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SUNFLOWER BROOMRAPE (*Orobanche cumana* Wallr.) AND WEEDS IN SUNFLOWER CROPS WITH MINIMIZED TILLAGE IN A STEPPE ECOTYPE CROP ROTATION

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Abstract

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An important reserve for increasing the productivity of agricultural production is a scientifically based crop structure and the use of rational crop rotations, which implement the optimal ratio of agroecological standards. The aim of the research was to determine the influence of elements of agrotechnical measures, in particular, the saturation of crop rotations with sunflower, soil tillage system on the number and species composition of various agrobiological groups of weeds in sunflower crops, including the weed parasite sunflower broomrape (*Orobanche cumana* Wallr.). Weed control measures and the spread of the parasitic weed sunflower broomrape in sunflower crops have been carried out according to the methods generally accepted in agriculture and weed science. The scheme of the experiment included crop rotations with saturation in the structure of sunflower sowing of 12.5, 20, 25, 33.3, 50, 100% and three systems of basic tillage: moldboard plowing, disc tillage, and no-tillage. As a result of the research, it has been found that the systems of disc tillage and no-tillage cause an increase in the number of weeds in sunflower crops compared to the moldboard plowing by 1.3–1.5 times. On average, over the years of research, the abundance of weeds in the plots when using disk tools was 10.4–15.1 pcs./m^2, moldboard plowing was 7.1–12.4 pcs./m^2, and before harvesting was 2.6–5.2 and 4.1–12.4 pcs./m^2. The highest degree of sunflower broomrape damage has been observed in 2-fields crop rotation (winter wheat—sunflower) and permanent sunflower cultivation, as 16.0–32.4% of affected sunflower plants have been observed here. The intensity of sunflower broomrape damage to sunflower plants was higher in the moldboard plowing system and amounted to 1.2–8.3 pcs./per plant, which exceeded disc tillage and no-tillage by 1.2–1.6 times. The maximum seed yield of 2.92–2.95 t/ha has been obtained in 8- and 5-fields rotations with the use of moldboard plowing. The lowest yields of sunflower seeds were in short-rotation crop rotations with a sunflower saturation of 50% in the structure of sown areas and permanent cultivation and amounted to: moldboard plowing—1.75–2.21 t/ha, disk tillage—1.57–2.01 t/ha, and no-tillage—1.49–1.95 t/ha. Given the urgency of supplying the global market with sunflower oil, in the future it is necessary to increase the concentration of sunflower in the structure of sown areas to 30-40% through the system of basic tillage, selection of resistant hybrids, and use of herbicides.

Key words: sunflower, broomrape, weed, crop rotation, soil tillage, yield.

Introduction

In recent decades, Ukraine has seen an increase in weed infestation of crops, with the weed seed bank and vegetative organs of their reproduction in the arable layer of black soil exceeding 500 million pcs./ha (Zuza, 1995; Ivashchenko, 2002; Chumak et al., 2011; Tkalych et al., 2011; Tsyliuryk et al., 2018).

A parasitic weed, sunflower broomrape, is becoming particularly widespread in sunflower crops, significantly reducing the oilseed yield by 30–70% or even more (Tsykov, Matyukha, 2006; Shi et al, 2015; Velasco et al., 2016; Ye et al., 2017a; Janusauskaite, Kadziene, 2022). The main reasons for the negative trends are violations of agrotechnical measures, including scientifically based crop rotations and simplification of the system of basic arable land cultivation, namely the rejection of layer-by-layer stubble peeling and radical minimization of technological processes without taking into account restrictions and risk factors. In addition, under current business conditions, sunflower is grown on unreasonably large areas without taking into account biological characteristics and the impact on the yield of subsequent crops, with violations of cultivation technology. In particular, with a significant deviation from the recommended terms of return to the previous place of cultivation and even in repeated and permanent crops (Castejón-Muñoz et al., 1990; Akhtouch et al., 2013; Fernández-Martínez et al., 2015; Jebri et al., 2017; González-Cantón et al., 2019; Fried et al., 2022).

In terms of competitiveness and biological suppression of weeds, sunflower is inferior to continuously sown cereals (wheat, barley, and oats). However, it prevails over such row crops as corn and sorghum. The critical period of sunflower plant development is 35–40 days, lasting from germination to the beginning of the boll formation phase. The biological basis of this phenomenon is the slow growth of plants at the beginning of the growing season, and the technological basis is the wide-row sowing method, which creates favorable conditions for the germination of weed seeds. That is, the oilseed crop needs reliable protection at the developmental stage on the scale of BBCH 10–16, primarily from the first, most powerful wave of weeds. Because during this period of time, cultivated plants are not able to fill free ecological niches in crops (as part of the agroecosystem). After closing the rows and forming a powerful root system, sunflower plants deprive weeds of energy supply and successfully compete for living space, except for sunflower broomrape, which continues to parasitize oilseed plants, because due to its biological characteristics, it does not need additional lighting of the lower tier in crops for its vital activity (Dorado et al., 1998; Eizenberg et al., 2004; Fernández-Martínez et al., 2009; Kaya et al., 2012; Jebri et al., 2017; Jatoi et al., 2022).

