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# CHANGE OF WEEDINESS IN A FIVE-FIELD CROP ROTATION BY MINIMIZING THE MAIN TILLAGE OF THE SOIL AND DIFFERENT LEVELS OF FERTILIZER AND ITS IMPACT ON CROP PRODUCTIVITY

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***Abstract***

*This researchwas carried out in a stationary field trial on a typical deep low-humus black soil at the experimental field of Bila Tserkva National Agrarian University. The aim of the research was to assess the productivity of a crop rotation using the main tillage of the soil, which included mouldboard for sunflower (25-27 cm), mouldboardless for corn (25-27 cm) and for soybeans (16-18 cm) and disking for winter wheat, spring barley and white mustard (10-12 cm). The results proved that in this crop rotation the productivity was the highest. Cenotic resistance to weeds was highest in winter wheat and lowest in corn. During the period of the experiment (2012-2021) the potential weediness on unfertilized plots was unchanged and the annual application of 12 tons of manure + $N_{95}P_{82}K_{72}$ and 16 tons of manure + $N_{112}P_{100}K_{86}$ per hectare of crop rotation increased this indicator by 2.4 and 6.0%, respectively. The used for the main cultivation of the soil mouldboardless and disking (continuous shallow) causes the spread of rhizomatous and root rhizomes and the localization weeds and an increase the number of seeds of other species in the upper soil layer (0-10 cm). In the weed component of agrophytocenoses of crop rotation the increases of dicot species under mouldboard tillage and monocots - under mouldboardless tillage. Productivity of crop rotation on fertilized and unfertilized plots is almost at the same level for mouldboard and mouldboard & mouldboardless tillage but it is significantly lower for mouldboardless and disking tillage. The highest efficiency in crop rotation provided by differentiated cultivation with used of 12 tons of manure + $N_{95}P_{82}K_{72}$.*

**Key words:** *main tillage, fertilizers, soil, weeds, agrophytocenoses, crop rotation, yield, productivity.*

## INTRODUCTION

The primary tasks of resource-saving mechanical tillage are weediness control and effective use of soil moisture. The main tillage of the soil is aimed at ensuring its optimal structure and regulating the number of weeds [34, 36]. Tillage, herbicides and weeds-interaction can have definite implications for crop growth and yield [1]. In Ukraine a lot of results scientific research were obtained regarding the influence of mechanical tillage on weediness of agrophytocenoses but these data are quite contradictory [24, 26, 47, 48].

Modern agrarian production for successful operation requires for arable land the development and implementation of a system of complex measures for the gradual reduction of the level of potential soil debris by seeds and bodies of vegetative reproduction of weeds, taking into account the specifics of each field [17].

Weeds are recognized to hold a key role within agroecosystems; they are the greatest contributor to plant diversity, they represent crucial resources for other taxa and they may provide crops with important ecosystem services [27]. Since reducing the intensity of tillage, on the one hand, has a positive effect, but, on the other hand, is associated with a possible undesirable effect on weeds and productivity it is necessary to develop strategies that can combine weed control and conservation tillage [15].

According to Sizov A.I. et al. [43] the main place of accumulation and preservation of weed seeds is the arable layer of the soil. The use of man on arable lands of different systems of the main cultivation of the arable layer promotes the penetration of the weed seeds in different horizons of the soil. Modern arable land, which has been used for growing crops for a long time, has significant reserves of weed seeds in all horizons of the arable layer. Therefore, the use of plowing only partially reduces the reserves of unwanted vegetation - weeds in the upper soil horizons.

Crop rotation such as diversification with legume crops is an alternative strategy to maintain soil quality and crop productivity when compared with monocultural cropping patterns [45]. Long-term field experiments provide reliable information on the sustainability of agriculture, where large amounts of fertilizer are used each year. Also, soil microbial properties and crop yields depend on time and the influence of plant diversity [49].

Farming systems have different effects on soil physical properties and crop yields [37]. A conservation tillage system is thought to have more weed problems due to their higher number of seedlings [4]. Therefore, it is needed to adopt such practices, which help to eliminate or at least reduce the weed problem in conservation agriculture.

A direct relationship has been established between the duration of rotation and the productivity of crop rotation: the shorter the rotation period than lower the yield of agricultural crops. This especially applies to 2-3 field crop rotations [5]. In such crop rotations with a share of grain crops of 70-100%, continuous shallow and sometimes No-till is quite often used. Annual use of herbicides with the same active ingredient causes resistance in weeds. As a result of many years of activity in the arable land of our country in the arable layer of soil, significant reserves of seeds and organs of vegetative reproduction of weeds of various species have been formed. The size of such depot is an important indicator of the level of agronomic culture of farming in regions or specific farms and fields [19].

