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# Ecologization of tillage methods with the aim of soil fertility improvement

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The reasonability of the necessity of soil fertility improvement in Ukraine by introduction of tillage systems is grounded in the article. The peculiarities of the main tillage methods (ploughing, minimum and zero) are considered, taking into account the national and world's experience. The advantages and disadvantages of each tillage method, which enable to evaluate their significance for agricultural producers, are identified. The criteria of the evaluation of tillage systems on the basis of sustainable development according to agronomical, economic, social and ecological directions are suggested. The necessity of introduction of tillage methods is proved, as their use allows to increase the productivity of agricultural machinery and the resources involved, to reduce the incurred costs and ecological impact on the environment as well as will provide a long-term development of agricultural production.

**Key words:** minimum tillage; organic farming; soil fertility; soil and climatic conditions; agricultural lands; natural environment

## Introduction

The development of the agrarian sector of Ukraine in recent years has had a stable and positive direction of growth, there is an increase in the rate of agricultural production. At the same time, these positive trends in the volume of production have a negative impact on the natural environment, because they are carried out through intensive technologies, increasing the impact on it, that threatens the existence of present and future generations.

The results of such an irresponsible attitude of agricultural producers (owners and tenants of agricultural lands) lead to the development of erosion processes, the increase of degraded soils (annually by 90 thousand hectares), soil losses (600 million tons) and water (16 billion m3). So, almost every third hectare (30.7%) is eroded, and the second one is deflationally dangerous, every fourth hectare is sour. The average annual losses of humus due to the unbalanced introduction and removal of organic matter and erosion are more than 1.0 t / ha (1228 kg / ha) of land in cultivation, losses in terms of only nitrogen are equivalent to almost 10.0 billion m3 of gas (Romaniuk, 2010).

Therefore, in Ukraine, which is an agrarian country and has 33 million hectares of agricultural land (70% of the total territory, of which 80% is arable land), issues and measures for quality and soil fertility should have top priority both at the national level and among producers of agricultural products and scientists of the agrarian sector. So, the condition of agricultural land requires urgent measures to prevent and eliminate erosion processes, increase their deflationary stability, reduce acidity and restore humus (Kaminsky, 2012). The effectiveness of these measures primarily depends on a responsible attitude of landowners and land users, since in pursuit of excess profits the exploitation of agricultural land is shattering. Thus, along with the overcoming of the consequences of the devastating impact on agricultural land, it is necessary to take measures for its conservation. Tillage systems are becoming a topical issue. The international experience of their use can be adopted in Ukraine. Tillage systems were studied by such leading Ukrainian scientists as V. Adamchuk, M. Bezuhlyi (Bezuhlyi, 2016), S. Bulyhin (Bulyhin, 2003), M. Havryliuk, V. Medvediev (Medvediev, 2016), M. Patyka (Patyka, 2011), V. Pashtetskyi (Pashtetskyi, 2013), V. Petrychenko (Agriculture, 2011), V.P. Sytnyk and others. The features and benefits of tillage in organic farming were considered by S. Antonets (Organic, 2010), V. Pysarenko (Pisarenko, 2017), P. Pysarenko (Pysarenko, 2009), V. Rekunenko, P. Stetsyshyn, V. Pyndus (Fundamentals, 2011), S. Ponomarenko (Ponomarenko, 2017) and others. However, they studied separate tillage systems. It does not allow to evaluate their advantages and disadvantages for the purpose of the practical implementation in Ukraine.

The purpose of our research is to identify the advantages and disadvantages of existing tillage practices, taking into account current trends in increasing profitability and reducing the environmental impact.

