DOI: 10.22620/agrisci.2022.35.010

# AN OVERVIEW OF NO-TILL TECHNOLOGY IN THE CONCEPT OF CONSERVATION AGRICULTURE

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**Abstract**

This review article summarises some of the most important terms and definitions of the vocabulary used in conservation agriculture (CA) and no-till technology (NT). It also presents the concepts and foundation principle of CA. The article cites selected sources with detailed historical notes and a chronological narrative about the development of the concept of conservational agriculture, machinery, devices and techniques that no-till technology applies. Due to the vastness of CA as a subject, the current review deals very briefly with some of the topics such as economic benefit, weed control, cover crop and crop rotation, use of herbicides. The availability of controversial results about no-till does not allow any final conclusion about the feasibility of that technology. It could be expected that on different soils, in different geographical conditions, depending on the machinery used and the combination of particular elements of the technology, the outcome of its adoption is highly probable to be different. Despite this variability in technology adoption, in cases of no significant reduction in crop yield, the application of technology seems worthy due to the ecological benefits which it provides. However, there is another important consideration that should be taken into account in NT adoption - any expectations for quick revenue should not be considered feasible because ecological sustainability could only be achieved in a long-term application of CA and NT.

**Keywords:** conservation agriculture, no-till, weed control cover crop, crop rotation, occasional tillage

## 1. Introduction

The contemporary management of natural resources and climate change is expected to put further pressure on agriculture adaptation in relation to successful dealing with several important ecological issues such as: soil, water and biodiversity protection and greenhouse gases reduction (Basch et al., 2012). The sustainable agriculture which applies ecological principles requires the identification of the most important factors that could restrain the optimal productivity, and thus implement any necessary actions in order to overcome them. Some economic limitations cannot be ignored in the first place and have to be carefully considered (Triplett & Dick, 2008). Despite the significant contribution of the conventional agriculture to the historical development of agriculture and human society, the extensive long-term use of traditional conventional tillage has a negative effect on soil (Hobbs et al., 2008). Deep mouldboard ploughing is a specific and distinctive operation of conventional tillage. In Sweden, for example, the mouldboard ploughing is used for over 80 % of the area with annual crops. The depth of the ploughing is usually up to 20±25 cm, but the depth of about 30 cm is not an exception, especially in sandy soils (Etana et al., 1999). Conventional tillage can cause significant soil erosion (Lindstrom et al., 1992). It can change the soil physicochemical and hydrological properties (Rahman et al. 2008), can affect soil organic matter (SOM), microbiological characteristics and its biochemistry (Melero et al., 2011), can affect the soil microbial communities and the synthesis of soil enzymes (Acosta-Martinez & Tabatabai 2001), can release the soil deposit of greenhouses gases such as – carbon dioxide ($CO_2$) methane ($CH_4$) and nitrogen oxide ($N_2O$) (Plaza-Bonilla et al., 2013, Chellappa et al., 2021, Smith et al., 2010, Lal, 2015). Conventional tillage causes significant changes in the soil ecosystem (Karaca et al., 2011).

Conservation agriculture (CA) is the main component in a new and alternative paradigm and philosophy which would require a fundamental change in the perception of agriculture, its sustainability and productivity (Table 2). The optimal crop productivity in the agro-ecosystem depends on factors such as: a proper choice of crop, sowing time, providing the crop with nutrients and water during its phenology phases, disease prevention, effective weed and pest control (Flohr et al., 2018, Bajwa et al., 2020). The type of soil tillage and the use of other technologies which include significant modification of tillage, and furthermore, even a complete lack of tillage would have a significant impact on soil quality and crop productivity (Triplett & Dick, 2008). Such significant changes in the tillage practice are going to be perceived as controversial to the traditional agriculture and would require a high level of adaptation. In its full range, the transition from conventional agriculture towards conservation agriculture would inevitably affect the way of thinking, laws and regulations, institutional rules, agricultural machinery, labour standards and organisation of work (Huggins & Raganold, 2008, Kassam et al., 2015, Schneider et al. 2010).

The adoption of CA and no-till (NT) has been primarily implemented due to economic considerations such as reducing labour and energy costs, and later, on ecological grounds (Derpsch, 2014). The idea and the first attempts for CA introduction were actually initiated by farmers rather than scientists, but the adoption of the technology was the result of a successful collaboration between farmers, scientists, agronomists, machine engineers, research and development (R&D) agencies (Peiretti & Dumanski, 2014, Monjardino et al. 2021). The CA adoption requires from farmers experiments with new technologies, acquiring the knowledge and a constant adaptation to new conditions (Coughenor & Chamala, 2000) and from governmental bodies – a complete understanding of all important long-term economic, social and ecological benefits which the paradigm of CA could offer to farmers and society (Kassam et al., 2015).

In a global scale, despite the available information on the benefits of CA, very few farmers have simultaneously adopted all the elements of the technology (Monjardino et al., 2021). There is rationality behind such approach - CA is a multileveled and multifaceted innovation that would require a consecutive manner of adoption and a gradual substitution of the available and already established agricultural technologies. In order to access the effect of the combinations of different elements of CA such as NT, cover crop and crop rotation Monjardino et al. (2021) used the data for a 10 years' period provided by a representative farm in Mexico. The authors applied integrated framework that included bioeconomic simulation, risk analysis, adoption theory and impact assessment. The results revealed a significant difference in the economic parameters when the multicomponent package was replaced by a package with a reduced number of components. As a result of the analysis, the authors have suggested that the adoption of a limited number of components of the CA system could increase the adaptability of farmers and decrease their economic uncertainty in some risky contexts (Monjardino et al., 2021).