The level of potential littering of arable land by seeds and organs of vegetative reproduction of weeds (0-30 cm) in the main soil-climatic zones is very high and makes up from 114 thousand pcs./m$^2$ (Steppe zone) to 171 thousand pcs./m$^2$ (Forest-steppe zone). Virtually all soil-climatic zones are present on arable lands and form the most important parts in the structure of the stock of seeds in the soil, the representatives of the botanical families of Chenopodeaceae 51.8-62.7%, Amaranthaceae 12.8-21.6%, Poaceae 6.4-11.2%, Polygonaceae 4.5-5.3%, Brassicaceae 1.6-6.2%, Asteraceae 1.1-2.6%. The average indices of the ability of ground-weed seeds of weeds of different species to germination are: Polissya zone – 7.7%, Forest-steppe zone – 8.2%, Steppe zone – 5.9%. On arable land are able to germinate on average: Polissya - 1,887 sq/m$^2$, Forest-step - 4,674 sq/m$^2$, Steppe – 2,242 sq/m$^2$ [17, 18].

According to forecasts, the average annual air temperature in Ukraine will increase by 0.4°C every ten years, which will cause an increase in the frequency of droughts. Aridization of the climate exacerbates the problem of water supply for agrophytocenoses. As a result of these negative climate changes, the area of very dry and dry zones of Ukraine increased by 7% and covers more than 29.5% of the territory or 11.6 million (37%) of arable land [3].

It was found that in the Right Bank Forest-Steppe of Ukraine, weediness of agrophytocenoses in short crop rotation was practically the same for plowing and mouldboardless and for shallow tillage it was 6-25% higher. Therefore, it is recommended to carry out shallow tillage (10-12 cm) with simultaneous slitting to a depth of 40 cm [21].

In the tillering phase of winter wheat and spring barley, mouldboard-mouldboardless tillage had the advantage of arable layer moistening. When sowing white mustard, the most moisturized soil layers were under differentiated tillage, the least moisturized – under mouldboardless tillage [32].

Research in the fight against weeds has been aimed at increasing the effectiveness of herbicides or replacing them with other measures, such as, for example, mechanical control. To increase the sustainability of agricultural systems, a paradigm shift in the control of segetal plants is necessary: from a single tactic and approach to a comprehensive control of weeds in crops [40].

According to the results of field experiments at the Sumy Agrarian University, it was established that green manure made from oilseed radish significantly decreased weed infestations and weed weight, especially of early weeds and winter weeds. The method of tillage had a greater influence on the weed infestation-34 and 46% compared with the application of green manure-29 and 39%. The sweep ploughing at a depth of 28-30 cm with green manure application reduces the effect of potato overgrowth with weeds and helps to get the largest crop yield-up to 30.3 t $ha^{-1}$ [25].

Weediness of agrophytocenoses of grain-row crop rotation under direct sowing was 57% higher than under ploughing. At the same time, in the first year of using direct-seeding, this indicator was at the level of plowing, and in the third crop of the crop rotation, it exceeded the control by 50% [8]. A significant decrease in yield under direct-seeding was noted in corn in the third year of crop rotation, in winter wheat - in the fourth year, sunflower and spring barley - in the fifth year [9].

Integrating preventive and interventional methods of weed control remains essential in managing weed communities in direct-seeding of rice to prohibit the evolution of herbicide resistance and to maximize the relative contributions of individual components where herbicides are not widely used. There remains a need to further develop understanding of the mechanisms and dynamics of rice weed competition and of the community dynamics of weed populations in direct-seeding of rice to underpin sustainable weed management practices [38].

In terms of seeds as a source for weeds, the change in primary tillage means a change in depth where weed seeds are shifted or not to deep layers by tillage operations [39]. Considering the ability of most types of weeds to germinate from a depth of up to 5 cm, and some types up to 10 cm, surface treatment only ensures reliable storage of their seeds in the soil. Such processing stimulates the germination of weed seeds and, first of all, annual species [18]. Seeds with a comparatively low dormancy and seed persistence for instance of graminoid weeds or volunteers would not survive for a longer period [13].

Previous studies have established that the highest yields of winter wheat, soybeans and corn obtained with mouldboard tillage, and spring barley and sunflower with mouldboardless tillage in crop rotation. Under disc and systematic mouldboardless tillage in crop rotation the yield of all crops decreased significantly and with an increase in the rates of mineral fertilizers the difference between the control and these tillage options grew [30, 31].

With zero tillage in the rotation of fallow-wheat or mungbean-wheat more spread of weeds was observed (total dry biomass of weeds 72.4-109.6 and 105.6-112.1 $g/m^{-2}$ in the first and second year respectively). On the contrary, disturbed soils (deep tillage, bed sowing and conventional tillage) in any of the crop rotations had lower weed infestation (weed biomass 0.4–7.1 and 1.1–5.4 $g/m^{-2}$ in the first and second year, respectively). The sorghum-wheat rotation had a strong suppressing effect on weediness in all tillage systems. At the same time, the effect of the crop rotation factor was more noticeable in the second year of the experiment [41].

In Ukraine 13 million hectares of arable land are technologically suitable for minimal tillage and 5.5 million hectares can be used for No-till [33]. During the transition from the traditional tillage technology to the No-till system an increase in weediness of agrophytocenoses was noted, especially in the first 3-4 years of its implementation [28].

No-tillage reduced weed density and dry biomass and resulted more grain yield even in weedy control relative to the rest of the tillage practices. Highest grain yield (4.52 t ha$^{-1}$ ) was obtained with label herbicide dose followed by its 50% reduced dose tank mixed with Sorgaab (4.28 t ha$^{-1}$ ) under zero tillage system [20].

