Management of Herbaceous/Horticultural Crops

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Preserving soil quality and increasing soil water availability is an important challenge to ensure food production for a growing global population. As demonstrated by several studies, conservative crop management, combined with soil cover and crop diversification, can significantly reduce soil and water losses.

conservation agriculture smart technologies soil conservation agricultural machinery

1. From Conservation Agriculture to Precision Conservation Management

Conservation agriculture (CA) is based on the integrated management of soil, water and agricultural resources in order to reach a sustainable agricultural production in ecological, economical, and social terms. Despite some resistance concerning the management aspects (i.e., weed control) and absence of adequate drills, planters and transplanters, the adoption of conservation practices represents great potential for herbaceous and horticultural crops. The adoption of “recommended agricultural practices” is a solution to the environmental issues and to achieve global food security [1]. Such practices would include use of conservation tillage, growing cover crops, using bio-solids and amendments, enhancing soil fertility through judicious use of fertilizers and adopting precision farming and water conservation. Over the years the concept of CA has assumed connotations progressively more linked to the concept of precision CA and to new technologies aimed at performing specific agronomic practices, considering the real needs of crops. Berry et al. [2] proposed “Precision Conservation Management Zones” like a viable combination of site-specific management zones and precision conservation management zones in order to maximize resource use efficiency, soil and water conservation and economic returns. The authors referred to a significant maximisation of N efficiency of corn crops without reducing grain yield and minimisation of NO_3-N leaching and offsite transport of N by means of the use of the Global Navigation Satellite System (GNSS), remote sensing and geographic information systems (GIS) tools. Moreover, precision conservation management will benefit from novel advances in the areas of telecommunications and micro-technology that can contribute to enhance real-time information. A few years later, other studies [3][4][5] have expanded the definition of precision conservation to a developing science based on the new geospatial technology (i.e., map analysis, spatial statistics, surface modelling, spatial data mining). These technologies allow to link a system from a site-specific location to a field, a set of fields (farm), or a regional scale in order to identify landscape risk areas, make management decisions, implement conservation practices and enhance crop production. In this regard, some studies carried out in NE Italy have investigated farm economic net return and environmental aspect [6] of three different conservation tillage practices (NIT—non-inversion tillage, MT—minimum tillage and NT—no-tillage). These operations were performed at variable intensity within predefined two management zones of a maize field in NE Italy: an area with a consistently higher yield and another one with a consistently lower yield. The overall results suggest that NT, employing a double-disk no-till planter, resulted in being a method with a lower environmental impact due to higher soil carbon sequestration and lower nitrate leaching. Moreover, the adoption of site-specific NT within the two different areas was more economically sound than all other tillage practices uniformly performed in the field. Nevertheless, claims of increased profitability from measuring, mapping, and site-specific management have in many instances fallen short, conditioning farmers to be more sceptical of precision agriculture. By contrast, Kitchen [7] demonstrated that the use of computers and sensors for real-time decisions in cropping systems could represent a new way of agricultural management to achieve conservation and other environmental benefits. As an example, the sensor system could predict about 66% of the variation in soil organic matter within fields but also a side-by-side field assessment of two on-the-go soil compaction sensor systems could be capable of sensing compaction at various soil depths.

2. Evaluation of the Agronomic Performance of the Application of the Smart Strategies and Innovative Agricultural Machinery Used for Conservation Agriculture (CA)

2.1. Crop Yield

Many studies have been carried out in Mediterranean areas to compare the effects of several conservation tillage practices with those of conventional ones on yields of cereals, legumes, etc. These studies showed inconsistent yield results, as well as significant differences from one year to the other and from one site to the other, showing that crop response to specific practices could differ as a function of soil type and other associated management practices [8][9][10][11][12][13][14]. Moreover, the findings of these studies suggest that the adoption of soil conservation tillage is practicable for different cropping systems that reach equivalent or better performances than CT.