In the system of agrotechnical measures aimed at reducing the weed seed bank and actual weed infestation, scientifically based crop rotations and basic tillage play an important role (Pabat, 1992; Pabat et al., 2003; Çelik, Ünver, 1999; Schneider et al., 2017; Achankeng, Cornelis, 2023; Shevchenko et al., 2024). In particular, the concentration of sunflower in the crop rotation is based on the permissible time duration of sunflower broomrape seed viability, which creates a spatial zone of danger of infection of the sunflower root system by root-like growths for 7–9 years (Molinero-Ruiz et al., 2014; Seiler, Jan, 2014; Kalinova et al., 2020). The use of crop rotation does not require additional costs, but allows to increase the yield and profitability of crops, contributes to the preservation and expanded reproduction of soil fertility, helps to regulate water and nutrient regimes of the soil, improves the phytosanitary condition of crops (reducing the degree of weed infestation), in particular, reduces the number of sunflower broomrape (García-Torres et al., 1994; Louarn, Boniface et al., 2016; Nabloussi et al., 2018; Ye et al., 2023).

When using disk tools, up to 50% of the total number of weed seeds is concentrated in the 0–10 cm layer, which can have both positive and negative consequences. Given the low culture of farming on such an agro background, there is a potential danger of increasing the harmfulness of the weed component of the crops. At the same time, weed seeds localized in the upper layer are exposed to sharp fluctuations in soil temperature and moisture, as a result of which some of them lose germination, others shorten the period of biological dormancy, and under favorable conditions germinate quickly, and are destroyed before sowing, during crop care, or after harvesting the oilseed (Pabat et al., 2003; Semercl et al., 2010; Rîşnoveanu et al., 2016; Wang et al., 2018; Ye et al., 2020; Shevchenko et al., 2024).

The aim of the study was to detemine the influence of elements of agrotechnical measures, in particular, the saturation of crop rotations with sunflower, soil tillage system on the number and species composition of various agrobiological groups of weeds in sunflower crops, including the weed parasite sunflower broomrape (*Orobanche cumana* Wallr.). To establish the optimal and environmentally friendly parameters of modern elements of sunflower cultivation technology in order to reduce the herbicide (chemical) load in oilseed crop and to green weed control.

Material and methods

Weed control measures and the spread of the parasitic weed sunflower broomrape in sunflower crops, namely its concentration in the structure of crops and soil cultivation by moldboard plowing, disc tillage, no-tillage, have been studied in field experiments at the Institute of Cereals of the National Academy of Agrarian Sciences of Ukraine of Ukraine on the land-use territory of the experimental farm «Dnipro», Erastivska Experimental Station and Scientific Center of Dnipro State Agrarian and Economic University during 2018–2021. The scheme of the experiment included crop rotations with saturation in the structure of sunflower sowing of 12.5, 20, 25, 33.3, 50, and 100%.

1. Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower (12.5%);
2. Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain (20%);
3. Black fallow/fallow—wheat winter—corn for grain—sunflower (25%);
4. Black fallow/fallow—wheat winter—sunflower (33.3%);
5. Wheat winter—sunflower (50%);
6. Sunflower (100%).

The experimental schemes also included three radically different systems of basic tillage, such as moldboard plowing (for all crops of the crop rotation, moldboard plowing is performed with a PO-3-35 plow to a depth of 20–22 cm for spring barley, 23–25 cm for corn and sunflower, 25–27 cm for black fallow (in autumn), disk tillage (for all crops of the crop rotation, disk tillage is performed with a BDVP-6.3 harrow to a depth of 10–12 cm) and a no-tillage (using direct sowing of sunflower with a Great Plains YP825A seeder).

In order to reduce the overall background of weeds, the soil herbicide Primextra TZ Gold 500 S (Metallochlor, 312.5 g/l + Terbuthylazine, 187.5 g/l) has been applied at 4.5 l/ha and row spacing has been carried out. In the variant of no-tillage, Roundup herbicide has been applied at a dose of 4 l/ha, which ensured reliable weed control in the postharvest period. All other elements of agricultural technology were standard and generally accepted for the steppe zone (Tkalych et al., 2011; Tsykov, Matyukha, 2006).

Accounting for weed infestation of sunflower crops has been carried out according to the methods generally accepted in agriculture and weed science. Namely, by quantitative and weight and species methods, which provided for the accounting of the number and air-dry mass of weeds at the beginning (sunflower stand at BBCH 12–14 stage) and at the end of the crop vegetation (harvesting) in eight replications along the diagonal of the plot. The experiment has been conducted in quadruplicate, with a total area of 330 m² and a 100 m² accounting plot (Ivashchenko, 2002).