Some scientists note the deterioration of the phytosanitary condition and agrophysical properties of the soil (density, hardness, water permeability) under No-till systems [16]. They note that the transition period from direct sowing to the No-till system should be up to four years and the system itself originates from the creation of a 3-4 cm layer of plant residues on the surface of the field [6]. The application of mulching allows you to regulate the density of weeds in agrophytocenoses under No-till systems. To control the growth of annual and perennial weed species the layer of straw mulch should be more than 5 cm [17].

According to other data No-till can help weed management because weed seeds do not survive as long lying on the soil surface compared with burial in soil. Integrating no-till with diverse crop rotations has enabled producers in the semiarid steppe of the USA to manage weeds with 50% less cost compared to tilled rotations with less crop diversity [2].

Crop rotation diversification can be achieved through perennial and cover crops and no-till practices which may be an effective strategy for increasing soil carbon and nitrogen storage in the long-term, but uncertainty remains regarding the relationship between crop performance and health soil. Crop rotation diversification increases surface soil organic carbon sequestration, soil microbial activity and long-term crop productivity [7].

According to the results of the conducted research under rainfed Mediterranean conditions it is established that wheat yield was greater with conventional tillage than with no tillage. Wheat yield showed no additional response to N fertilizer rates above 100 kg ha$^{-1}$. N use efficiency and N uptake efficiency were greater with conventional tillage than with no tillage [23].

The response of wheat to fertilizer N rates in drought years (with rainfall below 450 mm in the growing season) to be low or nonexistent. However, wheat responded to N fertilizer in years where rainfall during the vegetative growth period exceeded 500 mm, but the response depended on the rotation. Under these conditions a small N rate (50 kg N ha$^{-1}$) could be used at seeding, and additional N fertilizer could be applied as a top dressing at the end of tillering or the beginning of stem elongation depending on the winter rainfall [22].

Nutrient availability and plant diversity are two important factors determining crop productivity in agricultural ecosystems. Long-term inorganic or organic fertilization significantly increased soil total N by 27% – 77% and crop yield by 237%–419% and decreased soil pH by an average of 0.4 units when compared with non-fertilized control [50].

The application of fertilizers significantly increased the productivity of agricultural crops and also influenced the structure of soil bacterial and fungal communities. The application of mineral fertilizers together with manure can reduce the influence of environmental factors on the structure of the soil bacterial community, mineral fertilizer alone or the application of wheat straw in combination with mineral fertilizers [14].

The use of macronutrients (NPK) leads to an increase in maize fresh mass productivity by 11.4-21.0%, DM productivity by 11.4-17.0% and an increase in $CH_4$ output potential by 11.2-30.9%, compared to options without their application [10]. It is recommended to cultivate compatible crops of corn and sweet sorghum against the background of $N_{120}P_{80}K_{80}$ and mouldboard [11].

In accordance, Soon Y. K. & Clayton G. W. [44] no influence of the interaction of tillage with crop rotation on changes in wheat productivity or grain quality indicators.

Tillage treatments also did not affect the yield of other crops in the crop rotation and the concentration of nutrients. During the second cycle of crop rotation the yield of wheat was 22% higher under no-tillage compared to conventional tillage and N fertilizer requirement decreased.

The purpose of the research was to establish the influence of the main tillage and fertilizer systems on the yield of crops and the productivity of grain-row crop rotation.

## MATERIALS AND METHODS

The research was carried out on the experimental field of the Bila Tserkva National Agrarian University on a typical deep, low-humus, medium-loam black soil during 2012-2021 in a stationary five field crop rotation, where four systems of basic tillage (Table 1) and four fertilizer systems were studied: 0 - without fertilizers, 1 - 8 t/ha of manure + $N_{76}P_{64}K_{57}$, 2 - 12 t/ha of manure + $N_{95}P_{82}K_{72}$, 3 – 16 t/ha of manure + $N_{112}P_{100}K_{86}$.

Crop rotation fields were fully deployed in space and time. The experiment options were replicated three times, the plots of the first order (tillage system) were placed sequentially in one tier, and the plots of the second (fertilizer doses) were sequentially placed in four tiers.

Table 1. Systems of basic tillage in crop rotation

| № field | Crop | Tillage* | | | |
|---|---|---|---|---|---|
| | | mouldboard (control) | mouldboardless | mouldboard & mouldboardless (differentiated) | disking (continuous shallow) |
| | | Depth (cm) and cultivation | | | |
| 1 | Soybean | 16-18 (p.) | 16-18 (d.t.) | 16-18 (r) | 10-12 (d.h.) |
| 2 | Winter wheat + white mustard on green manure | 10-12 (d.h.) | 10-12 (d.t.) | 10-12 ( d.h.) | 10-12 (d.h.) |
| 3 | Sunflower | 25-27 (p.) | 25-27 (d.t.) | 25-27 (p.) | 10-12 (d.h.) |
| 4 | Spring barley + white mustard on green manure | 10-12 (d.h.) | 10-12 (d.t.) | 10-12 (d.h.) | 10-12 (d.h.) |
| 5 | Maize | 25-27 (p.) | 25-27 (d.t.) | 25-27 (d.t.) | 10-12 (d.h.) |

*Note: p. – plowing, d.h. – disc harrow, d.t. – deep tiller.
Source: Authors own results.