## Results and discussion

In the last 20-30 years, the so-called combined (differentiated) tillage system has gradually developed in Ukraine, which involves the use of various methods and tools, taking into account the soil-climatic conditions, requirements of plants and precursors. This system has many positive features and is based on: surface (0-8 cm), shallow (8-16 cm), medium (16-24 cm) and deep (24-

32 cm) tillage methods. However, its main disadvantages include (Medvedev, 2016): disturbance of soil and soil erosion, increased losses of organic matter as a result of the fact that the upper layer of soil is tilled too often and is in an overly aerate state for a long time; overconsolidation of the subsurface and sub-seed (spring) layer as a result of the use of heavy energy loading and wheeled tractors, when the mentioned soil layers have moisture close to optimal and therefore are the most sensitive to overconsolidation; the excessive consumption of petrol because of a large number of certain technological operations.

It is well-known that the territory of Ukraine has 4 soil-climatic zones, 9 soil-climatic subzones, 23 nomenclatures of soils and 1147 types. Hence, it is not difficult to conclude that none of the known tillage methods can be the only for all agricultural lands (Bezugly, 2016). Consequently, the modern tillage methodology and further scientific research concerning soil cheapening should take into account the impact on natural environment as well as corresponds to the concept of sustainable development. Under these conditions, it is necessary to look for the paradigm of combining economic interests and raising living standards with the improvement of the state of environment. Modern tillage methods should be based on alternative values, methods, beliefs (Chayka, 2013).

Thus, for centuries a plough has been used to till the soil and promote the preparation of an optimal seedbed through the soil rotation. A plough can be used to turn over the grassland in one pass, rolling up weeds, plant residues and manure from the farm in the ground. The soil will be loosened and aired that will facilitate its faster warming and drying, as well as the mobilization of nutrients. Thus, at first sight, the use of a plough is entirely advantageous, however, a more detailed study reveals its certain drawbacks (Table 1).

**Table 1.** Drawbacks of ploughing

| Directions of impact | Remarks |
|---|---|
| Soil fertility and productivity | 1. Contributes to the intensification of aerobic processes and decomposition of organic matter that reduces fertility.<br>2. Loosened and dispersed soils do not allow to roll up seeds to the required depth.<br>3. Uneven rolling up of seeds because of clods.<br>4. Reducing field germination of seeds and yield of crops due to water disbalance, compaction, disturbance of the soil and inhibition of microbiological processes. |
| Erosion and water balance | 1. It is the main cause of water and wind erosion.<br>2. Contributes to the loss of plenty of water. |
| Soil structure and firmness | 1. Crust formation on the surface at precipitation.<br>2. The soil dispersion, disbalance of nutrients and gases.<br>3. The excessive compaction and deformation by agricultural machinery.<br>4. The soil overconsolidation due to a large number of mechanical operations that leads to disturbance of the soil and its firmness.<br>5. Formation of clods.<br>6. Destruction of an aggregate and capillary structure of the soil.<br>7. After the use of a plough the soil is completely uncovered, unprotected in winter and susceptible to clogging and erosion. |
| Humus and soil organisms | 1. Inhibition of microbiological processes through the soil compaction.<br>2. Decrease in the population of dew worms.<br>3. In winter, microorganisms are lost due to the open ground. |
| Grown agricultural products | 1. Contamination of grown products due to the formation of excess nitrates in the soil in the process of mineralization of organic matter.<br>2. Worse taste and consumer qualities due to lack of the required number of micro- and macroelements. |
| Environmental impact | 1. Large emissions of gases to the atmosphere due to a rapid decomposition of organic substances.<br>2. Increase of $CO_2$ emissions by agricultural machinery.<br>3. The ecological disbalance. |

The source: developed by the author

At the same time, according to the data of foreign researchers, the best possible effect can be achieved under the conditions of minimum tillage. It promotes improvement of the soil structure, maintains its structure and microorganisms in it, prevents humus disruption without deep and intense loosening. Also, it improves the soil elasticity and protection against the soil erosion, its water balance. However, despite these advantages, the refusal of ploughing causes certain challenges. For example, the harmful effects of weeds can be significantly increased, or plant nutrition can be minimized (Minimum, 2016).

Under the minimum tillage before sowing, the soil is cultivated less intensively or not cultivated at all, that also has certain advantages (Table 2).

