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Influence of cultivation methods on the soil aggregate state in the context of weed development in winter wheat plantations

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Abstract. Weed control in winter wheat crops is an important issue. There is a risk of increasing populations of certain weed species that are resistant to some of herbicides used for winter wheat crops. This could be controlled by a combination of agronomic, mechanical, chemical, and biological methods. After introducing winter wheat into the rotation and improving tillage, the weediness of regular black soils with perennial root and emerged weeds were significantly reduced. The formation of nodal and rudimentary roots had a significant effect on the productivity of winter wheat under different soil moisture conditions. The highest yield of winter wheat was obtained when sown at the optimum time, with higher stem density and ear productivity due to better grain fullness. We studied what effects did the tillage methods have on the aggregate state of the soil in relation to weed development in winter wheat crops, finding that the structural and aggregate composition of the soil played an important role in winter wheat crops, influencing both the development of the crop root system and the water-physical balance of the chernozem, as well as naturally influencing the course of erosion processes in the experimental plots, and having a universal dynamic in terms of adaptation of aggregation and disaggregation processes. Prolonged mechanical stress on soil can cause destruction of its structure. For instance, continuous ploughing or moldboardless tillage with little or no manure application may permanently reduce soil fertility by increasing humus mineralisation. Subsequently, these factors may cause a significant decline in the soil's structural and aggregate composition, resulting in larger amounts of dusty particles smaller than 0.25 mm and cloddy particles larger than 10–12 mm. The soil's structural condition before sowing winter wheat in early September, on average for 2011–2016, indicates increased dispersion of the tilth layer (0–10 cm) in the experimental variants where shallow disc tillage of 10–12 cm was applied. Increase in the number of clods larger than 10 mm in the areas where moldboardless tillage had been applied can be attributed to significant soil drainage. The soil's aggregate state was rated as good, with 8.7% in the 0–10 cm soil layer and 1.7% of clods > 10 mm in the 0–30 cm layer. In 2014–2016, it was rated as satisfactory, with 7.4% and 9.8% of clods > 10 mm, respectively. Shallow disc cultivation resulted in slightly worse indicators: 6.6% and 8.3% of clods > 10 mm in soil layer 0–10 cm and 0–30 cm, respectively, in 2011–2013; and 7.2% and 6.9% of clods > 10 mm, respectively, in 2014–2016. In general, the parameters of optimal structural condition were positive. The tillage method used had a considerable effect on weed growth and development, particularly for those with a root and rhizome structure. It also affected the prevalence and development of pests and diseases in winter wheat. Agrotechnical methods of weed control do not guarantee complete destruction of weeds. Mechanical moldboardless tillage to the depth of 14–16 cm and disc tillage to the depth of 10–12 cm left the fields with 4.1 to 8.8 annual weeds per square meter and 1.3 to 3.3 specimens of harmful root weeds such as *Convolvulus arvensis*, *Lactuca tatarica* and *Cirsium arvense*. Mechanical moldboardless tillage to the depth of 14–16 cm and disc tillage to the depth of 10–12 cm left the fields with 4.1 to 8.8 annual weeds per square meter and 1.3 to 3.3 specimens of harmful root weeds such as *Convolvulus arvensis*, *Lactuca tatarica* and *Cirsium arvense*. Post-harvest residues (4–5 t/ha) can provide almost complete protection against weeds by covering the soil surface. However, pests and diseases may spread more easily due to preservation of fungal spores on the surface of plant residues and preservation of pest larvae in the straw and soil. The distribution of weed seeds in the soil was altered when the rotational tillage of common chernozems in winter wheat cultivation technology had been replaced with energy-saving minimum tillage (shallow flat-cutting disc tillage). This resulted in the concentration of most of the weed seeds (85–90%) in the upper soil layer (0–10 cm).

Keywords: soil; aggregate structure; variation partitioning; yield.

Introduction

Modern, highly effective chemicals for crop protection are widely used to ensure the economic efficiency of farming (Kalogiannidis et al., 2022). Weeds, diseases, and pests remain significant factors that reduce winter wheat yields by more than a third (Jørgensen et al., 2019). Harmful and beneficial organisms cannot be considered in isolation from agrophytocenoses in the field (Morderer et al., 2019). They are essential components of ecological systems, and changes in their numbers and taxonomic composition are caused by changes in environmental

conditions and unequal responses of individual species to plant-protection products, as well as by the specifics of grain growing technology in general. Of particular importance in agricultural practice are agronomic and chemical measures for growing winter wheat as the main food crop (Rempel et al., 2020). The study of winter wheat yields under different technologies of its cultivation in the Steppe of Ukraine showed that in all experimental variants without exception, the use of mineral fertilisers ensured the formation of higher crop productivity (Bondar & Makarenko, 2020). The highest yields were produced following the application of full mineral fertiliser $N_{90}P_{60}K_{60}$ to the pre-sowing cultiva-