The sown area of the elementary plot was 171 $m^2$ (9 x 19 m) and the accounting area was 112 $m^2$ (7 x 16 m). The area under the experiment was 3.7 ha.

Cattle manure, ammonium nitrate, simple granulated superphosphate, and potassium salt were used as fertilizers. Weediness on the date of harvesting of crops was determined: actual by the quantitative-weight method, and potential by the method of washing soil samples on sieves with a hole diameter of 0.25 mm (Kalentyev method) [29].

## RESULTS AND DISCUSSIONS

The highest weediness of soybean agrophytocenoses was under disk cultivation (continuous shallow). The actual and potential weediness with was under mouldboard 84 pcs./$m^2$ and 88.7 million pcs./ha, mouldboardless – 143.0 and 117.4, mouldboard & mouldboardless (differentiated) – 77.0 and 76.3, disking (continuous shallow) – 98 pcs./$m^2$ and 98.7 million pcs./ha for crop rotation (Table 2). These indicators of weediness are higher for mouldboardless by 70.2 and 32.4%, disking – 16.7 and 11.3%, and lower for mouldboard & mouldboardless by 8.3 and 14.0% than for the control (mouldboard). The raw mass of weeds under mouldboardless and disking is 1.5 times higher than the control and under differentiated (mouldboard & mouldboardless) 24.3% less. Although the raw mass of weeds is almost at the same level for tillage with a mouldboardless and a disking, both actual and potential weediness are higher by 46.8 and 19.4%, respectively, for the second than for the fourth tillage option.

The actual and potential weediness of winter wheat was 52 pcs./m$^2$ and 100.6 million pcs./ha under mouldboard in crop rotation, mouldboardless – 89 and 127.7, mouldboard & mouldboardless – 47 and 86.0, continuous shallow – 66 pcs./m$^2$ and 109.2 million pcs./ha. When tilling the soil with a mouldboardless and disking the actual weediness was 74.0 and 28.0% and the potential weediness is 27.5% and 8.7% higher compared to the control. These indicators are, respectively, 10.0 and 8.7% lower for differentiated than mouldboard tillage. The highest number of weeds in winter wheat crops was under continuous shallow – 199.1 g/m$^2$, which is 80.2; 23.6 and 105.6 g/m$^2$ more than, respectively, for the first, second and third variants of tillage. This indicator for mouldboardless and disking tillage exceeded the control by 48.5 and 68.7%, respectively and for mouldboard & mouldboardless tillage it was inferior to it by 21.8%.

In the agrophytocenoses of sunflower the lowest number of weeds was obtained under mouldboard & mouldboardless tillage, the indicators of actual, potential weediness and the raw mass of weeds were 69.0 pcs./m$^2$, 97.3 million pcs./ha and 141.8 g/m$^2$, which by 11.8, 11.9% and 24.6% less compared to the control.

For soil cultivation with a disk harrow (continuous shallow) these indicators were 1.26, 1.23 and 1.49 and a mouldboardless tillage – 1.61, 1.41 and 1.55 times higher than in the control options.

Table 2. Weediness of agrophytocenoses of crop rotation under different systems of main tillage and fertilization (2017-2021)