The data have been analyzed using Statistica 10.0 software (StatSoft Inc., USA). The data have been tabulated as x ± SD (x ± standard deviation). The differences between values in control and experimental variants have been determined using the Tukey's test, where differences have been considered significant at $P < 0.05$ (with Bonferroni correction). Crop capacity was determined using mathematical statistics (dispersion method).

Results and discussion

The weed counts conducted at the beginning of the sunflower growing season indicate a low and medium degree of weeds in the crops, which depended on weather conditions, method and depth of tillage, and so on. In the field experiments, there was a steady tendency to increase the number of weeds when using disk tillage and no-tillage by 1.3–1.5 times compared to the moldboard plowing. On average, over the years of research at the beginning of the sunflower growing season, the abundance of weeds in plots with moldboard plowing was 10.8–19.3, disc tillage was 12.1–22.5, and no-tillage was 14.1–25.3 pcs./m^2 (Table 1).

During the growing season, sunflower plants increased their vegetative mass and closed their leaves between rows, creating optically dense crops at the beginning of the budding phase. The degree of soil shading in some areas was different, which ultimately significantly affected the development of competitive relations associated with re-weeding and accumulation of weed vegetative mass. At the time of harvesting, compared to

Table 1. Weed infestation of sunflower crops depending on the main tillage and crop rotation (sunflower stand at BBCH 12–14 stage), pcs./m^2 (average for 2018–2021, x ± SD, *n* = 4).

Crop rotation	Soil tillage		
	Moldboard plowing	Disc tillage	No-tillage
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	13.4 ± 1.3^{b}	14.7 ± 1.4^{bc}	16.2 ± 1.7^{c}
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	12.3 ± 1.2^{ab}	13.5 ± 1.3^{b}	15.7 ± 1.6^{bc}
Black fallow/fallow—wheat winter—corn for grain—sunflower	11.6 ± 1.1^{a}	12.9 ± 1.3^{ab}	14.8 ± 1.4^{b}
Black fallow/fallow—wheat winter—sunflower	10.8 ± 1.1^{a}	12.1 ± 1.2^{a}	14.1 ± 1.4^{ab}
Wheat winter—sunflower	17.2 ± 1.8^{c}	20.0 ± 1.9^{d}	23.7 ± 2.2^{de}
Sunflower	19.3 ± 1.9^{cd}	22.5 ± 1.9^{d}	25.5 ± 2.4^{e}

Note: Different letters indicate values that are significantly different from each other in Table 1 according to the Tukey test (P < 0.05) with the Bonferroni correction.

