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A comparison of the energy consumption of rainfed durum wheat under different management scenarios in southern Italy

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ABSTRACT

An energy consumption analysis comparing 12 management scenarios of durum wheat grown in southern Italy was carried out in order to identify the most energy efficient system with regard to productivity.

The results showed that yield parameters were significantly affected by the tillage system and revealed that conservation tillage entailed the fewest field operations and lowest energy requirements with higher yield.

Nitrogen rates had slight effects on yield parameters, whereas a linear relationship was found between increasing energy input and increasing nitrogen fertilizer. The highest proportion of energy input came from diesel fuel, followed by nitrogen fertilizer.

Total input energy used per hectare increased with the increase in management intensity. However, per 1 kg of grain, energy intensity was directly linked to grain yield. The lowest average of 1.8 MJ kg^{-1} was for conservation tillage, followed by intensive tillage with 2.9 MJ kg^{-1}, whereas reduced tillage was the most energy intense with 3.1 MJ kg^{-1}.

Conservation tillage of durum wheat in southern Italy can be used to maintain or increase productivity with only a minimum energy input.

1. Introduction

The agricultural sector requires energy as an essential input to production [1]. Recently, it has become more energy-intensive in order to supply more food to the increasing population [2]. Energy use analysis in agriculture is essential for an efficient, sustainable and financially viable production [3], since such production entails lower costs and reduces resilience on fossil fuels [4].

Traditionally, grain production systems rely heavily on the input of non-renewable or fossil energy [5]. These energy inputs are in direct forms such as diesel and electricity used for cultivation, transport, and other on-farm production activities, and in indirect forms such as the energy used in the manufacture and transport of fertilizers, herbicides and farm machinery [6]. All of these have direct effects on the depletion of fossil fuel resources and have varying effects during the life cycle on the final product of 1 kg of durum wheat. Hopper [7], for example, estimated that Canadian prairie agriculture required about 4.5 MJ of non-renewable energy to produce 1 kg of wheat in 1981; but this indicator varies with the cropping system and management practices being used. In Italy, it has been estimated that the energy consumption in agriculture amounts to around 0.42×10^9 GJ $year^{-1}$, of which 55% is related to arable crops [8].

In Italy the high demand for durum wheat as a raw material for bread and pasta requires a high input of energy. Durum wheat is one of the most widespread cereals in Italy, thus it is fundamental to study it in depth in order to save energy for sustainable production. Alternative management systems in durum wheat cultivation are needed to maintain acceptable levels of productivity yet also reduce economic and environmental costs.

The energy use for tillage in wheat production is a major direct expense in terms of fuel costs for farmers. High energy use for tillage is usually associated with high machinery costs and labor inputs [9], which differ greatly according to the tillage systems used [10]. A study conducted by Zugec et al. [11], for instance, demonstrates that conventional tillage such as moldboard plowing is one of the most expensive and organizationally slow systems, and is a significantly greater energy and labor consumer. Others like Harman et al. [12] and Smart and Bradford [13] agree that reduced and/or no-till is increasingly attractive to farmers because it clearly reduces input costs such as fuel, labor and machinery repair and depreciation costs as compared with a conventional system.

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Table 1
Soil characteristics of the study site.

Characteristics	M. Unit	Value
Total nitrogen	%	0.196
P_2O_5 assimilabile (Olsen Method)	ppm	40
Nitrate	ppm	14.3
Ammonium	ppm	Trace
Organic matter (Walkley–Black method)	%	2.8
Total lime	%	8.8
pH		7.72
Sand	%	39.78
Silt	%	37.40
Clay	%	22.82

As a response to the negative impact of soil degradation processes under different tillage systems, conservation tillage practices with protective cover of crop residue are being developed in many parts of the world [14]. Increased depth merely increases draft requirements, energy consumption and tillage time. Tillage should thus be kept to the minimum depth required to create an acceptable seedbed [15]. Tabatabaeefar et al. [16] reported that reducing tillage results in lower energy consumption as well as protection against soil erosion and a reduction in the time and energy required for seedbed preparation. However, in most cases, there is a decrease in yield when reduced tillage systems are used [17].

Energy and the environment are mutually dependent [18]. For example, Helsel [19], and Clark and Parmenter [20] reported that the energy equivalent value used to calculate energy consumption attributed to nitrogen fertilizer include the production, packaging, transportation and application. On the other hand, energy consumption for environmentalists represents the energy used in the entire production chain of wheat, which could lead to environmental problems such as depletion of fossil fuel resources.