tion and nitrogen fertilization in early spring – N_{30} (4.13 t/ha). The study of peculiarities of the development of growth processes of winter wheat plants in the autumn growing season depending on the sowing dates showed that the plants sown on 25 September in black fallow were characterised by optimal indicators of the formation of above-ground vegetative mass. Weeds significantly reduced wheat yields and deteriorated the grain quality due to neglect of appropriate agronomic cultivation practices and in the absence of chemical protection products in the fight against harmful weeds. Care for winter wheat crops must begin immediately after sowing (Minhas et al., 2023). If there is insufficient soil moisture, the soil can be compacted using ring-spur rollers, 35–45 cm of slotting can be carried out, snow can be retained, and herbicides can be applied. These practices ensure high yields of this crop even in sparse crop conditions (Biberdzic et al., 2020). The influence of precursors and fertilisers has been proven to affect winter-wheat grain yields. The best precursors of this crop were black steam, oat, and pea mixture and peas (Cherenkov et al., 2018). The effectiveness of a three-component cereal-legume-cabbage mixture as a winter wheat precursor compared with traditional barley-pea mixtures has been confirmed (Timaeus et al., 2022). This mixture exceeds the yields of crops with a longer growing season. In the northern subzone of the Steppe of Ukraine, one of the most widespread weeds that significantly reduce the yield of winter crops is fescue (*Avena fatua* L.). In addition to fescue, other weed species also infested the fields where this leading crop was grown.

The problem of weed control in winter wheat crops is of great importance (Benjamin et al., 2010). There is a threat of increase in certain weed populations resistant to some herbicides used in winter wheat crops (Nakka et al., 2019). The latter can be controlled by combining agronomic, mechanical, chemical, and biological methods. After introduction of winter wheat into the crop rotation, while improving soil tillage, the contamination of black soil with perennial root and sprout weeds decreases significantly (Lotfi & Pessarakli, 2023). The formation of nodal and rudimentary roots has a significant impact on the formation of winter wheat productivity under different soil moisture conditions. The highest yield of winter wheat was produced when sowing at the optimum time and when a higher stem density and ear productivity were obtained due to better grain fullness (Morgun et al., 2019). The climatic conditions of the place where the relevant experiments were conducted were of great importance in growing the crop, and the research analysed in detail the past, present and future situation in this crucial process of cultivating the country's leading food crop (Raza et al., 2019). The transition to ploughless and surface tillage using flat-cutting and disc tillage tools significantly worsens the phytosanitary condition of arable land and significantly increases the level of weed infestation of this crop (Kouwenhoven et al., 2002). It has been proven that black fallow is the best precursor for winter crops (González-García et al., 2021). Peas also have a positive effect. After perennial grasses, soil cultivation typically involves disking with heavy harrows in two traces, followed by shallow loosening of the soil with combined units. After harvesting peas and corn for silage, the fields are promptly disced in two passes with heavy harrows to 8–10 cm depth, followed by cultivation. In order to ensure timely sowing of winter wheat after the designated precursors, all these operations must be carried out in a precise and regulated manner. The highest weed mortality in wheat crops occurred when a disc seeder was used in combination with light harrows, which loosened the soil by only 30% in one pass. The choice of harrow type depends on the development capacity of winter wheat, as well as the density and depth of the tillering node and the mechanical composition of the soil (Khorami et al., 2018). Underdeveloped, weedy winter crops are harrowed at low speed on clay soils with medium or light harrows and on loamy soils with light single-tine harrows. The needle-shaped harrow has been proven to perform well on all soil types (Serguntsov & Serguntsova, 2019).

Direct harvesting provides the highest yields of winter wheat when the grain is fully ripe (Silifonov, 2023). Even well-developed winter wheat crops are cut off quite heavily when cultivated with heavy harrows. The lowest weed mortality was observed in the crops cultivated with heavy harrows. In dry weather, when the arable land is deep, it is advisable to carry out rolling and harrowing simultaneously with ploughing to prevent the soil from drying out too much. In such cases, ring-toothed or ring-spur rollers are attached to the right of the plough to break up the clods and compact the soil, while harrows then loosen and level the arable surface. Grain crops are the most important non-