By referring to the period examined (2000–2019), one of the oldest studies in these concerns has shown that MT with a rototiller was the most sustainable practice because of the increase of wheat grain yield (*Triticum aestivum* L.) and the improvement of soil physical properties over the long term compared with CT and MT with disc in Turkey [15]. In Central Italy, an experiment carried out on maize and soybean compared conventional mouldboard ploughing (CT), MT (by using two orthogonal rotary harrow passes for every year), RT (ridging with a 0.7 m spacing using a furrow opener and annually restored by means of a light ridging pass on the following years) and NT. This experiment showed that no significant differences due to soil tillage were found for grain yield and irrigation water use efficiency, except for soybean in only one year, in which yields and irrigation water use efficiency were 59% higher on conservation tillage treatments compared with CT [8]. Ruisi et al. [13] carried out a set of experiments in the South of Italy (Sicily Region) during 20 years in order to compare the effects of NT practices and CT on the productivity and quality of durum wheat. They showed that, in the semiarid Mediterranean environments, the factor that most affects wheat productivity is soil water availability, which is greater for the crop in

NT than in CT. For these reasons, the yield differences between NT and CT noted during the trial were related to the water stress level suffered by wheat during its growing period. In particular, the regression analysis revealed the superiority of the NT approach over the CT technique with respect to the tillage practices when grain yields were low and, conversely, an advantage of CT in the opposite case. On average, no differences in yield were observed between the two tillage techniques as reported in other studies carried out in similar environmental conditions [9][10][12]. Moreover, in order to emphasise the potential of the NT technique, the authors suggest that the farmer needs to: (i) adopt a rational crop sequence, because a cumulative detrimental effect of NT with time was found for continuous wheat cultivation, probably as a consequence of the progressive increase in the incidence of certain residue-born pathogens of wheat; and (ii) with respect to the system managed with CT, increase the rate of N fertiliser to compensate for the lower N availability in the soil that occurs in NT versus CT (as a consequence of both the reduction of the rate of mineralisation of the organic matter and the increase in N losses) [13]. A similar study carried out in Spain by Lampurlanés et al. [16] demonstrates that under semi-arid rain-fed conditions, soil water storage increases with the use of conservation tillage systems, being amplified with the degree of aridity of the site, leading to a greater crop yield. A study of Canakci et al. [17] was carried out in Turkey with the aim of assessing performances of a no-till seeder equipped with a double disc-type furrow opener, under dry and wet soil conditions using maize (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean *(Glycine max* L.) seeds sown following wheat (*Triticum aestivum*). The results showed that the percentage of emergence of soybean plants in dry soil conditions was low while the percentage of emergence of maize and soybean in wet soil was higher. Also, sowing depth uniformity was better in wet soil than in dry soil. In general, there was acceptable data variability for sowing maize and cotton in dry and wet soils and for soybean into wet soil as concerns evaluated indices (mean emergence time, percentage of emergence, multiple index, miss index, quality of feed index, precision index of horizontal distribution pattern, and sowing depth uniformity). The study of Troccoli et al. [14] reports findings from national and international scientific literature and also some results of a long-term experimentation conducted in the South of Italy (Puglia Region). This study shows the effects of CA on crop yields show controversial results but, in general, yields are less than in CT with mouldboard ploughing. Sometimes NT can produce equivalent or greater yields than CT especially in dry climates [10][18][19][20]. This means that CA should not lead to yield penalties [21]. However, the different environmental conditions and the time of transition from conventional agriculture to the permanent state of CA strongly affect the grain yields. However, Ceccanti et al. [22] found a significantly higher level of bioactive compounds in leafy vegetables in a short-term experiment with a CA cropping system. These results greatly support CA practices despite yield losses. At the same time, soil properties could benefit from CA practices. Organic matter increases with CA and, consequently, increase underground water quality, reducing erosion processes and improving soil moisture retention. In this way also biodiversity is higher with NT than CT [14][23]. In France, Legrand et al. [23] highlighted the species richness and evenness significantly higher in fields under MT practices than in fields under CT, despite the fact that the core microbiota was similar between fields under these two practices. Other studies carried out in southern Italy [24] showed that no significant differences were revealed between the soil tillage treatments on *Brassica carinata* in terms of soil fertility comparing CT and MT. In particular, the CT practices included mouldboard ploughing (40–45 cm deep) and both disk harrowing and vibrating tine cultivation; the MT practices involved two disk harrowing events with at least 7 days between them and just one instance of vibrating tine cultivation (10–15 cm deep). In the context of sustainable agriculture, the results of this study show that it is possible to sustain Brassica production and increase some nutrients in the soil with organic amendments (e.g., sewage sludge followed by the application of compost) and reduced tillage. Concerning bulk density, the findings are different. Some studies have reported a strong increase in bulk density with NT compared to mouldboard ploughing while others found similar bulk density values with CT and NT systems. Due to the rearrangement of soil sand particle aggregates by biological processes and by the action of coulters and shanks of no-till seeders and planters coulters, the layer from 0 to about 7 cm appears less compact than the underlying layers [14]. Moreover, other studies demonstrated that soil compaction values were frequently greater in NT systems than in CT, especially in the top layer. A field trial carried out in southern Italy, on a clay soil at the 10th year of NT, showed that usually NT had cone index values slightly higher than CT, excluding dry conditions and the thin soil layer (0–0.15 m) when NT soil looked to be less compact than CT [14]. The results of a study carried out in the North of Italy, alternating autumn and winter crops, provide insights on yields, CO_2 emissions and SOC. In particular, SOC oxidation rates were overall lower under NT as well as the greatest reduction in CO_2 emissions. These results underline the benefits of NT adoption in terms of soil fertility preservation and CO_2 emissions mitigation also thanks to the lower number of passes required by NT practices and the higher working capacity of machinery used in NT. By contrast, NT practices achieved higher emissions from pesticides and sowing operations [25]. A study aimed at investigating the effects of CT, RT and NT practices on sunflower yields in South-eastern Turkey showed that sunflower yields and agronomic properties were significantly affected by tillage methods. In fact, the highest yields were found in CT methods and lowest yields were found in RT practices carried out by means of cultivator + float + direct seeding machine [26]. For the success of CA techniques and particularly of NT (transplanting on no tilled soil), in addition to a proper use of specific on purpose transplanter, there is a clear need to optimize the choice of the cover crops and to define and apply at best methods to terminate and transform them in dead mulch. These findings have been highlighted by the results obtained in horticultural crops by several authors in very recent field experiments on the use of a CA and organic agriculture management carried out in Italy (at the Universities of Pisa and Perugia). Moreover, there is also the need to set up strategies based upon the adoption of thermal and mechanical treatments able to guarantee good weed management after the transplanting [27].