| Cultures of crop rotation | Fertilizer levels in crop rotation | Potential weediness of arable (0-30 cm) soil layer, million pcs/ha | | | | Actual weediness of agrophytocenoses | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | pcs./m$^2$ | | | | raw mass, g/m$^2$ | | | |
| | | The main tillage in crop rotation | | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Soybean | 0 | 94.3 | 122.4 | 81.0 | 104.0 | 87 | 150 | 81 | 102 | 193.2 | 295.9 | 171.2 | 285.1 |
| | 1 | 90.6 | 118.9 | 77.9 | 100.5 | 85 | 139 | 78 | 99 | 185.2 | 277.4 | 169.7 | 273.9 |
| | 2 | 85.9 | 115.8 | 74.3 | 96.4 | 82 | 135 | 76 | 96 | 179.0 | 269.1 | 163.9 | 266.8 |
| | 3 | 84.1 | 112.5 | 72.0 | 93.8 | 78 | 128 | 73 | 94 | 168.7 | 260.3 | 157.0 | 259.6 |
| Winter wheat | 0 | 105.5 | 138.9 | 90.7 | 114.4 | 55 | 87 | 51 | 71 | 118.0 | 174.1 | 92.5 | 200.6 |
| | 1 | 101.9 | 131.9 | 87.4 | 109.8 | 52 | 92 | 48 | 67 | 119.8 | 175.4 | 93.9 | 200.8 |
| | 2 | 99.1 | 122.5 | 83.9 | 107.1 | 50 | 75 | 46 | 63 | 119.5 | 176.7 | 93.8 | 198.5 |
| | 3 | 95.7 | 117.5 | 81.8 | 105.5 | 48 | 70 | 42 | 60 | 118.1 | 175.6 | 93.5 | 196.5 |
| Sunflower | 0 | 105.2 | 139.5 | 91.7 | 122.2 | 68 | 108 | 64 | 81 | 177.1 | 275.4 | 161.6 | 267.1 |
| | 1 | 109.2 | 148.4 | 97.0 | 130.2 | 79 | 120 | 72 | 95 | 188.1 | 289.4 | 162.5 | 278.3 |
| | 2 | 110.6 | 157.2 | 98.4 | 138.5 | 81 | 129 | 78 | 102 | 190.3 | 293.5 | 164.8 | 280.6 |
| | 3 | 115.5 | 171.9 | 101.9 | 147.8 | 84 | 137 | 81 | 115 | 194.2 | 295.9 | 168.2 | 284.1 |
| Spring barley | 0 | 99.5 | 127.2 | 84.7 | 120.1 | 65 | 99 | 61 | 80 | 154.8 | 239.4 | 128.2 | 245.6 |
| | 1 | 95.2 | 124.3 | 80.1 | 110.1 | 61 | 93 | 58 | 76 | 139.2 | 213.2 | 114.3 | 230.9 |
| | 2 | 92.0 | 120.1 | 75.8 | 105.6 | 58 | 88 | 54 | 71 | 132.5 | 197.2 | 106.6 | 222.8 |
| | 3 | 88.9 | 116.2 | 71.8 | 102.1 | 56 | 82 | 52 | 70 | 127.3 | 186.1 | 101.8 | 218.6 |
| Corn | 0 | 106.3 | 135.9 | 91.6 | 106.6 | 94 | 142 | 85 | 110 | 300.1 | 530.2 | 280.8 | 392.4 |
| | 1 | 119.5 | 148.0 | 104.2 | 119.2 | 107 | 154 | 98 | 122 | 311.0 | 504.8 | 298.5 | 394.0 |
| | 2 | 134.3 | 160.7 | 116.4 | 131.6 | 121 | 164 | 112 | 133 | 318.2 | 475.7 | 297.0 | 402.5 |
| | 3 | 149.9 | 176.9 | 132.4 | 147.5 | 129 | 170 | 122 | 140 | 322.3 | 458.7 | 277.5 | 410.5 |
| $SD_{05}$ | A | 8.3 | | | | 12.0 | | | | 30.0 | | | |
| | B | 8.9 | | | | 9.0 | | | | 17.4 | | | |
| | AB | 8.6 | | | | 10.0 | | | | 23.2 | | | |

Source: Authors own results.

In the agrophytocenoses of spring barley the indicators of actual, potential weediness and the raw mass of weeds were for mouldboard tillage 60 pcs./m$^2$, 93.9 million pcs./ha and 138.5 g/m$^2$, mouldboardless tillage – 101.0, 122.0 and 209.0, differentiated tillage – 58, 78.1 and 112.8, continuous shallow tillage – 74 pcs./m$^2$, 109.5 million pcs./ha and 229.5 g/m$^2$. They were the lowest in plots of mouldboard & mouldboardless tillage, which was 96.6, 82.8 and 81.1% less than the control. Actual and potential weediness were the mouldboardless tillage which is higher than the control by 70.7 and 30.6%. Raw weed mass was 166.8% greater in disking compared to mouldboard tillage.

In the agrophytocenoses of corn for the first, second, third and fourth tillage options actual weediness was 113.0, 163.0, 104.0 and 126.0 pcs./m$^2$, potential – 127.5, 155.2, 111.2 and 126.2 million pcs./ha, and the raw mass of weeds – 312.9, 492.4, 271.9 and 399.0 g/m$^2$.

The number and raw mass of weeds for disking were higher by 11.2 and 28.0% compared to the control. The lowest indicators of active, potential weediness and raw mass of weeds were under differentiated tillage, which is 8.1, 13.0 and 13.2% less than mouldboard.

In the crop rotation for the first, second, third and fourth tillage variants, the actual weediness was 77, 124, 71 and 92 pcs./m$^2$ the potential weediness was 104.3, 135.3, 96.1 and 115.7 million pcs./ha and the raw mass of weeds – 187.8, 288.2, 151.6 and 275.5 g/m$^2$. Of the four systems of basic tillage in crop rotation the highest anti-weed efficiency is characteristic of differentiated tillage, for which the above-mentioned indicators are respectively 7.8, 7.9 and 19.3% less, compared to the control options.

It was established that mouldboard and mouldboardless tillage have different effects on soil fertility. Therefore, it is important to more effectively use their positive influence on the soil and agrophytocenoses, reducing their negative effect [35].

The long-term experimental data obtained by us in a stationary field experiment confirm the conclusion of other scientists that the highest anti-weed efficiency can be achieved with differentiated main tillage, which includes plowing once every 4-5 years and in the rest of the time period various depths mouldboardless and disking tillage. Such a system of main tillage ensures not only the natural destruction of weed seeds but also increases biological activity and improves the nutrient regime of the soil [26, 42].