ploughed precursors to winter crops in the Ukrainian Steppe (Ptashnik et al., 2021). On the fields allocated for winter wheat cultivation, grain crops must be harvested in a group-flow method. After harvesting, stubble removal and ploughing with ploughs equipped with skimmers to 20–22 cm depth, followed by harrowing and rolling with ring-spur rollers, is mandatory. Even the optimal timing of the spring vegetation of winter wheat cannot guarantee favourable weather conditions for the further development of the crop. The amount of precipitation, the availability of the necessary heat and air humidity during the flowering phase of wheat plants, and especially during grain filling, may be of particular importance (Anderegg et al., 2021). When growing winter crops, it is imperative to pay attention to the fact that herbicides of different classes selectively affect the physiological and morphological characteristics of the crops' reproductive organs. Experiments were conducted on winter wheat cultivation under three technological systems: intensive, integrated and biological (Drews et al., 2009), revealing that the yield of winter wheat under the biological system of cultivation decreased by 35.1% (from 77 to 55 c/ha) compared to the intensive system. These results indicate that it is too early to abandon the use of mineral fertilisers and herbicides altogether, especially in cultivation of winter crops, as opposed to greening agricultural technologies. On the other hand, winter wheat cultivation should be based on the main ecological principle of preserving and increasing the country's natural resources (Huang et al., 2019).

The suppression of weeds by winter wheat sown after fallow is quite effective. It has been proven that under favourable development conditions, winter wheat suppresses weeds well, and such crops do not require chemical protection at all (Beres et al., 2010). Wheat cultivation should be considered in the context of agroclimatic conditions (Aparecido et al., 2024). In the southern and southeastern regions of the country which partially or fully includes the Dnipro region, its development is delayed and the growing season (seed germination – maturation) is extended to 270–315 days. This factor must be taken into account when growing this valuable food crop in the modern conditions. It should also be noted that winter wheat uses a large amount of water, namely 4–5 thousand m^3 /ha, to form the crop (Berca et al., 2021). Therefore, the optimal soil moisture for it is 70–80% of the total moisture capacity, especially during the critical period of crop development – from tillering to earing, when its generative organs are fully formed. The transpiration coefficient of the crop is 550–600. The bulk of winter-wheat roots are located in the 0–20 cm soil layer. Nevertheless, they reach the depth of 70–100 cm on fallow land (before wintering) and 50–70 cm on non-fallow land. The competitiveness of wheat is quite high, and therefore 91.5% of a weed coverage in well-developed agroecosystems is not a reason to use herbicides, as high cost of the latter does not always pay off in terms of economically viable yields. Such fields directly contribute to the clearing of winter crops from weeds (Petit et al., 2016). In dense winter wheat crops, many weeds of various types do not reach the light stage of development because the lower stem tier lacks sufficient illumination during the tube emergence and earing phases. As these weeds do not form viable seeds in such cases, the corresponding winter crops do not require chemical protection with herbicides at all. When placing winter wheat in different parts of the crop rotation, the doses of fertiliser applied to its crops are of great importance. Crops, in particular winter wheat, can successfully control and displace weeds at the optimum sowing density (Buchanan et al., 2016). Seeding density is important, i.e. the number of plants per unit area used for the crop (Valério et al., 2013). In dense crops, weeds grow more slowly and have a reduced growth rate due to lack of light for their germination in the upper part of the stem. In addition to protecting wheat crops from weeds with herbicides, it is also important to pay attention to fungicidal and insecticidal protection of the crop from diseases and pests. It was found that in thinned or weakened winter-wheat crops, only herbicides that affect specific species (or biogroups) of weeds should be used without causing harm to the environment. It has been proven that, depending on timing of soil treatment, there are three ways to apply herbicide: pre-sowing treatment, treatment before germination, and immediately after start off germination. It is known that the transition to minimal tillage of common chernozems should be accompanied by strict weed control in the Ukrainian steppe farming environment. Effects of individual herbicides on weed infestation and grain yield of winter wheat varieties Selianka and Kuialnyk was carefully studied. It has been found that in winter wheat crops, in combination with application of herbicides to

control weeds, attention must be paid to the destruction of pests and diseases, after conducting necessary assessments of contaminations and infestations (Singh & Jolly, 2004). If these effects are detected, fungicides and (if necessary) insecticides should be used immediately in combination with herbicides to suppress the epicentres of weeds, diseases, and pests in wheat crops. It should also be noted that the issue of studying the combined effect of herbicides and insecticides in the control of weeds, diseases, and pests in winter wheat crops was analyzed in the domestic and foreign scientific literature, but only in a fragmentary way (Kraus & Stout, 2019). In our study, we have identified and for the first time recommended for production in the Steppe zone of Ukraine such tank mixtures of chemicals that, when applied to crops, ensure maximum destruction of weeds of different biogroups and the most common diseases and pests.

Therefore, the objective of our work was identifying the impact of cultivation methods on the aggregate state of the soil in the context of weed development in winter-wheat plantations.