The effects of different tillage systems in Mediterranean conditions have been studied in terms of agronomical aspects. Yield responses to tillage systems can differ widely with respect to soil type, crop species, precipitation and region [21]. However, there is little information in the literature concerning the energy balance of durum wheat.

Some producers adopt minimum and/or no-tillage as alternative management practices to reduce fuel consumption and reduce soil erosion and other forms of environmental degradation [22–24]. Several studies [25–29] have confirmed ecological and economic advantages of direct seeding. Despite the potential benefits of direct seeding from an environmental and financial point of view along with the possibility of its application in most European countries, the evolution of conservation agriculture has been slower in the European Union than in other parts of the world.

Apart from the positive effects on soil conservation and sustained land productivity, another major impact of conservation tillage is lower labor costs, generally leading to higher income and a better standard of living for the farmers [14]. However, a conservation tillage system with direct drilling has proven successful, especially in South America [14], but the impacts of this system in the Mediterranean climate, especially in the southern Italy, are still not well known.

2. Materials and methods

The study was conducted at an experimental farm belonging to the University of Bari, in a typical Mediterranean area (southern Italy), located in Policoro; 40°10′20″ N, 16°39′04″ E. This site is 15 m above sea level and is characterized by a Mediterranean climate according to the De Martonne classification [30] with an average annual rainfall of 560 mm distributed mainly during autumn and winter, and with a maximum temperature reaching 40–42 °C in the summer. The soil is loamy (Canadian texture) and has the characteristics shown in (Table 1).

In the framework of a three-year crop rotation experiment started in 2009–10 season, 9 ha of durum wheat (*Triticum turgidum* L. var durum) cv IRIDE was sown in parallel with 9 ha of faba bean (Vicia faba*var. equina* Pers.) cv PROTHABAT 69, both of which were organized in a split-plot design with three replicates. Both phases of wheat and faba bean were present and rotated each year with the main plots being wheat and faba bean.

Within each main plot of wheat, treatments consisted of four nitrogen fertilizer rates (0, 30, 60 and 90 kg nitrogen ha^{-1}) applied in the subplots. Intensive, reduced, and conservation tillage – see definitions below – were employed as the main treatment. The faba bean phase of the rotation was subjected to the same tillage systems as the wheat, but no nitrogen fertilizer was used. A total of 12 scenarios resulting from the interaction between tillage and nitrogen fertilizer rates were compared in terms of energy consumption during production in order to identify the most energy efficient system with regard to productivity.

The tillage systems used were designed based on their intensities in terms of fuel consumption, time required and depth as following:

- Conservation tillage (CT) i.e. planting crops in unprepared soil to obtain appropriate seed coverage using a direct drill seeder (IGEA 2700 SEMINASODO, Italy).
- Reduced tillage (RT) i.e. a subsoiler at 20 cm depth in late August usinga *volgarino* chisel with 7 dents. Disc harrowing at a depth of 15 cm was performed in November to obtain the optimum level of soil disturbance for producing the crop and, at the same time, minimizing damage to the soil structure.
- Intensive tillage (IT) i.e. an intensive method to a depth that entails using higher fossil fuels. Furthermore, mouldboard plowing at a depth of 35 cm was performed in late August, followed by disc harrowing at 15 cm in November to prepare the seedbed.

To reach the objective of the study, intensive tillage was designed to be higher than the other two tillage systems mentioned above in terms of time and fuel consumption. Plant yield parameters and energy indices were either measured or calculated.

2.1. Wheat yield parameters

Harvesting was affected directly on the field using a plot combine harvester with a 1.4 m width to measure grain and straw yield at plot level. Ten-meter long were harvested from the center of each plot to obtain a harvesting area of 14 m^2 for both wheat grain yield and straw. Considering the wide dimension of each single plot (27 × 30 m), the harvesting was repeated 3 times for each plot to obtain a more accurate measures. At the end, data used per plot was the average of the three harvesting times. Wheat straw was weighed directly in the field, whereas wheat grain was transported to the lab for cleaning so as to obtain the total weight per harvested area, which was then converted into kg ha^{-1}.

2.2. Energy and time requirement

Using the data shown in Table 2 for fuel consumption and the work duration of machinery used for crop establishment in the 12 scenarios, the amount of input and output energy required for the cultivation of 1 ha of durum wheat was calculated based on energy equivalent values given in the literature (Table 3), for the following