPCC) have recommended that mitigation practices should enhance sustainable production, product quality and have additional benefits for farmers (Foster et al., 2006; Rogner et al., 2007), which can be accomplished through efficient use of agriculture inputs (Notarnicola et al., 2012). Recently, policy makers, producers as well as researchers are trying to develop effective farming practices through a reduction in input intensities and related GHG emissions, while maximizing the potential economic returns (Janzen et al., 2006). One of the key strategies is to adopt improved farming practices (Gan et al., 2011a,b; CAST, 2011) including diversified cropping systems (Janzen et al., 2006) and crop rotation (Halvorson et al., 2008).

Today, given the changing climate, agriculture has a devolved commitment to reducing national GHG emissions (Audsley and Wilkinson, 2014), while insuring productivity. Although intensive agriculture may ensure high yields, it can cause serious environmental damage. Farm inputs, for example, are applied to maintain or improve crop yield, however they contribute directly to GHG emissions. Agrochemical production, distribution and on-farm operations can also indirectly contribute to the total emissions (Philip et al., 2000; Lal, 2002). As wheat production requires high inputs of nitrogen fertilizer and agrochemicals to achieve sufficient yields for the increasing population, the use of these fossil energy inputs can be optimized through improved management practices (Khakbazan et al., 2009). In recent years, research on sustainable agricultural practices have focused on the introduction of legume/wheat cropping system in order to limit the input (Pelzer et al., 2012). Previous studies (i.e. Aurich et al., 2006; Mendoza et al., 2006; Gan et al., 2014; Alhajj Ali et al., 2015) have investigated various forms of agricultural management in terms of emission reduction including tillage, fertilization and crop rotation. However, the calculation methodology, emission factors and primary farm data that reflect the local conditions in order to better understand and, therefore, develop mitigation strategies for italian context are still scarce.

One of the mitigation strategies we propose in this study is the adoption of conservation tillage in the form of zero/no-tillage. The Emissions Gap Report 2013 from the United Nations Environment Programme highlights the importance of no-tillage practices in agriculture as an alternative to conventional tillage (Powlson et al., 2014). The technique of planting crops in unprepared soil has been addressed by researchers and policy makers because of its benefits in reducing GHG emissions through increasing carbon sequestration (Schuman et al., 2002; Barber et al., 2011; Zhang et al., 2013), and enhancing soil structure and fertility, which minimize $N_2O$ production (Jordan et al., 2000; Brock et al., 2012) through its effect on biological processes in the soil that produce $N_2O$.

Despite the potential effects on $N_2O$ emissions and N losses to the environment, N fertilizer remains essential to global crop production. The efficient use of N fertilizer (NUE) presents another mitigation option which can lead to a dramatic reduction in $N_2O$ emissions both directly and indirectly (Lemke and Farrell, 2008). Given that 15.8% of the global N fertilizer production is used for wheat production (Heffer, 2013), a significant amount of nitrogen will potentially be lost to the environment through various biological processes. Several studies (i.e. Berry et al. (2008) and Mahmuti et al. (2009)) have indicated that N fertilizer application contributes 75% of the total GHG emissions in wheat production. Despite the yield response to N fertilizers, environmental parameters such as nutrient losses and GHG emissions need to be analyzed in relation to the N application rate.

The cultivation of wheat emits GHGs throughout the production cycle. The intensity of these emissions can be measured by mean of carbon footprint (CF). Calculating the CF of agriculture products has become an integral part of any political agenda regarding climate change (Wiedmann and Minx, 2008; Cucek et al., 2012). The interest in reducing the CF and incorporating it in “eco-labeling” is becoming increasingly widespread due to the increase in consumer awareness of the environmental impacts of their food (Williams and Wikstrom (2011) and Yang et al. (2014)). This has led many food growers to examine the effect of farming practices on CF (Gan et al., 2012) and their contribution to the global warming in order to identify possible mitigation options (Ponsioen and Blonk, 2012). In fact, when we predict future global warming and its contribution to climate change, the amount of future GHG emissions is a key variable. However, to implement sustainable management strategies, aspects related to other environmental impacts that might effect the ecosystem and therefore crop productivity should be considered.

The present study proposes and tests different wheat management systems by evaluating their performances in reducing GHG emissions using different farm-input intensities. The aim was to reduce GHG emissions per unit area and per kilogram of product, while maintaining and/or enhancing crop productivity. The final aim is to identify best management strategies by evaluating their effectiveness in counteracting the impacts of negative climate changes for sustainable durum wheat production in southern Italy.

## 2. Material and methods

### 2.1. Site description

Study site was previously described in detail (Alhajj Ali et al., 2013, 2015). Data used in the calculation of GHG emissions and CF are collected from a winter durum wheat field experiments conducted during five growing seasons (2009/2010–2013/2014) at an experimental education centre belonging to the University of Bari, in Policoro (MT) (40° N, 17° E) a typical Mediterranean area in southern Italy.

### 2.2. Experimental set up and data collection

Twelve management systems were proposed and applied using different input quantities. The proposed systems were resulted from the combination between different N fertilizer rates (0, 30, 60 and 90 kg of nitrogen $ha^{-1}$) and different levels of soil disturbance - conventional (CT), reduced (RT) and no-tillage (NT). Differences between tillage type can be found in Alhajj Ali et al. (2013). Wheat *Triticum turgidum* L.var. *durum*) cv IRIDE was rotated with faba bean (*Vicia faba* var. *equina* Pers.) every year for five years (two cycles of wheat and faba bean plus start-up year). Wheat was sown in November and harvested in June each year for grain yields. Wheat yield parameters were collected in each growing season for the whole study period. Data used for emission estimations were a sum of five years and three replicates. In addition, grain protein content was determined in the lab using the NIR FOSS grain analyzer to assess it relationship with resulted CF.

### 2.3. Goal and scope

Total amount of GHG emissions were estimate under each proposed management system. The goal was to identify best management practices in durum wheat cultivation. The total GHG emissions were linked to grain yield in order to calculate emission

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