With the increase in fertilizer rates, there was a decrease in soil weediness in crops soybean, winter wheat, and spring barley and an increase in crops corn and sunflower, which is associated with the application of manure to these crops. The application of the maximum rate of fertilizers ensured a decrease in weediness of crops winter wheat, soybeans and spring barley by an average of 6, 10 and 12% and an increase in crops of sunflower and corn by 18 and 37%, compared to unfertilized options.

Actual weediness in agrophytocenoses of sunflower and corn increased by 25 and 27 % when applying the highest rate of fertilizers (16 t/ha of manure +$N_{112}P_{100}K_{86}$), compared to unfertilized options. In the agrophytocenoses of soybean, winter wheat and spring barley crops the opposite trend was observed: in the unfertilized variants this indicator was in crops soybean 105 pcs./m$^2$, in crops winter wheat – 66 and in crops spring barley – 76 pcs./m$^2$ and at the plots with maximum rate of fertilizers – 93.3, 65.5 and 65.0 pcs./m$^2$.

The raw mass of weeds during the harvesting period of winter wheat was almost at the same level in both fertilized and unfertilized variants (146-148 g/m$^2$). Before harvesting soybeans and spring barley this indicator on unfertilized plots was 237 and 192 g/m$^2$, while the maximum level of fertilization was 217 and 172 g/m$^2$. In the agrophytocenoses of sunflower the raw mass of weeds on the unfertilized variants was 220 g/m$^2$ and on the plots with the maximum rate of fertilizers – 235 g/m$^2$. In the agrophytocenoses of corn there were no changes in the raw mass of weeds depending of the fertilizer.

The average indicators of actual and potential weediness and raw mass of weeds by crop rotation were in soybean 100 pcs./m$^2$, 95 million pcs./ha and 217 g/m$^2$, winter wheat – 64, 106 and 199, sunflower – 92 , 124 and 278, spring barley – 73, 101 and 230, corn – 127 pcs./m$^2$, 130 million pcs./ha and 400 g/m$^2$.

Due to the well-developed root system and leaf surface, sunflower shades the soil and has a high competitiveness against weeds, in contrast to corn, which grows slowly in the initial growing period. In terms of cenotic resistance to weeds corn is significantly inferior to winter wheat, which is confirmed by the results of experiments and other scientists [46].

In our research, the number of weeds and their raw mass had the lowest indicators in the agrophytocenoses of winter wheat, while in crops soybean they were 1.56 and 1.09 times higher, in crops sunflower – 1.44 and 1.40, in crops spring barley – 1.14 and 1.16, in crops corn at 1.98 and 2.01.

Table 3. Change in weediness during two rotations of crop rotation under different systems of main tillage and fertilization (2011-2021)

| The main tillage in crop rotation | Fertilizer levels in crop rotation | | | |
|---|---|---|---|---|
| | without fertilizers | 8 t/ha of manure + $N_{76}P_{64}K_{57}$ | 12 t/ha of manure + $N_{95}P_{82}K_{72}$ | 16 t/ha of manure + $N_{112}P_{100}K_{86}$ |
| Potential weediness of the arable soil layer in August 2011, million pcs/ha | | | | |
| mouldboard (control) | 103.3 | 104.0 | 103.6 | 103.8 |
| mouldboardless (chisel) | 105.0 | 102.8 | 102.7 | 104.6 |
| mouldboard &mouldboardless (differentiated) | 104.0 | 103.6 | 104.3 | 102.2 |
| disking (continuous shallow) | 102.5 | 105.2 | 105.2 | 102.9 |
| Potential weediness of the arable soil layer in August 2021, million pcs/ha | | | | |
| mouldboard (control) | 95.0 | 96.7 | 98.5 | 101.5 |
| mouldboardless (chisel) | 123.3 | 125.5 | 127.0 | 129.5 |
| mouldboard &mouldboardless (differentiated) | 86.2 | 88.0 | 91.0 | 92.6 |
| disking (continuous shallow) | 110.1 | 112.6 | 114.6 | 116.7 |
| Actual weediness in July 2012, pcs./$m^2$ | | | | |
| mouldboard (control) | 85.0 | 107.0 | 123.0 | 135.0 |
| mouldboardless (chisel) | 94.0 | 129.0 | 162.0 | 194.0 |
| mouldboard &mouldboardless (differentiated) | 80.0 | 97.0 | 108.0 | 114.0 |
| disking (continuous shallow) | 90.0 | 117.0 | 138.0 | 156.0 |
| Actual weediness in July 2021, pcs./ $m^2$ | | | | |
| mouldboard (control) | 70.0 | 74.0 | 76.0 | 78.0 |
| mouldboardless (chisel) | 110.0 | 118.0 | 124.0 | 132.0 |
| mouldboard &mouldboardless (differentiated) | 65.0 | 68.0 | 69.0 | 70.0 |
| disking (continuous shallow) | 83.0 | 92.0 | 98.0 | 103.0 |
| Raw mass of weeds in July 2012, g/$m^2$ | | | | |
| mouldboard (control) | 270.5 | 326.2 | 352.5 | 366.5 |
| mouldboardless (chisel) | 328.5 | 438.6 | 516.2 | 604.4 |
| mouldboard &mouldboardless (differentiated) | 257.1 | 301.7 | 314.0 | 319.9 |
| disking (continuous shallow) | 331.0 | 419.2 | 466.3 | 506.6 |
| Raw mass of weeds in July 2021, g/m2 | | | | |
| mouldboard (control) | 214.5 | 219.2 | 211.2 | 209.6 |
| mouldboardless (chisel) | 359.8 | 375.1 | 370.4 | 383.6 |
| mouldboard &mouldboardless (differentiated) | 191.3 | 193.9 | 184.1 | 179.0 |
| disking (continuous shallow) | 307.9 | 333.6 | 337.5 | 345.3 |

Source: Authors own results.