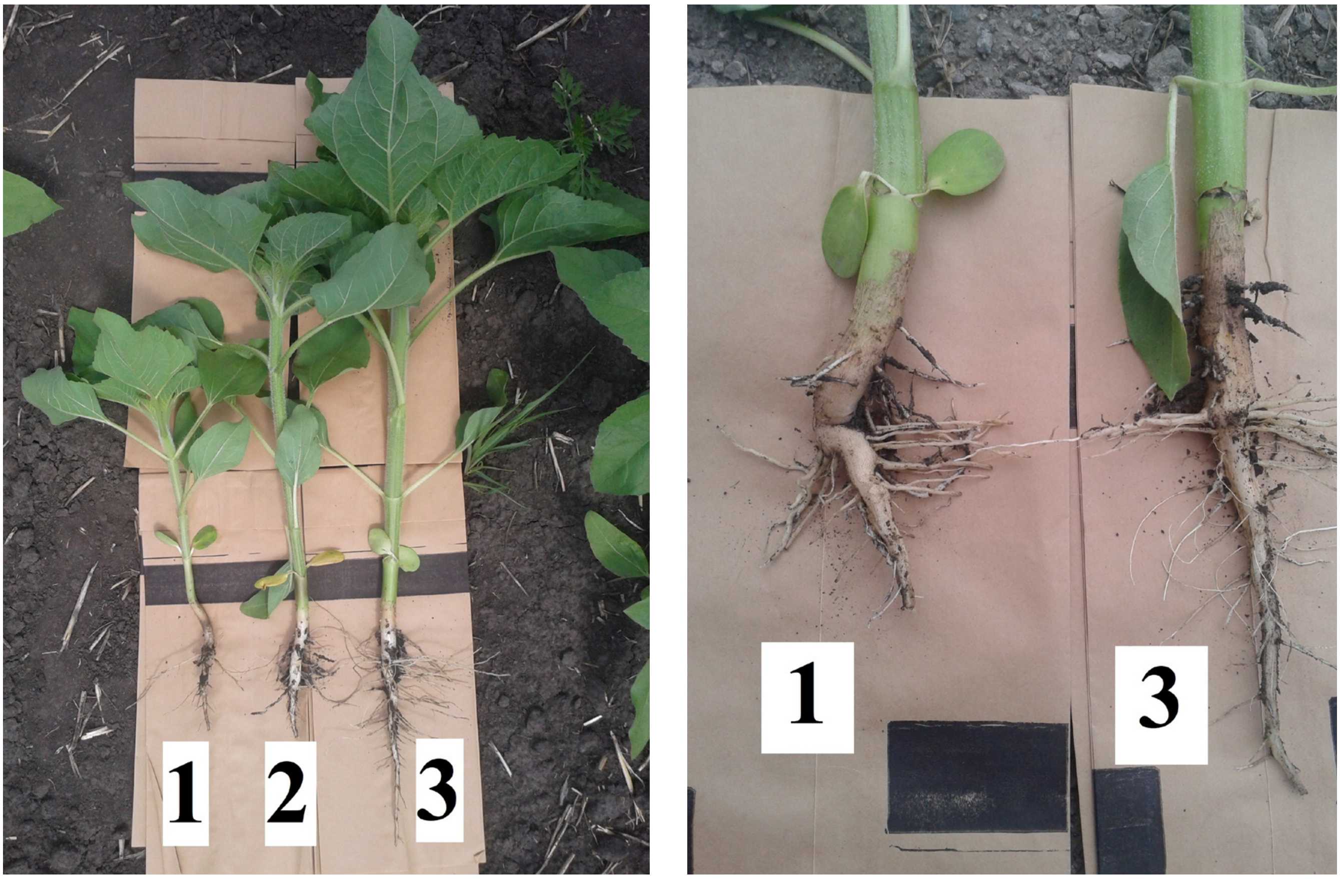

Fig. 1. Influence of soil tillage on the growth processes of sunflower plants at the initial stages of development: 1 – no-tillage; 2 – disc tillage; 3 – moldboard plowing.

Table 2. Weed infestation of sunflower crops depending on the main tillage and crop rotation (sunflower stand at BBCH 92–97 stage), pcs./m^2 (average for 2018–2021, x ± SD, n = 4).

Crop rotation	Soil tillage		
	Moldboard plowing	Disc tillage	No-tillage
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	2.5 ± 0.8^a	4.9 ± 1.2^b	8.8 ± 1.4^c
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	2.5 ± 0.8^a	4.7 ± 1.2^b	8.4 ± 1.4^c
Black fallow/fallow—wheat winter—corn for grain—sunflower	2.3 ± 0.7^a	4.2 ± 1.3^b	8.0 ± 1.3^c
Black fallow/fallow—wheat winter—sunflower	1.8 ± 0.6^a	3.8 ± 1.4^{ab}	7.1 ± 1.2^c
Wheat winter—sunflower	7.6 ± 1.2^c	9.5 ± 1.6^{cd}	16.0 ± 1.8^e
Sunflower	7.9 ± 1.4^c	10.3 ± 1.6^d	17.9 ± 1.9^e

Note: See Table 1.

Table 3. The air-dry mass of weeds depending on the main tillage and crop rotation (sunflower stand at BBCH 92–97 stage), g/m^2 (average for 2018–2021, x ± SD, n = 4).

Crop rotation	Soil tillage		
	Moldboard plowing	Disc tillage	No-tillage
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	12.1 ± 1.3^{ab}	14.6 ± 1.5^b	16.6 ± 1.5^{bc}
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	10.6 ± 1.2^a	13.5 ± 1.3^b	15.1 ± 1.5^b
Black fallow/fallow—wheat winter—corn for grain—sunflower	9.5 ± 1.0^a	12.4 ± 1.3^{ab}	14.0 ± 1.3^b
Black fallow/fallow—wheat winter—sunflower	9.1 ± 1.0^a	11.9 ± 1.3^{ab}	12.9 ± 1.3^{ab}
Wheat winter—sunflower	17.0 ± 1.6^{bc}	18.3 ± 1.7^b	21.3 ± 1.8^{bc}
Sunflower	19.5 ± 1.8^b	20.3 ± 1.8^b	23.7 ± 1.9^c

Note: See Table 1.

the spring determination, the weed infestation of oilseed crops decreased on average by 1.6–3.2 times due to interrow tillage at the stage of sunflower plant development according to the scale of BBCH 14–16 and density of crops (Fig. 1).

Table 2 shows the second wave of weeds, the emergence of which has been facilitated by the end of the effect of the soil herbicide Primextra TZ Gold 500 S, rainfall in the second half of the sunflower growing season, and a weakening of the biological competitiveness of cultivated plants (Ivashchenko, 2002). The quantitative values of weed infestation of crops in the phase of full seed ripeness were 2.5–7.9 pcs./m^2 when using the moldboard plowing system, 3.8–10.3 when using disc tillage, and 7.1–17.9 when using no-tillage, which indicates the preservation of the patterns inherent in the spring period.