Materials and methods

The experimental studies were conducted in accordance with the generally accepted research methods. The experimental part of the work was carried out during 2010–2020. The research on the biological (technical) effectiveness of herbicides for the protection of winter-wheat crops from weeds, pests, and diseases was conducted in the territory of Brigade No. 1 of the State Enterprise Research Farm Dnipro (Dnipropetrovsk Oblast) in accordance with the methods that were relevant at the time of the research. Podoliianka winter wheat was sown with a C3–3.6 grain seeder between September 12 to 18 at the seeding rate of 5.0 million grains per hectare, 250 kg of seeds. In all years of the experiments, the winter-wheat variety Podoliianka developed by the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine and the Myronivka Institute of Wheat named after V. M. Remesla of the National Academy of Sciences of Ukraine was used. The Podoliianka winter-wheat variety has been registered in the State Register of Plant Varieties of Ukraine since 2003. It was developed by the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine and the Myronivsky Institute of Wheat named after V. M. Remeslo of the National Academy of Sciences of Ukraine. This variety is a medium early alfalfa variety. It is characterised by a high level of tillering, medium thickness, and strength of the stem, which is hollow, green leaves of medium size without pubescence and waxy coating. The spike is white, conical, of medium length and density. The weight of 1,000 grains ranges 43.8 to 45.7 grams. This variety is classified as a strong wheat and has the growing season of 273 to 284 days. It is resistant to lodging with the score of 7.5 to 8.6 points and increased frost and drought resistance of 8.2 to 8.5 points. This variety also has average resistance to powdery mildew, brown rust, and fusarium. Its baking properties are excellent: protein content ranges 14.3% to 16.3%; crude gluten content is 31.0% to 35.8%; flour strength is 396 to 480 falling units; bread volume per 100 grams of flour reaches 1120 to 1210 millilitres; and the overall score is 8.0 to 8.5 points.

To achieve high grain yields, protection of winter-wheat plants from weeds, pests, and diseases, especially after earing, is necessary, using fungicides such as Falcon or Nurel D and post-emergence herbicides recommended for use on crops. For the cultivation of this variety, it is recommended to apply intensive technology using optimal doses of mineral fertilisers. The seeding rate is 4.5–5.5 million germinating seeds per 1 hectare. For economic reasons, granulated-compound fertilisers such as ammophos and nitroammophos are recommended to be applied simultaneously with sowing in the rows at the rate of 10–12 kg per hectare of phosphorus. Nitrogen fertiliser, in particular ammonium nitrate, is used for spring fertilisation of crops in the amount of 1.0 centners per hectare. Herbicides, insecticides, and plant growth regulators were applied at the beginning of the full tillering phase, when the wheat was just beginning to emerge, according to the methods that were relevant at the time using a small-sized OM-6 boom sprayer designed by the Institute on the basis of a T-25 tractor, or a field sprayer (during tests in production conditions) – OP-2000-08 with an MTZ-82 tractor with the consumption rate of 250–300 l/ha of the working solution of the preparations. Grain was harvested in the phase of full ripeness, when the moisture content was 10–12%, using a small-sized combine harvester Sampo 500. The so-

wing area in the experimental plots was 100 m², and the harvesting area was 43 m² with three replications. To determine the weediness of the crops, we used the methodology developed by the Institute of Grain Crops of the National Academy of Agrarian Sciences of Ukraine. This method involved overlaying 0.25–0.5 m² of survey frames along the largest diagonal of the plots at 5–10 points, followed by determining the quantitative and species composition of weeds and their conversion to 1 m² of field. During the last survey, all weeds found in the survey frames were pulled out, identified, and dried to the air-dry state, and then their aboveground biomass was determined. The moisture content of the crops was determined by the method of thermostat-weight drying, and herbicide residues in mature wheat grain were determined by gas-liquid chromatography. The wheat grain was harvested at the time of its full ripeness at the moisture content of 12–14% using small-sized combine harvester Sampo 500. The sowing area in the experimental plots was 115 m², and the area of 42 m² with three replications was used for harvesting.

The aggregate composition was determined by the Savinov's dry sieving method. Based on the results of dry sieving, the structural coefficient was calculated:

$$K_{st} = A/B,$$

where K_{st} is the structural coefficient; A is the sum of meso-aggregates with the size of 0.25 to 10 mm (%); B is the sum of micro-aggregates <0.25 and macro-aggregates >10 mm (%). It is believed that the higher the structural coefficient, the better the soil is structured.

The descriptive statistics and ANOVA were calculated using the software Statistica (Statsoft).