In 2011, on average, according to the experiment, the potential weediness of the arable layer was 105 million pcs./ha, varying from 103.5 to 104.0 million pcs./ha according to the tillage options (Table 3). At the end of the second crop rotation the potential weediness increased by 3.1% and amounted to 106.9 million pcs./ha and the difference between the tillage options was insignificant.

In 2021 the number of weed seeds in the arable layer of the soil decreased by 6 and 14 million pcs./ha (6 and 13%) under mouldboard and mouldboard & mouldboardless tillage. This indicator increased by 23 and 10 million pcs./ha (22 and 9%) when the soil was cultivated with a mouldboardless and a disking tillage.

In 2021 the potential weediness of the arable soil layer under mouldboardless and continuous shallow (disking) tillage increased by 29 and 16%, respectively and under differentiated tillage it decreased by almost 9%, compared to mouldboard tillage.

Over ten years of research on crop rotation this indicator increased by 3 million pcs./ha (3%).

In 2011 significant differences were observed in the number and mass of weeds in agrophytocenoses of crop rotation under different tillage systems. Thus, these indicators for mouldboardless and disking tillage were 145 and 125 pcs./m$^2$, 472 and 431 g/m$^2$ which exceeded the control by 28 and 11% and 43 and 31%, respectively. The number and raw mass of weeds decreased in 2021 compared to 2012 for mouldboard tillage by 33 and 35%, mouldboardless by 16 and 21, differentiated by 32 and disking tillage by 37 and 23% and in general by crop rotation by 26 and 28%.

Similar research results were obtained at the Institute of Agriculture of the Steppe Zone of Ukraine the number of weeds decreased the most when using plowing (25-27 cm) compared to mouldboardless tillage (25-27 and 10-12 cm) [46].

In 2021 the number and mass of weeds using mouldboard tillage amounted to 75 pcs./m$^2$ and 213 g/m$^2$, mouldboardless – 121 and 372, mouldboard & mouldboardless – 68 and 187, disking tillage – 94 pcs./m$^2$ and 331 g/m$^2$. Thus the increase in the number and raw mass of weeds when using a mouldboardless tillage was 60 and 73%, and with a disking tillage – 25 and 54%, respectively. When using the mouldboard & mouldboardless tillage these indicators decreased by 9 and 12%, compared to the control. On average the number of weeds decreased by 26% and their weight by 3% during the two crop rotation periods.

The application in 2021 of the first, second and third rates of fertilizers caused an increase in the number of weeds by 7, 12 and 17%, compared to unfertilized plots.

Over the ten-year period of research the potential weediness on unfertilized variants did not change and with the used of fertilizers it increased by an average of 4.8%.

With mouldboard tillage weed seeds in the plow layer are distributed more evenly than with other variants of the main soil tillage. Thus, in 2021, after plowing the green mass of white mustard (predecessor - winter wheat) into the soil, weed seeds were distributed in the soil layers of 0-10, 10-20 and 20-30 cm for mouldboard tillage – 39, 34 and 27%, mouldboardless – 67, 23 and 10%, mouldboard & mouldboardless – 49, 31 and 20%, disking tillage – 78, 17 and 5%. This indicates a well-defined localization of weed seeds in the upper layer of the soil after cultivation with a deep mouldboardless and a disk harrow tillage. Cultivation of the soil with these tools caused an increase in the number of perennial weed species, such as Cirsium arvense L., Convolvulus arvensis and Elymus repens L.

In the destruction of annual weeds and Cirsium arvense L. the double-layer plough was not inferior to the deep plough and is suitable for controlling weeds in organic farming. Shallow cultivation of stubble after harvest can significantly contribute to weed control in organic farming, in particular by reducing Cirsium arvense L. If there are no perennial weeds and the main tillage is done by soil inversion an omission of stubble tillage can be taken into consideration [12].

The yield of dry matter at the zero, first, second and third levels of fertilization in the crop rotation was under mouldboard tillage 2.12, 3.57, 4.64 and 5.66 t/ha; mouldboardless – 1.80, 3.14, 4.14 and 5.09; mouldboard & mouldboardless – 2.11, 3.54, 4.58 and 5.59; for continuous shallow (disking) tillage – 1.80, 3.15, 4.14 and 5.10 t/ha (Fig.1).

Without taking into account the straw of cereal grain crops the collection of fodder units was under mouldboard tillage 2.97, 5.00, 6.46 and 7.87 t/ha; mouldboardless – 2.54, 4.42, 5.77 and 7.09 t/ha; differentiated (mouldboard & mouldboardless) – 2.94, 4.92, 6.35 and 7.74; disking tillage – 2.55, 4.43, 5.79 and 7.11 t/ha, respectively at four levels of fertilization in crop rotation.