**Table 2.** Advantages of minimum tillage

| Advantages | Remarks |
|---|---|
| Soil structure and firmness | 1. Improvement of the structure.<br>2. Improvement of firmness and minimizing the soil compaction.<br>3. There is no plough pan due to the passage of untilled soil, the refusal of intensive and deep tillage. |
| Humus and soil organisms | 1. Reduction of the soil aeration that prevents humus disruption due to minimizing the depth of tillage.<br>2. Maintenance of dew worms.<br>3. Creation of favourable conditions for soil microorganisms.<br>4. Nutrition of dew worms due to plant residues on the surface. |
| Protection against erosion, water balance | 1. Reducing waterlogging, surface aqueous runoff and there is erosion.<br>2. Improvement of water filtration during heavy rain.<br>3. Protection against rain and wind due to plant residues on the surface.<br>4. Improvement of water supply from deeper layers of soil under the arid conditions (capillary action). |
| Grown agricultural products | 1. Relative ecological safety if to follow the technological process.<br>2. Sufficient taste and consumer qualities. |
| Protection of climate and environment | 1. Reducing the level of carbon dioxide release ($CO_2$) due to less mineralization of organic matter in the soil.<br>2. Decrease of emissions by agricultural machinery through reducing the depth of soil cultivation, even if more mechanical operations are carried out.<br>3. Contributing to reclamation and ecological rebalancing. |

The source: developed by the author

However, minimal tillage in the system without application of herbicides and fast-dissolving nitrogen fertilizers has certain disadvantages (table 3). They need some mobility and far-sightedness from agricultural producers in order to ensure high yields, profitability and high resource efficiency.

**Table 3.** Disadvantages of minimum tillage

| Disadvantages | Remarks |
|---|---|
| Varied and flexible mechanization | 1. The need for investment in modern agricultural machinery.<br>2. The choice of technology is determined by the weather conditions, so it should be powerful, durable and available at any time.<br>3. Normally employees and contract manufacturers have insufficient experience in mimimum tillage. |
| Rolling up plant residues | 1. There are difficulties with a large number of plant residues (for example, after corn).<br>2. Plant residues can block up seed drills, cultivating aggregates or spring harrows. |
| Effect on yield | 1. Slow warming of the soil in spring and its drying under the wet conditions that causes late or slow germination of crops.<br>2. Late mineralization of nutrients. |
| Weeds and their germination | 1. A difficult control of weeds.<br>2. Creation of favourable conditions for germination of rhizomatous (wheat grass, field bindweed, sorrel) and tap root weeds (dandelion, thistle). |
| Breaking of grassland | 1. Absence of the field free of weeds.<br>2. The need for a greater number of technological operations because of uneven ground surface during the first tillage.<br>3. Usually more passes by macninery are needed.<br>4. Longer period for drying the soil.<br>5. The damage from animal grazing and traces of machinery make minimum tillage more difficult.<br>6. There may be a problem with grass moths. |

The source: developed by the author

In minimum tillage there are various methods with different intensity of cultivation up to direct seeding, when they completely refuse tillage. The methods differ in two principles: the depth of tillage and the part of the soil surface that is cultivated. It is necessary to note that the spread of minimum tillage among practitioners is possible provided that they have almost the same yield as in the application of a plough and do not cause any serious problems with weeds in the long run.

Thus, in Switzerland sowing over mulch, sowing in bands and direct seeding are financially supported under the state program of the efficient energy use. In addition, producers, that use organic farming, receive additional support provided that minimum tillage is used and no herbicides are applied. In this regard, some representatives of organic farming have partially or completely

refused the use of ploughs in their farms over the years (they apply sowing over mulch). The research since 2012 on the use of knife rollers testify that the success of this method in practice has not been sufficiently predicted yet.