## 2. Conservation agriculture definition

Conservation agriculture (CA) is defined by the Food and Agriculture Organization of the United Nations (FAO) as follow: "*a farming system that promotes minimum soil disturbance (i.e. no tillage),* *maintenance of a permanent soil cover, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production*” (FAO, 2017). CA enhances biodiversity and supports the natural biological processes which are prerequisites for sustainable crop production (Singh et al., 2021).

Conservation tillage (CT) implies a very low level of soil tillage that includes the use of different techniques and machines and a different quantity of plant residues on the soil surface (USDA, 2017). There are several different types of conservation tillage techniques and their use sometimes is described by a variety of terms such as: *minimum tillage*, *mulch tillage*, *ridge tillage*, *strip tillage*, or *reduced tillage*. However, in all cases, these terms refer to the sowing in preliminary prepared soil surfaces with a different geometry (Hobbs 2007; Dumanski and Peiretti 2013; Derpsch et al., 2014). No-till technology (NT), in some cases denoted also as *direct seeding*, is classified within the group of conservational tillage techniques, but according to Reicosky (2015) it seems more logical to consider NT as a different group of CA because its main distinctive feature is insignificant or has no effect on the soil horizon.

According to Derpsch et al. (2014) most of the definitions for CA that exist in the scientific literature are not exact and thus terms such as *mulching*, *reduced tillage* and *minimum tillage* which in fact denote a different extent of soil tillage are very often collectively, and wrongly, considered as no-till. This lack of precision in the definitions and the ambiguity in the used terms are usually related to several issues such as: (1) the precise assessment (and reporting) of the extent of soil tillage and (2) the proper estimation of the quantity of surface plant residues (Derpsch et al., 2014). Such estimations are necessary for the proper comparison or the in-depth analysis of the data derived from different experiments (Reicosky, 2015). The lack of standardised terminology also imposes limits on the opportunities to draw conclusions about technology effectiveness and related additional options. One element which cannot be found in the FAO definition, for example, is the clear statement about the quantity of the plant residues on the soil surface. This important feature of the technology has been mentioned in some other definitions, and it informs that no less than 30 % of the soil should be covered with plant residues (Patel et al., 2008). According to the the Conservation Tillage Information Center (CTIC, 2002) which is a unit of an American non-profit organisation, if the main purpose of CA is soil protection against water erosion, then at least 30% or more of the soil surface should be covered with plant residues. If the soil is threatened mostly by air erosion, the recommended quantity of plant residues should not be less than 1 t per ha.

According to Reicosky (2015) the definition of the *minimal tillage* seems the most ambiguous and indecisive. According to some authors the *minimal tillage* refers to the tillage which is needed for soil productivity in a particular soil type and climate conditions (Foth, 1991). Similarly, in the dictionary created by Patel et al. (2008) the definition of the so-called *minimal tillage* refers only to the application of basic tillage which is necessary for plant growth and prevention of any soil deterioration, but no further explanations or clarifications related to the tillage are made. Currently, the most detailed and clear explanations about conservation agriculture and its elements could be found on the Internet site (https://www.ctic.org/resource_display/?id=322&title=Tillage+Type+Definitions) of the Conservation Tillage Information Center (CTIC, 2002). Even though, this information is not explicitly related to the scientific literature, it is very useful from a practical point of view.

## 3. The main principles of conservation agriculture

Three key principles of conservation agriculture have been established by the FAO as follows: (1) reducing the soil tillage or when it is done it has to comply with the practices of sustainable management; it preserves the soil structure, soil organic matter (SOM) and soil health in general; (2) increasing the soil cover through plant residues or intercrops whose aim is to retain soil water and nutrient resources and to support the biological activity which in turn is important to the integral control management of weed and pests; and (3) encouragement of the biological activity through crop rotation by using a diversity of annual and perennial plants through different approaches, i.e. planted in association or in a consecutive manner (FAO, 2011).

The adoption of CA is expected to increase the sustainability of the agro-ecosystem and to have significant effects on productivity and to provide important socio-economic and ecological benefits for farmers and society (Shrestha et al., 2020). In order to achieve its goals the sustainable agriculture should also apply some additional technological principles such as: (1) higher level of effectiveness of the key investments, water resources, soil nutrients, pesticides, energy cost, land use and labour; (2) simultaneous achievement of higher productivity and an increase in natural resources and ecological services; (3) preserving and maintaining the biodiversity which contributes to the balance in the agro-ecosystem and its resilience against abiotic, biotic and economic stress factors (FAO, 2011).

## 4. The adoption of CA and NT on a global scale

The first elements of the concept of conservational agriculture (CA) have emerged in the USA in the 1930s as a reaction towards the widespread and substantive problem of soil erosion. After the 1960s, the initiative has spread to other countries - most of them located in Latin America (Vankeerberghen & Stassart, 2016). Australia and Canada can be mentioned as an example of countries that have also broadly adopted CA (Bai et al., 2018). Globally, in 1999 CA has been applied on an area of approximately 45 million ha (Derpsch et al., 2011). Gradually, the area under CA has increased up to 72 million ha in 2003 and to further 111 million ha in 2009 which corresponds to an average increase of 6 million ha per year. The fastest adoption of CA has been registered in South America. One interesting feature is that NT, applied on almost 70 % of the agricultural soil in South American counties, is used as a permanent technology. For comparison, in the USA the agricultural lands under NT are occasionally subjected to conventional tillage (Derpsch et al., 2011).

The adoption of NT over more than 110 million ha globally reveals the high suitability of this technology under different climate conditions and a variety of crop species. Currently, the no-till technology can be found from the North Pole to the Tropics, from the sea level up to 3000 m altitude above the sea level; additionally, it is applied on irrigated soils with rainfall of 2 500 mm per year, as well as on very dry ones with only 250 mm of rainfall per year. The highest percentage of adoption (over 50 % of agricultural lands) is reported for Australia, Canada and the countries of the Southern cone (Chile, Argentina, Paraguay, Uruguay). The adoption of CA in Africa, Central Asia and China is also in progress (Vankeerberghen & Stassart, 2016).