2.2. Economic Feasibility

The estimation of production costs represents the most complex part of the economic evaluation given numerous variables to be considered. The technical analysis of production processes has shown that the main operation affected by changes in the transition from CT to CA is that concerning soil tillage. For this reason, the evaluation of the economic convenience between the two management systems should focus on this item. The first element of difference between CT and CA is represented by the reduction of interactions between operating machines and soil, limited to direct sowing in case of sod seeding. In terms of economical profitability, MT or NT may substantially reduce crop production costs, as mechanised tillage is a rather costly technique including fuel, labour and machinery costs. In the grain production systems, relative benefits of CA depend on the difference between the costs of soil tillage vs. the cost of chemical herbicides applied before sowing [14]. The reduced use of machines translates into savings due to the reduction of wear, fuel, lubricant and working time saving. In particular, experimental results confirm that, in general, the adoption of sowing on land allows significant savings to be attributed to lower (from 35% to 80%) fuel consumption, a reduction (from 40% to 60%) of time and labour costs (hours/machine and labour, spare parts and maintenance). Cost reduction is largely due to oil and energy saving [28]. Food and Agriculture Organization-FAO [29] reports economic benefits related also to labour savings and machinery depreciation, and some other authors report CA benefits on investments efficiency and productivity [30]. Labour requirements are generally reduced allowing farmers to save on time, fuel and machinery costs [21]. Apart from the agronomic and environmental benefits, this economic advantage proves to be a strategic element for the survival of many farms that face a globalized market with the prospect of a decrease in product prices and an uncertain international policy. In a recent study carried out in farms in central Italy that have long used cereal systems, it has been possible to verify that economic savings can be achieved by conservative agronomic practices compared to conventional ones, varying between 50 and 80 euros per ton of grain produced [31]. The economic convenience is strictly related to the machinery used. The technology currently available allows direct seeding to be carried out with specific seed drills that do not require any preparation of the seed bed. These machines are specifically designed to work on undisturbed soil in the presence of crop residues, equipped with appropriate devices for the prevention of seeding compacting and furrow closing, with re-covering units and compressor parts, to guarantee regular plant emergence. According to Scopel et al. [32], for both resource use efficiency and socio-economic results, the situation becomes more favourable after some years of conservation agriculture application when systems stabilise. A comparative field experiment, based on direct measurements of data about machinery and production factors used, was carried out in the north of Italy, one of the main areas of rice production in Europe. The results showed that the adoption of conservative techniques led to significant savings on production costs, thanks to reduced work time (−47% for MT and −61% for NT less) and to lower mechanisation costs (−42% for MT and −58% for NT) in comparison with CT practices. Moreover, the reduction in fuel consumption (−48% for MT and −63% for NT) means reduction of emissions and environmental impacts [33].

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