Regarding the influence of crop rotation on sunflower weed infestation, a typical pattern has been established in reducing the level of weed infestation of sunflower crops and crop rotation in general, with an increase in the concentration of steam to 33.3%, the number and weight of weeds in sunflower crops and crop rotations have been decreased in the following sequence: 8-fields (12.5% steam)—5-fields (20.0% steam)—4-fields (25.0% steam)—3-fields (33.3% steam) crop rotation. The highest level of weed infestation of sunflower crops was observed during the entire growing season in the study of 2-plot crop rotation and permanent sunflower cultivation and exceeded the weed infestation rates of crop rotations with a steam field by 2.3–3.6 times. This indicates the high agrotechnical ability of the steam field to clear crop rotation fields of weeds (Zuza, 1995; Ivashchenko, 2002; Tkalych et al., 2011).

The analysis of species differences of weeds at the beginning of sunflower vegetation depending on agrotechnical methods shows, first of all, an increase in the share of *Amaranthus retroflexus* L. by 2.0–5.5% under disk tillage and no-tillage, and a decrease in the number of *Chenopodium album* L. by 0.7–14.5%. This is primarily due to the positive response of *Amaranthus retroflexus* L. to shallow seeding, and *Chenopodium album* L. to poor germination in compacted soil, especially with a lack of moisture in the upper (0–10 cm) layer. During the second weed survey, *Ambrosia artemisiifolia* L., *Chenopodium album* L., and various species of bristle grasses (*Setaria* spp.) dominated the oilseed crops, which looked depressed due to lack of moisture and light.

Owing to the individual reaction of perennial weeds to different soil density and hardness, *Cirsium arvense* L. was present exclusively in the areas of disk cultivation, and the number of *Convolvulus arvensis* L. was higher when plowing to a depth of 23–25 cm.

The feasibility of applying certain agricultural practices in terms of ensuring proper weed control is based on the economic thresholds of their harmfulness, which are mostly based on quantitative indicators. At the same time, according to the research of many scientists, the correlation coefficients between the number of wild species and crop losses are low (Tsykov, Matyukha, 2006; Velasco et al., 2016; Ye et al., 2017b; Janusauskaite, Kadziene, 2022).

Sunflower yield losses correlate most strongly with the weight of weeds, in particular with their proportion in the total biomass of plants in crops. The advantage of the latter criterion is the relatively stable values of the indicators over a long period of time and the dominant role of crops (Zuza, 1995; Ivashchenko, 2002).

It has been found that the air-dry weight of weeds (sunflower stand at BBCH 92–97 stage) varied by variants in direct proportion to the change in quantitative values and on average was slightly higher when using disk tillage and no-tillage (11.9–23.7 g/m^2) than when using plowing (9.1–19.5 g/m^2) by 21.7–52.6% (Table 3).

With crop rotation options that included a field of black steam, the level of weed infestation of sunflower crops is estimated as weak (Ivashchenko, 2002). According to the calculations, the proportion of weeds in the total weight of the oilseed crop did not exceed 10%. That is, the development of weeds did not become threatening and their presence in the crops cannot be considered a factor of significant impact on sunflower productivity. In the experimental variants of crop rotations without a steam field, the mass of weeds was more than 2 times higher compared to crop rotations that had a steam field in the structure. The results obtained on the weed infestation of sunflower crops depending on crop rotation and basic tillage indicate a significant impact of these agrotechnological factors on the number and weight of weeds.

Studies have shown that the distribution and harmfulness of the weed parasite sunflower broomrape (*Orobanche cumana* Wallr.) had, in general, completely opposite patterns than when studying the usual segetal vegetation in sunflower crops. In particular, in the experiments on the study of rotational crop rotations, it has been found that the degree of manifestation of the active biological phase of sunflower broomrape parasitism naturally increased with a decrease in the time interval in the crop rotation between sunflower crops. This scientific fact is very important, as it is based on methodical monitoring of the mechanisms of behavior of the parasitic weed in crop rotation fields. Sunflower broomrape posed the greatest danger to the sunflower crop in a 2-crop rotation (winter wheat—sunflower) and permanent sunflower cultivation, because here for every 100 oilseed plants, 16.0–34.4 plants affected by broomrape were observed (Table 4).

As it turned out in the course of the research, there is a correlation between the degree of sunflower broomrape (*O. cumana* Wallr.) damage and the methods of main tillage, which is closely

Table 4. The degree of damage to sunflower plants by sunflower broomrape depending on the duration of its return to the previous place in the crop rotation and tillage system, % (average for 2018–2021, x ± SD, *n* = 4).