The adoption of CA in Europe began relatively later – in the middle of the 1990s of the 20$^{th}$ century. The initial attempts at adopting CA in Europe were primarily driven by the demand of production costs reduction rather than any response to ecological needs (Kuipers, 1970), but the pace of adoption was significantly improved with the implementation of new policies which became an integral part of the Common Agriculture Policy (CAP) of the EU (Kertész & Madarász, 2014, Gonzalez-Sanchez et al. 2016, Lal, 2015). According to Lugato et al. (2015) some steps towards improving and speeding up the adaptation and application of conservation technologies in Europe have been made through the implementation of necessary laws and their harmonisation. The most important arguments against the adoption of NT in Europe have been thoroughly presented in the analysis done by Basch et al. (2008). Among these arguments are: (1) a historical and socio-cultural attachment to conventional agriculture; (2) a lack of sufficient professional experience related to conservation agriculture; (3) the limited experience of agencies which provide advice in agriculture and to farmers about the adoption of the new technologies; (4) a lack of understanding about the principal capacity of the soil biosphere and its ability for self-improvement and self-restoring in cases when the tillage is not implemented and when the soil surface is covered with plant residues; (5) a necessity of adaptation of conservation technologies towards a variety of plant species, different types of soils and climate conditions which exist on the continent; (6) a relatively high price of machines and equipment in the no till technology and (7) a lack of synchronised policy according to the technologies and methods for weed, insects and disease control (Basch et al., 2008). However, currently, the EU is working on an updated version of the Common Agricultural Policy for the period 2023-2027 (EC, June 2022) in which all these issues probably are going to be considered and some solutions could be suggested.

The data of the European Conservation Tillage Federation (2017) about CA showed that only 5 % of the agricultural land in the 27$^{th}$ members of the EU was under some of the elements of the conservational tillage technology, but the NT was applied scarcely (3.44 %) on the agricultural lands (Table 1). The availability of discrepancies in the results of short-term experiments related to the adoption of CA and due to unrealistically short time-frame for achieving the expected outcomes also could be considered as reasons restraining the adoption of CA in the agro-ecosystems in Europe (Mitchel et al., 2019, Sartori et al., 2022).

**Table 1.** The FAO`s statistic about the farmland with conservation agriculture or the technologies of zero- и no-till, according to the data reported by different countries for the years 2016-2017.

| ***Country*** | ***Cropland under conservational agriculture. Unit - 1000 ha*** | ***Cropland area under zero or no-till. Unit - 1000 ha*** |
|---|---|---|
| | *Value* | *Value* |
| ***USA*** | *39561* | *42272* |
| ***Austria*** | *395,3* | *23,2* |
| ***Belgium*** | *92* | *82,7* |
| ***Bulgaria*** | *1336,82* | *4,84* |
| ***Germany*** | *4747,9* | *93,9* |
| ***Denmark*** | *252* | *32* |
| ***Estonia*** | *183* | *74* |
| ***Canada*** | *7826* | *19495* |
| ***Cyprus*** | *44,2* | *3,2* |
| ***Latvia*** | *68,4* | *12,8* |
| ***Lithuania*** | *34,4* | *0,9* |
| ***Norway*** | *52,92* | *465,87* |
| ***Portugal*** | *383,05* | *15,54* |
| ***North Macedonia*** | - | *13* |
| ***Hungary*** | *359,8* | *37,9* |
| ***Finland*** | *654* | *215* |
| ***France*** | *4620* | *529* |
| ***Holland*** | *116* | *8* |
| ***Croatia*** | *44* | *5* |
| ***Czech*** | *775/755** | *33* |

Source: FAOStat, https://www.fao.org/faostat/en/#search/no%20till

**5. Prerequisites for no-till adoption**

The adoption and implementation of NT could not be done successfully without a careful preliminary planning and fulfilment of some prerequisites. The lack of knowledge how to approach specific land conditions is usually the main reason for non-success, thus there is a strong necessity of acquisition of basic knowledge and concepts before adopting the conservative technologies (Vankeerberghen & Stassart, 2014). These prerequisites very often require several tests on soil parameters and consecutive steps towards their correction. Such activities have to be done in order to recover the nutrients balance of the soil and its active acidity (Derpsch, 2008). Experimental data revealed that the effectiveness of the no-till technique depends greatly on water content, soil type and structure (ratio of sand, clay and silica), the location of the field and its specific features (Davies & Finney, 2002, Fiorini et al., 2020, Nafi et al., 2020). Usually, soils with insufficient drainage are not very suitable for NT. The rough and uneven surface of the soil left after some other tillage operations can make the uniform sowing impossible which means that the soil should be flattened before adopting the NT. If there is a significant soil compaction it also should be lessened (Derpsch, 2008).

It is also known that the worst results from the application of NT are obtained when the cover crop have been deliberately omitted (Sun et al., 2015). Thus, the plant residues should be kept on place with a proper quantity in order to guarantee the success of the no-till technology. No sooner when all preliminary requirements are fulfilled than the farmer can proceed with buying the special machinery for the NT and to start implementing the technology. It is highly recommended that the adoption of the technology is done only partially over a relatively small portion of agricultural land, and only after the farmer is more experienced, he could proceed towards converting all the land to the NT. The experimental data also revealed that the NT is not very effective in monoculture farming, but the successful adoption depends also on the reasonable choice of either the plant species selected for the crop rotation or chosen as a cover crop (Derpsch, 2008). The acquisition of knowledge about the technology requires a period of time which according to the opinion of farmers is no less than five years (Derrouch et al., 2020). The process of increasing farmers' knowledge depends also on the free access to different technology modifications and novelties both on local and global level (Dumanski and Peiretti, 2013).