Results

Time, tillage methods, and depth of soil layers were able to explain 74.4% of the variation in the content of aggregate fraction > 10 mm in size ($F = 56.3$, $P < 0.001$, Fig. 1). Time was the most significant factor influencing the variability of the content of the aggregate fraction > 10 mm in size and was able to explain 51.8% of the variability of this trait (Fig. 2). The lowest content of this fraction was observed in 2011, and the highest content of this fraction was in 2013. The tillage method was able to explain 17.4% of the variability in the content of the aggregate fraction > 10 mm in size. Under the influence of tillage without polishing (14–16 cm), the content of this fraction was higher compared to the influence of disc soil cultivation (10–12 cm) ($F = 8192.9$, $P < 0.001$). The soil layer was able to explain 1.6% of the variation in the content of the aggregate fraction > 10 mm in size. The highest content of this fraction was observed at the depth of 10–20 cm.

The considered predictors were able to explain 72.6% of the variation in the content of aggregate fractions with the size of 0.25–10 mm ($F = 53.8$, $P < 0.001$). Time was the most significant factor influencing the variability of the content of the aggregate fraction of 0.25–10 mm and was able to explain 57.9% of the variability of this trait. The lowest content of this fraction was observed in 2013, and the highest content of this fraction was in 2011.

The tillage method was able to explain 11.6% of the variability in the content of the aggregate fraction with the size of 0.25–10 mm. Under the influence of tillage without polishing (14–16 cm), the content of this fraction was the lowest compared to the influence of disc soil cultivation (10–12 cm) ($F = 507510.2$, $P < 0.001$). The soil layer was able to explain 1.0% of the variation in the content of the 0.25–10 mm aggregate fraction. The highest content of this fraction was observed at the depth of 0–10 cm.

Time, tillage methods, and soil-layer depth were able to explain 40.5% of the variation in the content of aggregate fractions < 0.25 mm in size ($F = 14.6$, $P < 0.001$). The interaction between time and tillage methods was the most significant factor influencing the variability of the content of the aggregate fraction <0.25 mm in size and was able to explain 37.1% of the variability of this trait. The lowest content of this fraction was observed in 2016, and the highest content of this fraction was in 2012. The tillage method was able to explain 9.1% of the variability in the content of the aggregate fraction <0.25 mm in size. Under the influence of tillage without polishing (14–16 cm), the content of this fraction was the highest compared to the influence of disc soil cultivation (10–12 cm) ($F = 2719.8$, $P < 0.001$). The importance of the soil layer depended on the interaction with the tillage method (explaining 12.5% of the variation in the trait) and the interaction with time (explaining 15.4% of the variation in the trait).