Precise and practical studies of the FiBL in 2003-2011 show that during the transition from ploughing to minimum tillage the yield of crops is reduced by at least 10%. It deals with slowing of nitrogen mineralization in the soil in spring and the crop competition with weeds. As a result of the improvement of the soil structure, its minimum tillage on the experimental sites in Frick demonstrates higher yield starting from the fourth year, and in the long run the yield indicators increase by 11%. Minimum tillage has extremely significant advantages in dry years. In farms with experienced managers, the appropriate machinery and production regime, no differences in yield between ploughing and minimum tillage were observed. In some farms, at first, the problems of germination of shattered seeds of forecrops may lead to certain crop losses due to slight experience, inappropriate mechanization or unfavourable weather conditions.

Thus, a significant advantage of minimum tillage refers to humus accumulation and the soil elasticity improvement. The soil also absorbs carbon from air, contributing to the reduction of carbon-dioxide ($CO_2$) emissions. The humus layer in soils usually increases by 10%, and it is possible to store about 13 tons of carbon dioxide per hectare. The effect of climate conservation is intensified, because less fuel is used due to surface tillage (Minimum, 2016). Minimum tillage is currently important in organic farming, which has large prospects for development in Ukraine (Sirenko, 2011).

The next promising method of tillage is «zero», and the technology of sowing – «direct». Usually these terms are used as synonyms because tillage and seeding are carried out simultaneously. Zero technology is planting seeds in uncultivated soil under nurse crops by furrowing of the desired width and depth sufficient for seed digging. Other types of tillage are not used. It is allowed only to cultivate the sub-seed layer in case of its overconsolidation, but such tillage is carried out with special implements and the permanent ground-covering vegetation is not disturbed at this time (Bezuglyi 2016).

Zero tillage is relatively new and has not received deserved recognition among agricultural producers. This is due to the fact that the established stereotypes of compulsory cultivation prevail as an event which is impossible to do without. While according to incomplete data, almost 100 million hectares of arable land in the world are under zero technology. In Ukraine, only the corporation "Agro-Soiuz" in Dnipro region has relatively long and successful experience in the introduction of zero tillage.

The principles of zero technology are implemented as follows: the refusal of any tillage; the refusal of application of organic fertilizers (vegetable residues from the main, second and nurse crops are used instead of them); the prohibition of residues burning; the application of mineral fertilizers and plant protection products simultaneously with sowing or non-destructive tools; the use of special seed drills (Medvedev, 2016).

Zero tillage can have the following forms of implementation: the solid, when the soil cultivation is carried out entirely throughout the surface of the field to the depth of seeding-down; the band, that involves the soil cultivation with the formation of a band of a certain width in which seeds are sown; the slit, in which a slit is cut by a one-disk tool to the depth of seeding-down, then seeds are sown in this slit. It is obvious that there is a dependence of the possibility of the method of seed placement in the direction of movement of an aggregate (i.e. row, wide-row, strip, solid and single-grain) on the variant of the zero method of tillage. This coordination is observed at the stage of creation of technical means, taking into account their purpose (for grain crops or cultivated crops) and crop production technologies. Practice shows that special sowing machines with additional devices for soil cultivation or cutting narrow slits before passes of a coulter are used to implement the technology of direct sowing. The most widely used sowing machines belong to the American firm "John Deer", the Swedish "Wederstad" and the French "Kinch", etc. (Bezugly, 2016).

Today zero tillage technology is a fundamental and, to some extent, a revolutionary approach to agricultural technology, which is capable of suspending soil degradation and creating prerequisites for sustainable land-use. After 10-15 years, the soil under permanent vegetation adopts a natural non-degradation mode of energy and matter functioning and at the same time does not lose its productive function. In the world, this technology is considered, above all, as a soil protective event.

Followers of zero tillage state that zero technology is effective under any soil-climatic and farming conditions. There are positive examples in equatorial countries (Kenya, Uganda), in countries located 40 degrees of latitude south of the equator (Argentina, Chile) or 60 degrees of latitude north of the equator (Finland). Zero tillage is effective at a height of 3000 m, as it is observed in Bolivia and Colombia, at soil content of 90% of sand fraction (Australia, Paraguay) or 85% of clay (Brazil), at atmospheric precipitation of 200 mm (Western Australia), 2000 mm (Brazil) and even 3000 mm (Chile) (Medvedev, 2016).