**6. Conservational agriculture techniques**

According to its definition no-tillage leaves the soil undisturbed after the previous harvesting or affects no more than 5 cm of the soil surface (Soane et al., 2012). The sowing is performed with chisel ploughs, disks, field cultivators or sweeps, which make only the ridges, even if they are very shallow, but necessary for the seed planting (Harper et al., 2015). The weed control is conducted by the use of herbicide and the plant residues from the previous harvesting should be left on the soil surface (Foth, 1991).

One of the many modifications of the no-tillage is the so-called *strip tillage* which according to Harper et al. (2018) is denoted also as *zone tillage*. In the strip tillage the machines make narrow ploughing strips with a different depth and width and a middle undisturbed zone. Instruments such as the chisel plough can have straight or bended blades and usually affect the soil in the depth of 10 to 15 cm (4 to 6 inches). The use of a combination of instruments for deep ploughing results in disturbing the deeper soil layers and the ploughing can reach the depth of 38 cm (15 inches) and the discs that cut the plant residues also spread them throughout all affected levels of the soil horizon (Reicosky, 2015).

Another group of conservation techniques very often denoted with the collective term – *reduced tillage* is comprised of techniques such as *ridge till* and *mulch till*. During the ridge till, the seeds are planted on both sides of the ridge or on the upper edge of the ridge which has appeared after the tillage of the soil in the previous year (Harper et al., 2018). A *contour tillage* is performed when the tillage is done with the direction at right angles to that of the slope (Busari et al., 2015). After such techniques the plant residues are left on the soil surface during the winter months and at the time of sowing are simple barely displaced from the ridge edges. The technique of mulch till, however, uses the full set of machinery usually comprised of ploughs, discs and cutting instruments used in the conventional ploughing, but these devices are assembled in a manner that allows the remaining of at least 30% of the plant residues on the soil surface (Harper et al., 2018). The diversity of options for the tillage which affect different soil layers and a different quantity of plant residues have certain economic dimensions – with the decrease of intensity of soil tillage, a decrease in fuel costs could be expected (Shrestha et al., 2006, Reicosky, 2015).

According to Foth (1991), in some cases, the preliminary soil preparations, sowing and application of fertilisers and herbicides can be done with single machinery run over the field. In suitable conditions, the other operations are not recommended during the vegetation of the crop. The pressure of the tires behind the seeder makes a compaction of the soil only where the seeds have been planted and it does not affect the rest of the soil surface which facilitates the water infiltration.

## 7. Some practical aspects related to the adoption of CA and NT

The successful application of CA and NT requires the adoption of defined main principles, and a numerous research data has already demonstrated the interaction and dependence among the different elements of the technology. However, in the following text of the current review article the selected practical aspects of the NT technology have been presented separately solely in the interest of clarity but without ignoring their actual interrelationships.

### *7.1. No-till in prevention of soil erosion*

The water erosion of soil has a significant impact on its ecological balance. Some preliminary data on the adoption of NT indicated the possibility of mitigating soil erosion five to ten times in comparison to the conventional tillage (Tripplett & Dick, 2008). Sun et al. (2015) have made a metagenomic analysis about the effect of NT on the reduction of the soil surface water erosion and factors that can affect the effectiveness of different tillage practices. The data showed that the NT had significantly reduced erosion with 21.9% and 27.2% when compared with reduced tillage (RT) and conventional moldboard plough (MP), respectively. The influence of NT on water erosion, however, was more effective on artificially rather than on naturally irrigated soils in comparison to MP. The reduction of erosion under NT was significantly more when the slope estimations vary between the higher to the middle values (5–10%) when the NT is compared both with RT or MP, but there was no statistical difference between the tillage practices when the slope was very low (<5%) or excessive (>10%). In comparison to MP the effectiveness of NT in decreasing soil erosion had diminished with time, but the same was not confirmed for the RT. In comparison to the RT no-till significantly reduced erosion in soil with a low clay content (less than 33 % clay), but it increased slightly and statistically insignificantly the erosion of soil with a high clay content (more than 33 % clay). The effectiveness of NT in the reduction of soil erosion in comparison to RT has not been affected by the plane of soil mixing. When there were plant residues on the soil, the reduction effect of NT on erosion was comparable to RT, but if there were no remnants on the soil, the effect disappeared (Sun et al., 2015).

### *7.2. No-till economic benefit*

Derpsch et al. (2011) considered NT as a promising option for the optimisation of production and ecological services by a wide scope of economic, ecological and social benefits equally important for farmers and society. According to Foth (1991) the yield in minimal tillage is similar to the yield in conventional tillage, but because of the minimal tillage technique the energy costs could be reduced and as a result the net profit increases. A share of the financial resources could be allocated for obtaining herbicides. Experimental data have shown that after the adoption of NT, the energy costs could be reduced up to 50%, the reduction of the carbon footprint could reach 17% and the expenditure for the crop cultivation could be reduced by 35% (Yadav et al., 2020). Depending on the crop type and the number of machine operations, it has been estimated that the fuel consumption is up to 3 to 4 times higher in the conventional tillage and at least 2 to 3 times higher in the minimal tillage in comparison to NT (Harper et al., 2018).

The researchers have conducted a global meta-analysis using 5 463 paired yield observations from 610 studies about 48 crops in 63 countries in order to compare no-till with conventional tillage practices. In general, the results from the study showed that no-till reduces crop yield. However, this response is variable and depends on certain conditions that restrain the ability of no-till to provide equivalent or greater yield than the conventional tillage. The most important observation of the study is related to the fact that if no-till is combined with residue retention and crop rotation, some of its negative impacts are minimized (Pittelcow et al., 2014).