Crop rotation	**Soil tillage**		
	Moldboard plowing	**Disc tillage**	**No-tillage**
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	2.3 ± 0.6^{a}	2.1 ± 0.5^{a}	1.9 ± 0.5^{a}
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	5.4 ± 0.9^{b}	3.2 ± 0.6^{ab}	2.1 ± 0.5^{a}
Black fallow/fallow—wheat winter—corn for grain—sunflower	10.9 ± 1.2	8.8 ± 1.0^{bc}	6.3 ± 1.0^{b}
Black fallow/fallow—wheat winter—sunflower	15.6 ± 1.6^{d}	13.2 ± 1.2^{cd}	10.1 ± 1.1^{c}
Wheat winter—sunflower	21.7 ± 1.7^{e}	18.9 ± 1.8^{de}	16.0 ± 1.5^{d}
Sunflower	32.4 ± 1.9^{f}	28.6 ± 1.9^{f}	24.8 ± 1.7^{ef}

Note: See Table 1.

Table 5. The intensity of damage to sunflower plants by sunflower broomrape depending on the structure of crops and the system of tillage in crop rotation, pcs./per plant (average for 2018–2021, x ± SD, *n* = 4).

Crop rotation	Soil tillage		
	Moldboard plowing	Disc tillage	No-tillage
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	1.2 ± 0.3^{a}	1.0 ± 0.3^{a}	0.8 ± 0.3^{a}
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	1.4 ± 0.4^{a}	1.2 ± 0.4^{a}	1.1 ± 0.3^{a}
Black fallow/fallow—wheat winter—corn for grain—sunflower	1.8 ± 0.4^{ab}	1.5 ± 0.4^{a}	1.2 ± 0.4^{a}
Black fallow/fallow—wheat winter—sunflower	5.5 ± 0.7^{bc}	5.0 ± 0.7^{b}	4.6 ± 0.6^{b}
Wheat winter—sunflower	7.1 ± 0.7^{cd}	6.5 ± 0.7^{c}	6.0 ± 0.7^{c}
Sunflower	8.3 ± 0.8^{d}	8.0 ± 0.8^{d}	7.4 ± 0.7^{cd}

Note: See Table 1.