Zero technology is equally beneficial for both large and small farms, for example, in Brazil, where a farmer has no more than 5-6 hectares of land. In Paraguay and Ghana, where this technology dominates, the size of farms is even smaller.

In Latin America, there are no discussions about cultivation technologies, since zero tillage is unanimously accepted, positively evaluated, and negative points are hardly ever mentioned. Constant and necessarily thick vegetation (mulch) on the soil surface at the same time is considered as a new strategy of weed control. The use of tools for cutting annual weeds without mulch disturbance has become widespread (Agriculture, 2011).

Let's consider the agronomical, economic, social and environmental benefits of zero technology (table 4).

It is necessary to point out that the accumulated world's experience in zero tillage convinces that despite some unresolved issues and minor negative aspects, it has prospects for implementation in countries with highly mechanized agriculture, where the soils are predominantly depleted after extensive ploughing. Our studies (see table 4) also prove that the main advantages of zero tillage are in energy conservation and soil protection.

However, even the advantages mentioned above do not promote the spread of zero tillage in European countries, including progressive ones in the agrarian sense – Britain, Germany, France. At the same time, the experience of South American countries is very fruitful – in a short time, archaically backward agriculture has been converted to a level of modern high-tech and productive agriculture.

**Table 4.** Advantages of zero tillage

| Advantages | Remarks |
|---|---|
| Agronomical | 1. Reducing surface runoff decrease erosion and sealing.<br>2. Minimizing machine-tractor aggregates for operation.<br>3. The best water-air regime of the soil.<br>4. Increase in the content of organic matter and humus.<br>5. Arid and warm regions are more favourable for zero tillage because of showery precipitations. If the drainage conditions are favourable for rapid removal of excess moisture in spring, it contributes to zero tillage on all soils without any exception.<br>6. Well-drained soils of the middle texture promote the demonstration of the positive qualities of zero tillage best of all.<br>7. The most susceptible crops are winter wheat, corn and rye. |
| Economic | 1. Decrease in expenses for fuel and lubricants, time and machine-tractor units for operation.<br>2. Growth of crop yield (especially in the countries of South America).<br>3. Improved profitability of producers.<br>4. Decrease in expenses for road renovation after rainfalls due to the significant reduction of surface runoff, erosion and road deterioration.<br>5. Additional funds allow to buy new mechinery, fertilizers, and protection tools. 6. The bigger the farm is, the more favourable conditions for getting machinery are and the less negative effects on productivity in the transition period are.<br>7. Assistance in acculturation and efficiency of agricultural production. |
| Social | 1. Increase of farmers' income.<br>2. Improvement of their labour conditions. |
| Ecological | 1. Erosion is significantly reduced.<br>2. Reducing sequestration of carbon. |

The source: developed by the author

The reasons for this are: a small size of agricultural farms; unfavourable (cold and damp) soil and climatic conditions (mainly in the northern countries); large subsidies to farmers that do not encourage them to innovate; lack of effect at the first stages of implementation; heavy expenses for machinery and plant protection products; current stereotypes of thinking and conservatism. In addition, overproduction of agricultural products in western European countries affects, that also does not stimulate the introduction of new technologies (Medvedev, 2016). There are certain disadvantages of zero tillage (table 5), which should be removed at scientific and practical levels.