In the economic aspect the conventional, reduced tillage (RT) and no-till (NT) require similar quantities of seeds for planting and a regime for fertilization in order to achieve a particular yield, but the expenses for herbicides are higher with the RT and NT in comparison to conventional tillage. The conservational tillage techniques in which some or all mechanical operations are omitted have to rely on herbicides to achieve the same or similar effect on weeds. The expenditure for insecticides is comparable higher in the conservation tillage because the mouldboard ploughing has a more destructive effect on different insects and their soil niches, and thus causes a significant level of mortality among them. The conservation tillage could also favour relatively cool and moist soil which can slow down plant growth to some degree, thus resuling in a prolonged effect as much as smaller or undeveloped plants are more susceptible to pest damages (Harper et al., 2018).

### *7.3. Weed control*

Weed control is one of the serious challenges the CA adoption has to deal with. Weed ecology and management in CA are different from the conventional agriculture and this has affected the whole complex of weed characteristics such as: weed manifestations, seed bank status, mechanisms of distribution, dispersal and diversification, growing patterns and interactions competition. According to Foth (1991) the minimal tillage facilitates the weed control when sowing is done immediately after ploughing. The weed seeds which lay on the ploughing soil are in unfavourable conditions because they are in less contact with the soil and could not absorb water.

A variety of practices coupled with clearly mechanical methods applied by the reduced tillage have a different impact on the effectiveness of herbicides in weed control. It is extremely important also to access the differences after changing the approaches and methods of conservational tillage whose aim is weed control. The existing modification includes improvements in the techniques, use of bio herbicides, chemical herbicides, allelopathy. However, none of the abovementioned approaches, if used alone, could be sufficiently effective to achieve a satisfactory weed control, but combinations of methods could have a very positive outcome (Bajwa, 2014).

The research of Murphy et al. (2006) presented data from a six years' period and four farms with thirty-six fields in Ontario, Canada. The study examined the effect of soil tillage (moldboard, chisel plough, no-tillage) and three types of crop rotation (corn without rotation, corn with soy, and corn-soy winter wheat) on the diversity and distribution of weed seed, seed germination and soil seed bank deposit. The soil tillage had the most significant effect on germination density, diversity and weed distribution. The variety of weed was the greatest in NT, the use of chisel-plough had an intermediate effect and in the conventional tillage the species diversity was at its lowest degree. According to the authors, the results agree with the theory of ecological succession. The weed variety in NT has reached twenty different species; among them fifteen species were winter annual, two years old or perennial species. Even tough, after the period under consideration, the NT showed a reduction in the soil seed bank from 41 000 to 8 000 seeds $m^3$. However, the yield difference between the different tillage techniques or the types of crop rotation has not been established. The authors consider that the NT in combination with suitable crop rotation systems could reduce weed as well as the expenditure for weed control (Murphy et al., 2006). In contrast, the study of Demjanová et al. (2009) who collected data from soil experiments over a period of seven years has not found any significant positive effect of the adoption of reduced tillage techniques. The authors mentioned that the most significant outcome of the conventional tillage was on the seeds of perennial plants but, however, the crop rotation has an insignificant effect on the weed diversity. Canali et al. (2013) claimed that they have applied the newest technology for reduced tillage - the linetillage/roller crimper technique (ILRC) and reported on its very high effectiveness in weed control. The authors suggested that the use of new machine devices that succeeded in mixing the plant residues, not very excessively, can also suppress the weed development.

The study of Derrouch et al. (2020) collected farmers' feedback through a survey about the measures they have applied during the transition from conventional to conservation agriculture. The data showed a well-defined process of consecutive changes in the adopted techniques through the years. As an example, in the early stages of CA introduction the farmers had used herbicides before germination of weed seeds, but in later years they have used a two-step application – one before the weed seed germination and one after that. In the early phases of adoption of technology, the use of herbicides was intensive because the farmers choose to secure the production and did not want to take any risks compromising the yield. In general, the use of herbicides gradually decreased in the later phases of NT technology adoption.

The NT accompanied with a cover crop could significantly affect weed communities with a significant reduction of some annual weed species. Cordeau et al. (2018) have studied the effect of the depth of seeds burial along with the presence of a cover crop on the germination and the early development of annual weeds using experiment with two factorial designs (burial and unburial seeds, and the presence or absence of a cover crop). As a cover crop ryegrass (*Lolium multiflorum*) was used. The experiment was done in a greenhouse and fourteen weed species were included. Among the observed parameters were characteristics such as: number of germinated seeds, height of the weed plants and cover crop, contents of dry matter in the weed and cover crop and the number of leaves of the weed plants. The germination of five weed species was dependent on the burial of seeds and the germination diminished by 10.3% for the seeds left on the surface. The other five weed species germinated with 9.5% less frequency when there was a cover crop, but the four other weed species were not affected by any of the factors. The growth and development of all included in the study weeds decreased in the presence of a cover crop and the observed decrease has reached 50 %, 90% and 60% for the weed average height, dry matter content and the number of leaves respectively. The unburied seeds were not significantly affected and the same parameters for the average height, dry matter content and number of leave diminished only by 33.7%, 70.6% and 43.3% respectively and the specific response also was species dependent.