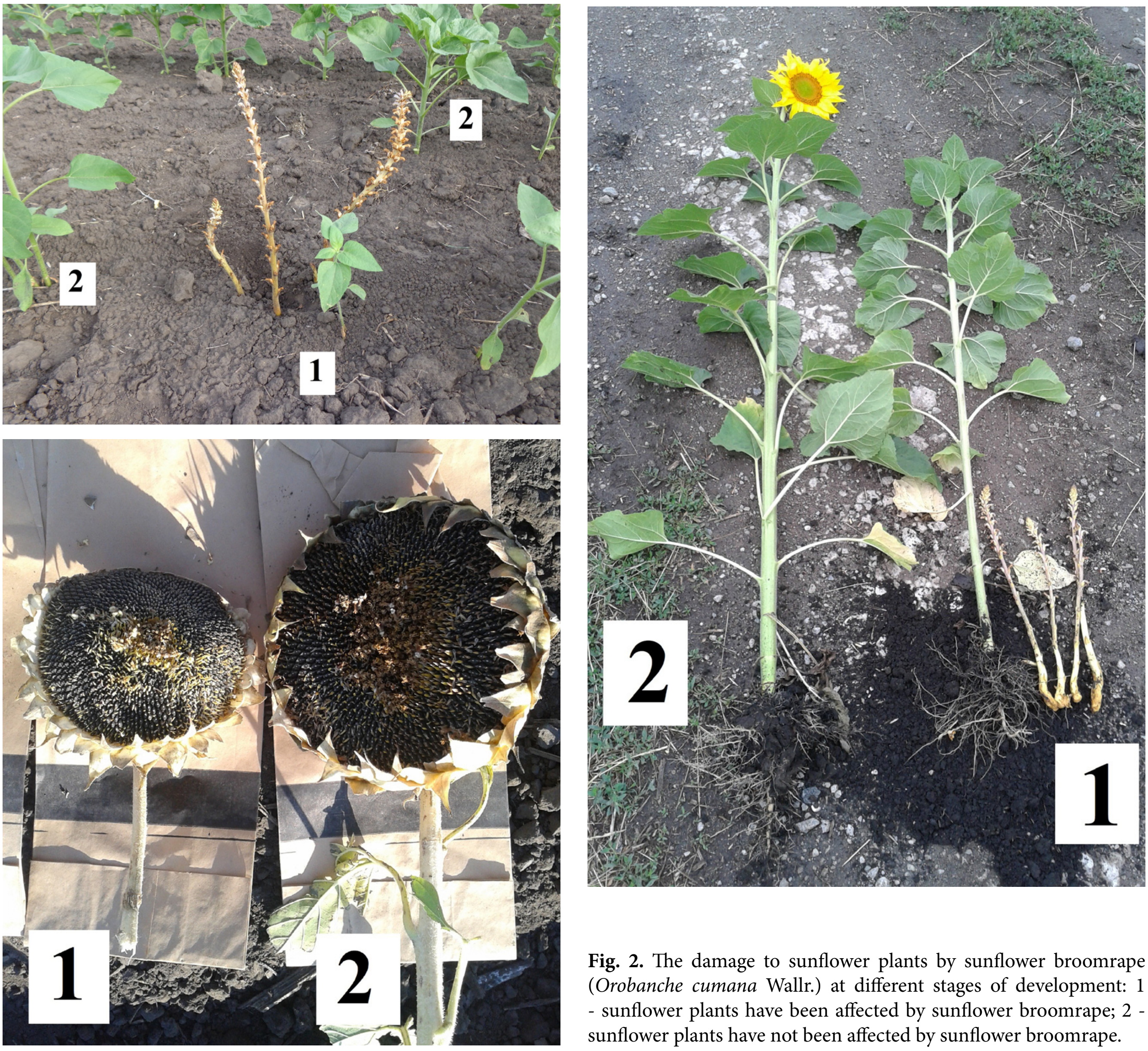

Fig. 2. The damage to sunflower plants by sunflower broomrape (*Orobanche cumana* Wallr.) at different stages of development: 1 - sunflower plants have been affected by sunflower broomrape; 2 - sunflower plants have not been affected by sunflower broomrape.

related to the place of seed storage in the upper part on the soil surface and plant residues, as well as its localization in the soil (Table 5).

The main feature of the spread of sunflower broomrape has been established, namely the increase in the degree of sunflower damage against the background of deep moldboard plowing and a decrease with the decrease in the depth of the main tillage when using disk tillage and no-tillage systems. For example, in a 2-field crop rotation (winter wheat—sunflower) and permanent sunflower cultivation, the sunflower broomrape damage was maximum and amounted to 7.1–8.3% when plowing was used, and decreased to 6.0–8.0% when disk tillage and no-tillage were used. This phenomenon is explained by the location of broomrape seeds in the soil, i.e. with increasing depth of seed plowing, they end up next to sunflower roots, which provoke its germination with their root secretions. After germination, young broomrape plants attach to the root system with root-like growths, where they develop intensively, parasitize, and reduce the yield of the oilseed (Figure 2).. In addition, when using disk tillage and no-tillage, broomrape seeds are located in the upper part of the soil, or on its surface or plant residues, which makes it impossible for them to germinate in denser soil, because there is almost no root system of the host (sunflower) and changes in moisture, light, and temperature conditions are sharply changing, which ultimately causes the gradual death of most seeds on the soil surface. Compared to the mechanism of weed infestation with autotrophic weeds, when plowing helped to reduce it, this seems paradoxical at first glance. However, it has its own logic of explanation, which is based on the fact that extremely small broomrape seeds germinate poorly in dense soil and also find a less developed root system in the upper layer worse than in the background of plowing (Tsyliuryk et al., 2018).

Table 6. The yield of sunflower depends on its concentration in crop rotation and the main tillage of the soil, t/ha (average for 2018–2021, x ± SD, $n = 4$).

Crop rotation (factor A)	Soil tillage (factor B)		
	Moldboard plowing	**Disc tillage**	**No-tillage**
Black fallow/fallow—wheat winter—corn for grain—soybean—barley spring—peas—wheat winter—sunflower	2.95 ± 0.14^{a}	2.74 ± 0.14^{ab}	2.59 ± 0.12^{b}
Black fallow/fallow—wheat winter—sunflower—barley spring—corn for grain	2.92 ± 0.12^{a}	2.71 ± 0.13^{ab}	2.55 ± 0.12^{bc}
Black fallow/fallow—wheat winter—corn for grain—sunflower	2.75 ± 0.13^{ab}	2.55 ± 0.12^{bc}	2.41 ± 0.11^{c}
Black fallow/fallow—wheat winter—sunflower	2.54 ± 0.11^{bc}	2.35 ± 0.10^{c}	2.24 ± 0.11^{cd}
Wheat winter—sunflower	2.21 ± 0.12^{d}	2.01 ± 0.10^{de}	1.95 ± 0.10^{e}
Sunflower	1.75 ± 0.11^{ef}	1.57 ± 0.09^{f}	1.49 ± 0.10^{f}
Least significant difference (LSD), t/ha (p = 0.05)			
for factor A	0.10		
for factor B	0.11		
for interaction AB	0.13		

Note: See Table 1.

The root system of sunflower can be affected by broomrape root-like growths (*O. cumana* Wallr.) during the entire active period of sunflower vegetation starting from the phase of 2 pairs of leaves of the crop. The ability of sunflower to provoke germination of broomrape seeds at the initial stages of organogenesis can be used as a cleansing measure against the parasite by destroying sunflower carrion the following year in a certain way by tillage (disking, cultivation, etc.) or herbicide up to 10 leaves of the oilseed. To destroy sunflower broomrape seeds, it is also possible to sow corn for several years in a row, as the root secretions of corn crops provoke germination of the parasite seeds by up to 60–70% and the death of seedlings over time (An et al., 2015; Ye et al., 2017b).