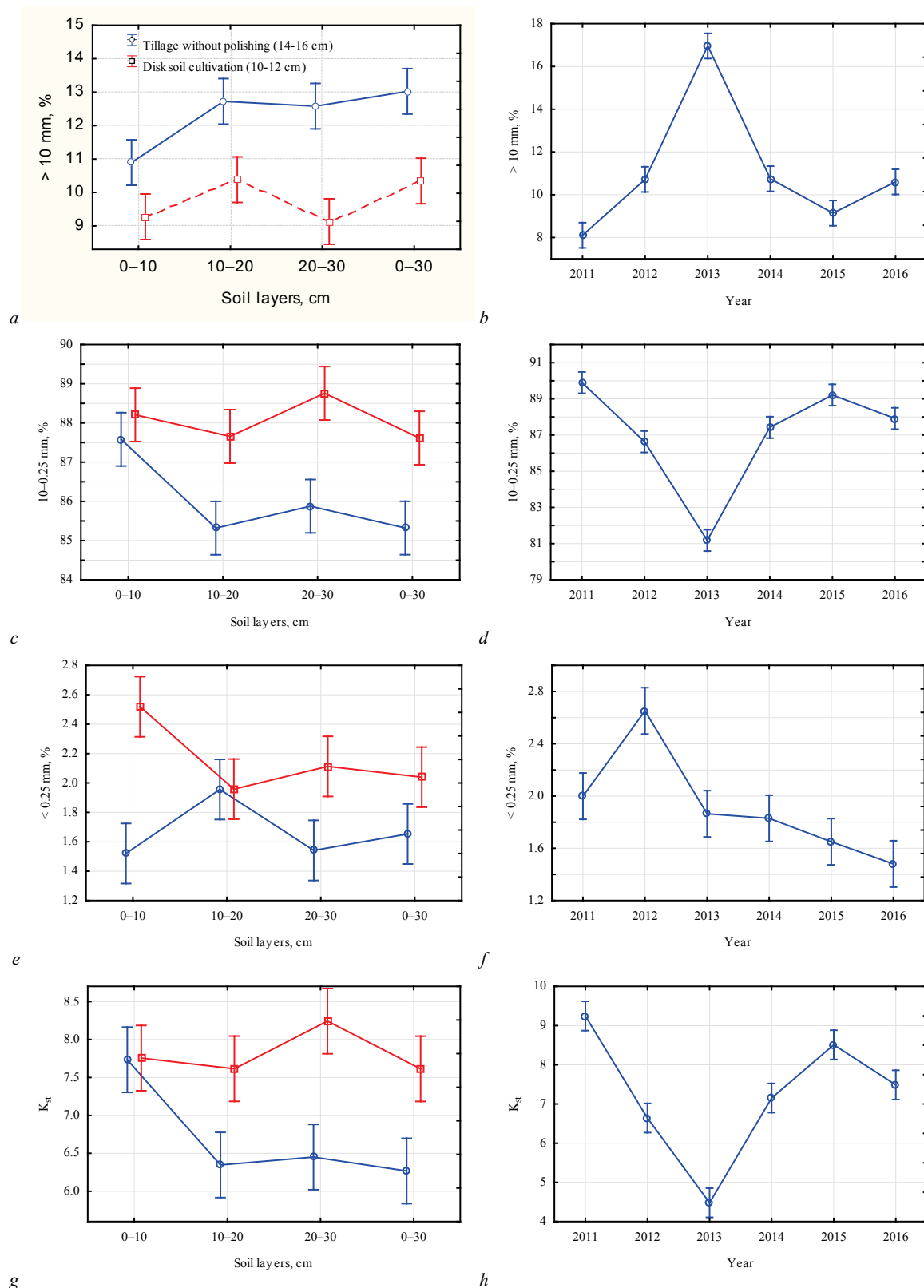


Fig. 1. Variation of soil aggregate fraction content under different tillage methods (tillage without polishing (14–16 cm) and disk soil cultivation (10–12 cm) in different soil layers (0–10, 10–20, 20–30 and 0–30 cm) during 2011–2016 (N = 5): "the "whiskers" indicate the 95% confidence interval: a is the variation of the aggregate fraction > 10 mm in size under the influence of different tillage methods and soil layers; b is the variation of the indicated fraction over time; c is the variation of the aggregate fraction 0.25–10 mm in size under the influence of different tillage methods and soil layers; d is the variation of the indicated fraction over time; e is the variation of the aggregate fraction < 0.25 mm under the influence of different methods of tillage and soil layers; f is the variation of the structure coefficient over time; g is the variation of the specified indicator under the influence of different methods of tillage and soil layers; h is the variation of the specified indicator

The considered predictors were able to explain 66.7% of the variation in the structural coefficient ($F = 39.1$, $P < 0.001$). Time was the most significant factor influencing the variability of the structural coefficient and was able to explain 52.8% of the variability of this feature.

The lowest content of this fraction was observed in 2013, and the highest content of this fraction was in 2011. The tillage method was able to explain 10.8% of the variability in the structural coefficient. Under the influence of tillage without polishing (14–16 cm), the struc-

tural coefficient was lower compared to the influence of disk soil cultivation (10–12 cm, $F = 8826.2$, $P < 0.001$). The role of the soil layer depended on the interaction with the tillage method (explaining 5.0% of the variation in the trait) and the interaction with time (explaining 6.0% of the variation in the trait).

Discussion

An important role in winter-wheat crops is played by the structural and aggregate composition of the soil, which affects both the development of the crop root system and the water-physical balances of chernozem, and also naturally interferes with the course of erosion processes in experimental fields and has a universal dynamics to adapt the processes of aggregation and deaggregation (Olesen et al., 2009). Under prolonged mechanical stress on the soil, factors that cause the destruction of the soil structure are often observed. For example, rather long-term tillage with and without rotation of the soil layer, with virtually no manure application, can lead (due to increased humus mineral-

isation) to final loss of soil fertility. In the future, these factors can lead to a significant deterioration in the structural and aggregate compositions of the soil (increase in presence of dusty < 0.25 mm and cloddy > 10 –12 mm fractions). The structural state of the soil before sowing winter wheat in early September, on average for 2011–2016, indicated increased dispersion of the topsoil (0–10 cm) in the experimental variants where shallow disc cultivation of 10–12 cm was applied. In turn, a rather significant increase in the number of clods larger than 10 mm in the areas of application of moldboardless tillage is explained, first of all, by a rather significant soil drainage. We found that the aggregate state of the soil was defined as good (on average, 8.7% in the 0–10 cm soil layer and 1.7% of clods > 10 mm in the 0–30 cm layer), and in 2014–2016, as satisfactory (respectively, 7.4% and 9.8% of clods > 10 mm). In the areas where shallow disc tillage was used, these indicators were slightly worse: in 2011–2013 – in the 0–10 cm soil layer – 6.6% and 0–30 cm – 8.3%; and in 2014–2016 – 7.2% and 6.9% of clods > 10 mm, respectively. But in general, the optimal structural condition indicators were also quite good.