It has been proven that the type of soil tillage with a crop rotation combination and chemical control of weed significantly affect the structure of weed community. As an example, the NT in soils in Italy showed a significant increase in the number of perennial and two years weeds (*Calystegia sepium*, *Cynodon dactylon*, *Cirsium arvense*, *Daucus carota*, *Sorghum halepense*) along with some annual weeds such as *Digitaria sanguinalis*, *Conyza canadensis* and *Kickxia elatine*, and some species which dispersion is done by the wind. The species associated with the vigorous tillage systems were the preliminary annual species belonging to the genus *Amaranthus* spp., but also *Chenopodium album* and *Echinochloa crusgalli* (Zanin et al., 1997). These data are in a very strong agreement with the data of Swanton et al. (1999) about the clay-sand soils in Ontario, Canada. The authors also suggested that the species such as *Chenopodium album* and *Amarantus retroflexus* could be associated with conventional tillage, and the presence of *Digitaria sanguinalis* - with NT. The observation made by Zanin et al. (1997) for the period of nine years about the evolution of a weed community under reduced tillage was explained as a secondary succession with the prevalence of annual species and species distributed by the wind. According to authors such a community might evolve in some more balanced association comprised by more perennial species, bushes and plant distributed by birds (Zanin et al., 1997). Understanding the changes in the weed community during the transition from conventional towards conservative agriculture could also help in the development of improved strategies for weed control (Ball & Miller, 1993).

The concept of succession of weed species with the time progression under CA is well-explained and presented with many details by Swanton et al. (1993). According to this concept the primary species are replaced by grass, perennial plants and weed with wind distribution and appearance of plants accompanied crop. The changes in the weed species profile could be either a long-term ecological succession or temporal fluctuation among the presented species. In order to study ecological processes a scientific approach has been proposed which uses a hieratical frame for all possible reasons, processes and factors responsible for the changes in the weed community under CA.

Currently, Malone & Polyakov (2019) considered that there are not enough data to answer the question if the conservation tillage is actually responsible for the increase in herbicides use in the long-term. The author suggested that the inclusion of a obligatory detection of the residual quantities of pesticides in the water could be a valuable concomitant analysis for the assessment of conservation technologies.

### *7.4. Cover crop and crop rotation*

The cover crop with its allelopathic effect and the crop rotation partially control weed, but a more radical solution to the problem requires the use of herbicides (Doucet et al. 1999, Ramesh, 2015). Several studies reported on the positive effect of the cover crop and the crop rotation in weed control and yield improvement with a supposed explanation to the biomass effects, but the reduction of weed numbers and changes in the dominance of problematic weeds could be observed only over time (Buchanan et al., 2016, Mhlanga et al., 2015). The benefits of conservational tillage, especially when rotated with leguminous crops, increase over time, suggesting that there are improvements in soil structure and fertility (Thierfelder et al., 2012). The avoidance or reduction of soil ploughing is also related to the increase of soil organic matter and the increased activity of soil organisms which surpass in both quantitative and qualitative aspects the soils under conventional tillage. The soil organisms are also important for the improvement of soil structure and porosity (Bottinelli et al., 2015). The ecological benefits of retaining a higher quantity of carbon in the soil are related to better plant growth and development and a decrease in the sediment deposit in the underground water sources (Huggins and Raganold, 2008). The use of legumes in the crop rotation increases the availability of nitrogen and thus reduces the necessity of application of a high quantity of mineral fertilisers. The crop rotation is also related to a higher degree of biodiversity because the different plant species would attract different microorganisms and the soil microbial community would also significantly increase its diversity (Harper et al., 2018).

The conservative tillage includes preserving a particular quantity of plant residues which can provide better water retaining ability and soil protection (Reicosky, 2015). Govaerts et al. (2007) considered the NT as an inefficient technique when it is not accompanied with a protective cover crop, and for that reason, the use of NT in the long-term could also result in decreased soil fertility. In comparison to the direct effects of the chemical methods the cover crop could be considered only as a kind of preventive method in weed control (Beach at al., 2018, Derrouch et al., 2020). Combining the continuous cover crop and NT in agro-ecosystems tries to imitate to a higher degree the natural ecosystems which have the ability to restore their optimal functionality through natural mechanisms (Hoorman et al., 2009). The thick cover crop layer protects the soil from the mechanical influence of water drops, imposes control over soil temperature and preserves the soil moisture, affecting weed through biological, physical (temperature and access to nutrients) or chemical factors (changes in the C/N ratio or a synthesis of components participating in the allelopathy) (Christoffoleti et al., 2007).

The protective cover crop also sustains a diversity of microorganisms which could oppose the biological pressing imposed by pests (disease causative agents, insects and weed) (Hoorman et al., 2009). The soil microorganisms, mostly mycorrhizal arbuscular fungi, but also some plants and some prokaryotes release a substance – glomalin (glycoprotein) which participates in the maintenance and stability of soil aggregates (Holatko et al, 2021). During winter a cover crop protects soil carbon and maintains the pace of its natural cycle. Because the nitrogen is related to the carbon preservation, the carbon deposit in the soil also provides protection to the nitrogen which in other cases could be prone to run off by the surface water. On the other hand, preserving the phosphorus in the soil is related to the low hypoxic effect and the prevention of the eutrophication in water basins (Hoorman et al., 2009).

Blanco-Canqui et al. (2011) studied the effect of the cover crop when coupled with a crop rotation of the winter wheat (*Triticum aestivum* L.), sorgo (*Sorghum bicolor* (L.) Moench), including the different levels of mineral fertilizing. In general, the results showed that the NT improved the soil physical properties and the changes in the soil organic carbon, induced by the cover crop, were in correlation with the physical properties of the soil. The study of Acosta-Martinez et al. (2003) associated the crop rotation with higher enzyme activities in soils. The results of Mirzaei et al. (2022) showed that the NT, coupled with a full quantity of plant residues, could be considered as a potential and effective method for reducing the $CO_2$ emission and mitigating climate change in semiarid soils.