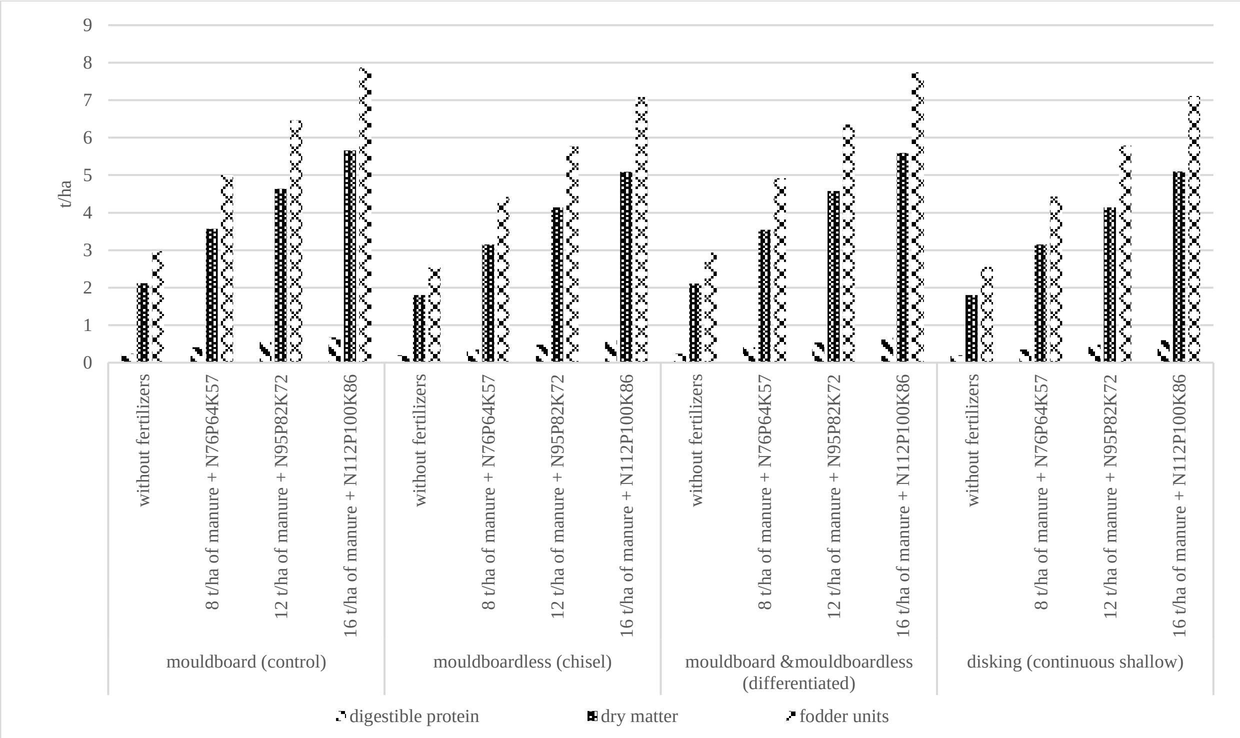


Fig. 1. Productivity of crop rotation under different systems of main tillage and fertilization (average for 2012-2021), t/ha
Source: Authors own results.

The collection of digestible protein was under mouldboard tillage 0.237, 0.409, 0.546 and 0.675 t/ha; chisel (mouldboardless) – 0.194, 0.354, 0.478 and 0.577 t/ha; mouldboard & mouldboardless – 0.237, 0.407, 0.542 and 0.669 t/ha; disking tillage – 0.195; 0.354; 0.481 and 0.599 t/ha ($SD_{05}$=0.033 t/ha).

## CONCLUSIONS

The use for the main cultivation of the soil mouldboardless and disking tillage affects the appearance and spread in the crop rotation of rhizomatous and root rhizomes weeds (*Cirsium arvense L., Convolvulus arvensis*) and an increase the number of seeds of other species in the upper soil layer (0-10 cm). Cenotic resistance to weeds was highest in winter wheat and the lowest in corn. In the weed component of agrophytocenoses of crop rotation the increases of dicot species under mouldboard tillage and monocots under mouldboardless tillage. The minimum mass and number of weeds in the crop rotation was under differentiated tillage. At the same time, the actual and potential weediness was 8%, and the raw mass of weeds was 18% less, compared to the control. On unfertilized plots, potential weediness did not change, and the application of 12 tons of manure + $N_{95}P_{82}K_{72}$ and 16 tons of manure + $N_{112}P_{100}K_{86}$ per hectare of crop rotation contributed to the growth of this indicator by 2.4 and 6.0%.

Productivity of crop rotation on fertilized and unfertilized plots is almost at the same level for mouldboard and mouldboard & mouldboardless tillage but it is significantly lower for mouldboardless and disking tillage. The highest efficiency in crop rotation provided by differentiated cultivation with used of 12 tons of manure + $N_{95}P_{82}K_{72}$.

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