**Table 5.** Disadvantages of zero tillage

| Disadvantages | Remarks |
|---|---|
| Agronomic | 1. Growth of weediness, the quantity of pests and manifestations of diseases.<br>2. Efficiency depends on characteristics of climate and soil.<br>3. The absence of full soil maps poses a threat of the use of zero tillage under unsuitable conditions in accordance with negative results.<br>4. Insufficiently studied issues of nurse crops, minimizing their competition with the main crop, synchronization of agrotechnological measures of sowing and harvesting, chemical processing of the main and nurse crops, adjustment of the crop rotation structure.<br>5. Heavy clay, sandy or dusty soils are less favourable for this cultivation due to their overconsolidation (natural or anthropogenically caused).<br>6. The amount of atmospheric precipitation is an important factor in the efficiency of the new technology. The higher level of precipitation adversely affects, especially in heavy clay and sandy cold soils.<br>7. Agricultural crops respond differently to zero tillage: barley and other grain crops (except wheat, corn and rye) are less susceptible, sugar beet and potatoes are the least susceptible. |
| Economic | 1. Efficiency depends on social and economic conditions.<br>2. Additional expenses for chemical plant protection products. |
| Social | 1. The use under unusual conditions can discredit zero tillage (for example, its introduction will increase unemployment in agrarian regions with large population).<br>2. The possibility of pesticides and heavy metals pollution. |
| Ecological | 1. Application of more chemical plant protection products.<br>2.Their pollution of ground water. |

The source: developed by the author

According to expert opinion from the European continent, Ukrainian black soils are ideal objects for the implementation of zero tillage. Thus, if we take a positive view of the experience of the American continent, Ukraine's agriculture, should be oriented as soon as possible towards the continuous introduction of zero tillage regardless of the soil-climatic and economic conditions. If we analyse the European experience, then we must act more carefully and gradually (Bezuglyi, 2016).
Consequently, taking into account the research given above, we suggest to evaluate tillage systems on the basis of sustainable development according to agronomical, economic, social and environmental criteria (table 6).

**Table 6.** Criteria of the evaluation of tillage systems

| Criteria | Remarks |
|---|---|
| Agronomic | 1. Usefulness of soil-climatic conditions.<br>2. Susceptibility of agricultural crops.<br>3. Measures to control weeds, diseases and pests.<br>4. Choosing crops for crop rotation.<br>5. Availability of the necessary agricultural machinery or the possibility of its attraction (lease, intermediary firms, etc.).<br>6. Orientaion on increasing productivity with preservation of quality and safety of products. |
| Economic | 1. Development and introduction of the long-term strategy of production development.<br>2. Orientation on the increase of production profitability.<br>3. The possibilty to attract additional financial resources.<br>4. The existance of well-established markets for products. |
| Social | 1. The ability of senior managers to introduce innovative methods, technologies and techniques into agricultural production (Yasnolob, 2017).<br>2. Competent personnel that positively respond to innovations of senior managers and are ready to cooperate with them.<br>3. Minimal pesticides and heavy metals contamination of products. |
| Ecological | 1. Contributing to restoration of soils and their fertility.<br>2. Reducing any negative impact on the natural environment. |

The source: developed by the author

## Conclusions

The results of the analysis of tillage systems used by farmers of the leading countries of the world testify that technologies which involve minimization of the depth of cultivation and the combination of carring out technological operations are widely used. The use of the latest technologies allows to reduce production expenses preserving product quality and impact on the natural environment.
Thus, Ukraine, which is aiming to be a leading agrarian country not only at the level of agricultural raw materials, but also final products, can not keep out of progressive soil protective, ecologically safe and effective directions in the development of agriculture. Current conditions of farming are characterized by: reduction of volumes of application of organic fertilizers; increase in prices for fuel and lubricants, mineral fertilizers and plant protection products; reduction in the number of machine operators working in agricultural production; decrease in the level of technical maintenance; international control of harmful emissions into the atmosphere. Under these conditions, it is reasonable to use energy-saving methods of soil cultivation, which can increase the productivity of agricultural machinery and the resources involved, reduce the incurred expenses and environmental load, provide long-term development and the opportunity to enter the world markets. However, the experience in minimum and zero tillage in Ukraine has not been sufficiently investigated, that prevents its distribution among agricultural producers. It provides a further perspective for future research with the aim of its practical use.

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