The experiment of Yadav et al. (2021) compared the effect of the NT, minimal and conventional soil tillage. The authors made the clarification that the minimal and conventional tillage were done with the same mechanical equipment and intensity, and the main difference was the availability of plant residues which in the case of minimal tillage were only partially incorporated in the soil. The NT and the minimal tillage with mulch have showed a higher average corn yield during summer in comparison to the conventional tillage by 39.5% and 48.4%, respectively. Additionally, two other important indicators for the good soil condition have had the highest levels under NT and minimal tillage accompanied with mulch (Yadav et al., 2021).

A very detailed meta-analysis done by Wang et al. (2021) compared the data from 117 articles and revealed that the effect of the cover crop on characteristics such as: retaining the soil moisture, the yield of consequent crop, and the coefficient of use of soil moisture were different and dependant on the geographical location across the globe. The authors conclude that the cover crop could not affect the yield of the next crop, but could reduce the evapotranspiration (ET) by 6.2% and increase the effectiveness of soil moisture by 5.0%. By way of maintenance of the biomass of cover crop in quantity of 5 Mg $ha^{-1}$ and by providing the time gap of 20 days between the planting of the cover crop and the consequent crop increased some parameters associated with a better water retention.

Gonzalez (2018) has made a follow-up study of a 28-year experiment to assess the influence of the conservation practices of no-till and the crop rotation systems (corn *Zea mays*; and soybean *Glycine max*) in comparison to chisel tillage and monocropping systems (continuous corn). The results from the study showed that the long-term NT had a positive impact on soil parameters such as: soil carbon and nitrogen (N), soil water and the diminished run off and losses of ammonium-N and nitrate-N. The authors reported that even with applying the CA principle for a crop rotation, in this particular experiment, the corn-soybean rotation negatively influenced soil C and N, soil water content, increased the run off and the losses of nutrients and herbicides when compared to the continuous corn. As a conclusion, the authors suggested that in order to preserve the soil health some additional conservation practices should accompany the no-till and corn-soybean rotations.

Due to a variety of existing factors that would affect the elements of the agro-ecosystem, it could be assumed that the effects of the cover crop would inevitably vary depending on climatic conditions, the type of agro-technical activities, the type of the cover crop, season for planting, plant density and the period or phase for its removal (Osipitan et al., 2019). A further and more detailed explanation on the ecological principles, how they can be applied and what could be expected in an ecological perspective towards the effect of a cover crop and a crop rotation could be found in Schlapfer & Schmid (1999), Erskine et al. (2003) and the review article by Malezieux et al. (2009).

### *7.5. Occasional tillage in NT*

The continuous use of NT is an effective technique in water erosion control (Prosdocimi et al., 2016, Bogunovic et al., 2018); it improves the soil physical properties (Tebrügge & Düring, 1999), maintains the soil moisture (Colecchia et al, 2015), and reduces production cost (Huggins & Reganold, 2008, Van den Putte et al., 2010). Along with the variety of NT its adoption could be accompanied with some problems such as weed control (Friedrich, 2005, Kassam et al., 2014), soil compaction and increased acidity (Nunes et al., 2015, Barth et al., 2018). One-time or so-called occasional tillage (OT) could offer a solution to the abovementioned drawbacks of NT. However, the introduction of such approach requires a preliminary consideration about the general outcome of the OT. What if it diminishes or even completely eliminates the benefits achieved by the NT? In attempt to find the answer to this concern, Blanco-Canqui and Wortmann (2020) collected and analysed the data obtained from 30 publications derived from the Web of Science and Goggle Scholar. The selected articles included in the analysis of the data about the effect of OT on soil erosion, soil characteristics, yield and some other ecological services after the long-term application of NT (Blanco-Canqui & Wortmann, 2020). The authors also discussed the factors which can affect the OT. Although they considered the number of articles on the subject to be very limited, but at least it provided some important key information about the subject. The scientific data revealed that the OT could increase the erosion and the loss of some mineral elements, to reduce the losses of some dissolved nutrients, but it has insignificant effect on the soil physical properties (Blanco-Canqui & Wortmann, 2020). Contrasting with the data published by Blanco-Canqui and Wortmann (2020) is the meta-analysis done by Peixoto et al. (2020) which has implied that OT improved some of the physical properties of the soil, but reduced the stability of soil aggregates. Since the soil compaction is among the main reasons used for the justification of the OT use, the development and introduction of suitable methods for monitoring and diagnostics of soil compaction appears to be imperative. Such monitoring would support the suitable and timely measures for solving the problem (Peixoto et al., 2019).

According to Blanco-Canqui and Wortmann (2020) the yield after OT has increased by 15%, decreased by 5% and does not change in 80 % of the reported experiments. The effect of OT on the soil and crop was limited to two years. The controlled traffic, cover crop, crop diversification and different products could accelerate the soil repair after the OT application which restricts the necessity of the OT application and increases the benefits of its one-time use. The method for conventional tillage, the depth, the frequency of its application, the period, but also the soil temperature and its water content significantly interact with the OT effects. The general conclusion of the authors pointed to the need for more data in order to precise the methods for the OT application. The one-time application of OT for the period of 5 to 10 years have a very slight or no effect on the ecological services of the soil ecosystem, and at the same time, it is a successfully accomplished reduction in soil compaction and provided some control over weed manifestation (Blanco-Canqui & Wortmann, 2020, Peixoto et al. (2020).

Some data implied that the conventional tillage even when applied occasionally in the technology of NT could have a significant negative effect. The study of Melero et al. (2011) compared some basic characteristics about the soil status after the application of conventional tillage in the soils in Spain where the NT was maintained for a period of seven years. The authors found out that the OT had led to the reduction of the total organic carbon, water soluble carbon, active carbon, of the carbon associated with microbial mass by 23%, 27% 12% and 19%, respectively. The reduction in the nitrogen content associated with microbial mass was even higher - 44%. The soil enzyme activity in the upper soil layer (0-5 cm) was also negatively affected since the dehydrogenases and glucosidases activity decreased by 37% and 51%, respectively.