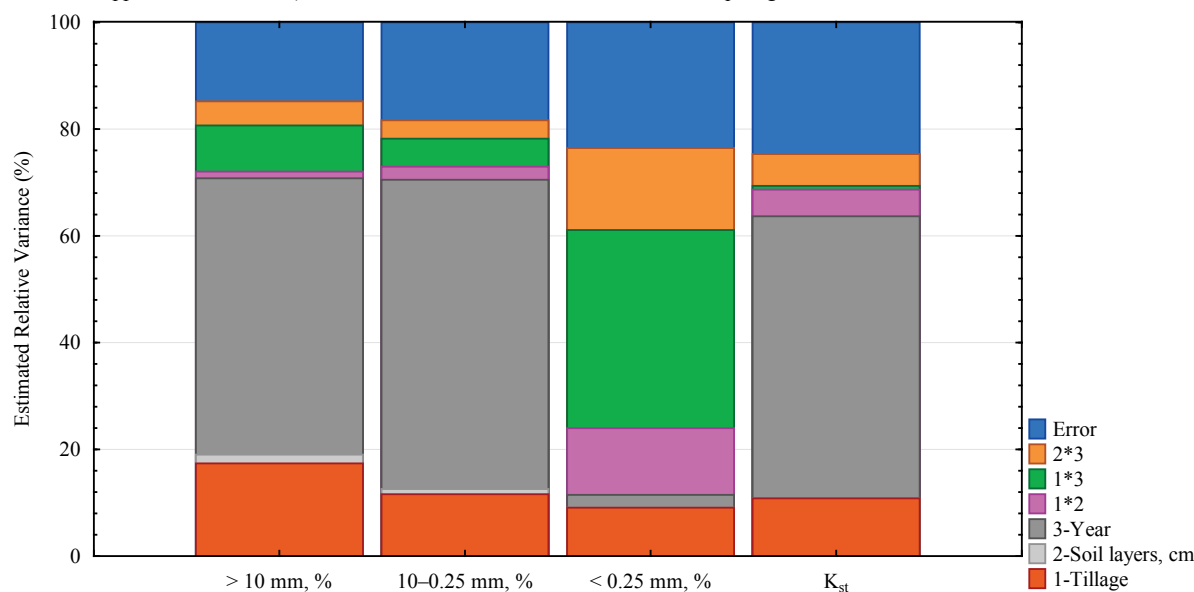


Fig. 2. Estimation of the relative contribution of predictors to explaining the variability of soil aggregate fractions and the structural coefficient: a second-order interaction model was considered: 1 is the influence of tillage methods (tillage without polishing (14–16 cm) and disk soil cultivation (10–12 cm), 2 is the influence of different soil layers (0–10, 10–20, 20–30 and 0–30 cm), 3 is the influence of the time factor (2011–2016); 1*2, 1*3, and 2*3 are the influence of the interaction of the respective predictors

Analysing the data on the content of valuable fractions of 10–0.25 mm in size, it should be noted that where no-till farming was practiced in 2011–2013, 65.2% of valuable fractions were recorded in the 0–10 cm soil layer and 66.4% in the 0–30 cm layer, respectively. In the same years, as can be seen from the data in Appendix 26, the above option was slightly inferior to shallow disc tillage (0–10 cm layer – 67.7%; 0–30 cm layer – 68.8%). In 2014–2016, the percentage of the 0–30 cm soil layer did not change (69.3% and 69.4%, respectively), and in the 0–10 cm layer, a certain percentage advantage of moldboardless tillage was determined compared to disc tillage (68.0% and 67.4%, respectively). In the case of shallow disc tillage in winter-wheat crops, the almost stable improvement of its structural condition compared to moldboardless tillage is explained primarily by decrease in mechanical impact on the soil surface, as well as decrease in the negative factors of destructive erosion processes and the presence of a slightly larger amount of plant residues of predecessors in shallow tillage. Regarding the content of dusty fractions < 0.25 mm in size, their amount averaged 1.2% in the 0–10 cm layer and 1.0% in the 0–30 cm layer in the variants with no moldboard tillage in 2011–2013. These figures were higher in the areas where shallow disc tillage was used (10–12 cm), respectively: 2.2%. In 2014–2016, this trend did not change in the 0–10 cm soil layer – 1.0% and 1.6%, respectively, and in the 0–30 cm layer – 1.5% for moldboardless ploughing, and 0.9% for disc tillage.