Along with the influence of crop rotations and main tillage on the planar spread of sunflower broomrape (*O. cumana* Wallr.) in sunflower crops, these elements of agriculture also determined the intensity of damage to individual plants of the crop. In short-rotation crop rotations (2-fields crop rotation (winter wheat—sunflower) and permanent sunflower cultivation), each affected plant within different cultivation systems was parasitized by 6.0–8.0 developed plants of sunflower broomrape with a gradual decrease in the intensity of damage to the root system in multifield crop rotations to 0.8–1.8 pcs., or 2.4–3.2 times. Reducing the concentration of sunflower to 12.5% in 8-field crop rotation significantly reduced the intensity of sunflower broomrape damage to 0.8–1.2 pcs. and was minimal compared to other crop rotations. There was also a lag in the growth and development of plants affected by sunflower broomrape, both in terms of developmental stages and biometric parameters, which is clearly visible in Figure 2. The development of the underground part of the root-like growths had similar dynamics to the aboveground part of the sunflower broomrape. That is, the number of underground fragments of sunflower broomrape in 2-fields rotation and permanent sunflower cultivation was maximum compared to 5-field and 8-field rotations.

It has been found that the combined effect of crop rotation, soil tillage system, abiotic and biotic factors (weed infestation of sunflower crops with autotrophic photosynthetic weeds and parasitic weed sunflower broomrape) had a significant impact on the yield of the oilseed (Table 6).

The maximum seed yield of 2.92–2.95 t/ha has been obtained in 8- and 5-fields crop rotations with the use of moldboard plowing. Methods of minimizing soil tillage in 8- and 5-fields crop rotations have been contributed to a decrease in yield to 2.55–2.74 t/ha. Expansion of the sown area to 25 and 33.3% has been contributed to a decrease in yield to 2.75 and 2.54 t/ha, respectively, which was less compared to 8- and 5-fields crop rotation due to the increased degree and intensity of sunflower broomrape damage.

The lowest yields of sunflower seeds have been recorded in short-rotation crop rotations where the share of sunflower crops was 50% in the structure of sown areas and permanent cultivation and amounted to: moldboard plowing system—1.75–2.21 t/ha, disk tillage—1.57–2.01 t/ha, and no-tillage system—1.49–1.95 t/ha. That is, there is a direct correlation between weed infestation and sunflower seed yield.

Conclusion

Disk tillage and no-tillage systems increase the number of weeds in sunflower crops by 1.3–1.5 times compared to the moldboard plowing before the first interrow tillage. On average, during the years of research, their abundance in the plots when using disk tools was 10.4–15.1, moldboard plowing—7.1–12.4 pcs./m^2, before harvesting, respectively, 2.6–5.2 and 4.1–12.4 pcs./m^2. The air-dry weight of weeds varied by variants in accordance with the change in quantitative values and was higher with minimization of tillage (8.1–15.7 g/m^2) than with moldboard plowing (7.3–12.3 g/m^2).

The distribution and degree of sunflower broomrape (*O. cumana* Wallr.) damage had been, in general, completely opposite patterns than in the study of common autotrophic photosynthetic weeds. The degree of manifestation of the active biological phase of sunflower broomrape parasitism naturally has been increased with a decrease in the time interval in the crop rotation between sunflower crops. The maximum danger to sunflower yields has been posed by sunflower broomrape in 2-field crop rotation (winter wheat—sunflower) and permanent sunflower cultivation, as 16.0–32.4% of affected sunflower plants have been observed here, each sunflower field in the crop rotation is an additional resource for the accumulation of sunflower broomrape seeds in the soil.

The maximum damage of sunflower plants by sunflower broomrape (*O. cumana* Wallr.) has been recorded when using the moldboard plowing system and amounted to 1.2–8.3 pcs. per plant, which exceeded the same indicator when using disk tillage and no-tillage by 1.2–1.6 times, which is explained by the location of sunflower broomrape seeds in the soil, i.e. with increasing depth of seed plowing, it is in more favorable conditions, near the sunflower roots that provoke its germination with their root secretions.

The maximum seed yield of 2.92–2.95 t/ha has been obtained in 8- and 5-field crop rotations with the use of moldboard plowing. The lowest yields of sunflower seeds have been recorded in short-rotation crop rotations where the share of sunflower crops was 50% of the area under crops and permanent cultivation and amounted to: moldboard plowing—1.75–2.21 t/ha, disk tillage—1.57–2.01 t/ha, and no-tillage—1.49–1.95 t/ha.

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