Wortmann et al. (2008) also reported on the negative effect of the OT, but they have focused on markers for microbial biomass in the soil. The results from the study showed that the microbial biomass declined even during a sporadic application of OT, including some alternative of the „mild“ type tillage. The biomarker used for the estimation of the quantity of arbuscular mycorrhizal fungi (AMF) (C16:1(c11) decreased by 22 % during the second year after the OT application, however, the increase of 6 % for the fungi biomarker (C18:2(c9, 12) was observed. These numbers indicated that the OT affected in a different manner the specific soil microbial groups and after the OT intervention the repair of the microbial biomass followed a different trend. Except AMF, all other groups of microorganisms succeeded in restoring their preliminary biomass levels which they maintained during the NT, but this required between one to three years after the application of OT.

The study of Lopez-Garrido et al. (2011) dealt with the assessment of the effect of OT on the semiarid soils in the west-south part of Spain which were under CA since 1995. The results showed that despite some slight increases in germination, accumulation of nutrients, and in the improvement in the level of nutrients assimilation, and an increase in yield of the wheat during the first year, the conventional tillage reduced the quality of soil. The observed positive changes were not retained during the next two years, and thus the authors concluded that the application of OT could not be sufficiently justified. Similar results have been reported also by Crawford et al. (2015) who studied the effect of three different types of OT (the OT is denoted as ST occasional strategic tillage - ST) on the soils in Australia which were under NT for a period between 7 and 44 years. The results from the study showed that ST had some effect on the weed control, but in the next year this effect was neither convincing, nor unchallenged. The primary effect of OT on the soil moisture was restricted only to the layers of 0 to 0.1 m depth and the available total and specific organic carbon, phosphorus and the total microbial enzyme activity were insignificantly affected both from the frequency and the type of technology of OT. To some extend the OT provided a positive effect on the weed control and thus the authors recommended the use of OT only if there is such a necessity (Crawford et al., 2015).

The experiment done by Liu et al. (2016) aimed to estimate biological indicators such as carbon of the microbial mass metabolic activity (analysis with MicroRespTM) and the total microbial activity in the soil which underwent OT. The data from the analysis of the main products derived after qPCR and the use of the reaction of polymorphism to the end fragment (T-RFLP) did not show any effect on the microbial communities. However, the use of chisel ploughing caused a significant increase in the quantity of the carbon microbial biomass as well as in the bacteria from *Alphaproteobacteria*, *Bacteroidetes* and *Firmicutes*. The other observation revealed an accelerated pace for decomposition of D+ cellobiose and mannitol in samples taken from 0–10 cm depth. However, the effect of the offset disc tillage was limited only to the increase in quantity of *Alphaproteobacteria* (+64.6%) in the soil samples from the same depth. In general, the authors concluded that the one-time application of OT with chisel plough or offset disk have an insignificant positive effect on the soil thirteen months after tillage.

According to Kirkegaard et al. (2011), the use of OT (strategic tillage) could be justified in order to avoid the risk of herbicides resistance, and in such cases, the OT application is not going to compromise all the benefits that have been gained by the application of CA.

## 8. Conclusions

The new paradigm of conservation agriculture is an attempt to convert the agro-ecosystems into more diverse and adaptable eco-systems in which some important mechanisms related to sustainability, productivity and self-balance could be activated. The assessment of the effectiveness of technology would continue to face difficulties for several reasons: firstly, because of the variety of elements which the technology applies; secondly, because of the specifics such as the type of soil, geographical location, rainfalls etc.; and thirdly, because of the reporting of conditions, experimental design and all other supplementary facts. On some soils and conditions, the NT has already proven its effectiveness, and it seems like a successful and very promising example of sustainable agriculture. In a broader scale the NT adoption will continue, but the transition is not going to be very smooth mainly due to economic considerations related to effective crop yield. The effects of NT on the ecological services are an important benefit, but the lack of quick revenue could be a serious obstacle to the NT adoption. In any case, NT is an option for the protection and recovery of soils threatened by wind, water and excessive tillage erosion.

**Table 2.** Selected research articles, reviews and meta-analysis that present some important topics related to conservation agriculture and no-till technology.

| *Topic* | *References* |
|---|---|
| *Historical notes* | *Kuipers (1970), Derpsch (1998), Lal et al. (2007), Basch et al. (2008), Huggins & Reganold (2008), Morris et al., (2010), Kertész & Madarász (2014), Andersen et al. (2016)* |
| *Machinery and devices* | *Lal et al. (2007), Triplett & Dick (2008), Reicosky (2015), Harper et al. (2018), USDA (2017)* |
| *Climate change* | *Gattinger et al. (2011), Lopez-Garrido et al. (2014), Du et al. (2017), Maucieri et al. (2021), Shakoor et al. (2021)* |
| *Weed management and the use of herbicides* | *Swanton et al. (1993), Buhler (1995), Locke et al. (2002), Chauhan et al. (2006), Chauhan et al. (2012), Fernandez-Cornejo et al. (2012), Nichols et al. (2015), Bajwa (2014), Eslami (2014), Anderson (2015), Sims et al. (2018), Osipitan et al. (2019), Cheng et al. (2022)* |
| *Crop yield* | *Kapusta et al. (1996), Van den Putte et al. (2010), Soane et al. (2012), Arvidsson et al. (2014)* |
| *Soil properties and quality* | *Bai et al. (2018), Blanco-Canqui & Ruis (2018), Luke et al. (2022)* |

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