During 2011–2016, observations were made before the main tillage for sowing winter wheat. These observations are aimed at identifying the presence of various weed biogroups, both annuals and root-sprouting perennials. The data obtained allow assessing the effective-

ness of weed control using mechanical tillage methods, such as moldboardless tillage to the depth of 14–16 cm and disc tillage to the depth of 10–12 cm, without the use of herbicides or their combined forms (Fig. 4.3–4.6). Before the main tillage, on average, in 2011–2013, 7.2 annual and 2.7 root-forming perennial weeds were recorded on the plots where no-till farming was planned, with the total of 9.3. In the cases where disc shallow tillage was implemented to the depth of 10–12 cm, annuals were recorded at the average of 10.4 units/m² over the three years of observation, and perennials – 3.4 units/m², the total of 13.8 units/m². In the plots where no-till cultivation was used afterwards, weed surveys revealed presence of 7.8 plants/m² of annual and 3.4 plants/m² of perennial root and sprout weeds. In those areas of the experiments where it was planned to use disc shallow tillage in the short term, presence of 12.1 units/m² of annuals and 5 units/m² of perennial rhizomatous weeds was noted, which totalled 17.1 units/m².

Weeds can harm crops in general and winter wheat in particular (Calado et al., 2010). Special studies were carried out in 2011–2016 in early September after the introduction of moldboardless tillage to the depth of 16 cm and disc tillage to the depth of 10–12 cm. Only mechanical methods before sowing wheat failed to completely destroy annual and perennial weeds that occurred in the experimental sites after harvesting the previous crops. When carrying out moldboardless tillage, it was possible to destroy many more different biogroups of weeds in the comparative analysis with disc tillage, primarily due to the greater depth of penetration of the working bodies of the machine into the soil when using the latter. Thus, on average, in 2011–2013, after using the moldboardless tillage at 14–16 cm, 3.4 units/m² of annuals and

0.8 units/m² of root perennials remained in the field, and after tillage with disc tools at 10–12 cm – 6.5 and 1.4 specimens/m², respectively, which was 3.1 and 0.6 units/m² more compared to moldboardless tillage. In 2014–2016, this trend increased further. With the introduction of no-till farming, 4.1 units/m² of annuals and 1.3 units/m² of malicious root weeds remained in the fields, such as *Convolvulus arvensis*, *Lactuca tatarica* and *Cirsium arvense*. Accordingly, after the application of shallow shelf tillage, this trend deteriorated even further, and the number of annual weeds was already 8.8 plants/m² (i.e. 4.7 plants/m² more compared to no-till), and perennial weeds of root origin – 3.3 plants/m² (2.0 plants/m² more) in the same comparison. The main soil tillage not only significantly affected the level of aboveground weediness, but also the underground distribution of weed seeds (Fig. 4.7–4.8). When replacing shelf tillage of common chernozems in winter-wheat cultivation technology with energy-saving minimum tillage (shallow disc tillage by 10–12 cm), the distribution of weed seeds in the soil changed by concentrating most of them (85–90%) in the upper (0–10 cm) soil layer. When using rotational ploughing contributed to the higher concentration of weed seeds in the lower layer of 25–30 cm, as well as on its surface of 0–5 cm.

The germination of weed seeds, especially from the lower layers of the soil, was significantly affected by agrophysical parameters, namely density and soil penetration resistance, as well as moisture, etc. (Dubey & Mall, 1972). The deeper the weed seed was in the soil, the less chance it had of germinating and it went into the dormant stage (anabiosis) in which it remained for years. When they reached the upper layers after tillage, weed seeds came out of the dormant stage and germinated. Thus, the use of agrotechnical methods in weed control once again emphasises the fact that without a systemic impact on weed plants with protecting chemicals, it is even theoretically impossible to completely destroy them using only mechanical methods, including rotational cultivation to the depth of 14–16 cm and disc cultivation to the depth of 10–12 cm before sowing winter wheat.

Conclusion

The use of a particular cultivation method had a significant impact on the growth and development of weeds, especially those with a root-sprout or rhizome structure. We also found prevalence and development of pests and diseases in winter-wheat crops. The use of agrotechnical methods to control weeds did not ensure their complete destruction only through mechanical harrowless tillage to the depth of 14–16 cm and disc tillage to the depth of 10–12 cm. The fields were left with 4.1 to 8.8 annual weeds per square metre and 1.3 to 3.3 specimens of malicious root weeds, such as *Convolvulus arvensis*, *Lactuca tatarica* and *Cirsium arvense*. The perfect projective coverage of the soil surface with post-harvest residues (4–5 tonnes/ha) provided almost 100% protection against weeds, as the latter do not germinate from the soil surface due to straw covering the surface. On the contrary, pests and diseases spread more intensively due to the accumulation of fungal spores on the surface of plant residues and the retention of pest larvae in straw and soil. Replacing rotational tillage of chernozems in winter-wheat cultivation technology with energy-saving minimum tillage (shallow flat-cut disc tillage) changed the distribution of weed seeds in the soil by concentrating most of them (85–90%) in the upper (0–10 cm) soil layer.

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