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Effect of minimum tillage, fertilizers and herbicides on weed abundance and crop yields

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Abstract. Minimum tillage, as an important element of the sustainable functioning of the agroecosystem, can lead to an increase in weeds in crops, especially when fertilizers are applied and the use of herbicides is reduced. This paper dwells on analyzes the results obtained during 2015-2018 on a long-term three-factor field experience, which included 4 gradations of tillage: moldboard plowing (MP), surface treatment with deep loosening (STL), surface-ploughing treatment (SP) and surface treatment (ST); 6 gradations of fertilizers: No fertilizers (F0), nitrogen (N), straw (S) straw + nitrogen (SN), straw + NPK (SNPK) NPK (NPK); 2 gradations of herbicides: Without herbicides (G0), With herbicides (WG). Our studies indicate that there is no significant effect of tillage on the number and dry weight of weeds. The positive effect of SP and SNPK on reducing the number and weight of perennial weeds and obtaining the highest yield has been established.

1. Introduction

Weeds are an integral part of every agrophytocenosis. They negatively affect the level of the yield and the quality of the agricultural products produced. The high number of weeds makes it difficult to perform many types of field work, including tillage and harvesting [1].

The most effective way to suppress weeds is a moldboard plowing system [2-3]. However, plowing can lead to destruction of the soil structure, accelerated mineralization of soil organic matter and the development of erosion processes [4-8].

The transition to the technology of minimum tillage can cause an increase in weeds in agricultural crops and, especially the most harmful perennial weeds [9-11], which often requires increased doses of applied herbicides [12]. Soil tillage affects the vertical distribution of weed seeds and roots in the soil profile, which forms different conditions and, accordingly, the efficiency of their germination [2;13-15]. Currently, the task is to determine a sufficient level of minimization of tillage, which ensures the number of weeds at a level that is safe for field crops [2;10].

The use of fertilizers is an important condition for obtaining high and stable crop yields. However, their use usually leads to an increase in weeds in crops. This is especially noticeable with unbalanced plant nutrition [1]. Minimum tillage and surface fertilization further stimulate the growth and development of weeds [3]. At the same time, there are studies in which there is a decrease in the number of weeds and the degree of their harmful effect on crops when using fertilizers [1;10].

A number of studies show the dependence of the spread of weed species on the use of nitrogen [1;16-17], phosphorus [1;18-20], potash [18;21] and organic [1] fertilizers. This may also determine the effectiveness of herbicide application [1;16].

On sod-podzolic medium loamy gleyic soil of the Nonchernozem zone of Russia, specific moisture conditions are formed, which determine the conditions and the possibility of minimum tillage. Weeds play an important role in determining the effectiveness of minimum tillage when using different fertilizers and herbicides.

2. Materials and methods

The long-term field experiment is located at the sod-podzolic medium loamy gleyic soil of the Yaroslavl region, Russia (57°42'39"N, 39°41'40"E). The experiment was established in 1995. This paper presents studies from 2015 to 2018. Crop rotation during the research years: 2015 (Spring Barley) - 2016 (Oat-Vetch Mixtures) - 2017 (Spring Wheat) - 2018 (Oat-Vetch Mixtures).

The scheme of the three-factor (4 × 6 × 2) experiment included 48 variants. On plots of the first order with an area of 756 m2 (54 m × 14 m), tillage systems were studied, on plots of the second order with an area of 126 m^2 (14 m × 9 m) - fertilizers and on plots of the third order with an area of 63 m^2 (9 m × 7 m) - herbicides.

Factor A. System of primary tillage:

- Moldboard plowing: plowing by 20 ... 22 cm with preliminary disking by 8...10 cm, annually, MP.
- Surface treatment with deep loosening: loosening by 25...27 cm with preliminary disking by 8 ... 10 cm 1 time in 4 years + single surface treatment to a depth of 6...8 cm in the remaining 3 years, STL.
- Surface-ploughing treatment: plowing by 20...22 cm with preliminary disking by 8...10 cm 1 time in 4 years + single surface treatment by 6...8 cm in the remaining 3 years, SP.
- Surface treatment: single surface treatment on 6...8 cm, annually, ST.

Factor B. Fertilizer system:

- Without fertilizers, F0.
- Nitrogen fertilizers (30 kg active ingredient), N.
- Straw 3 t ha^{-1}, S.
- Straw 3 t ha^{-1} + N30 (nitrogen fertilizer at the rate of 10 kg of active ingredient per 1 ton of straw), SN.
- Straw 3 t ha^{-1} + NPK (the rate of mineral fertilizers, calculated for the planned increase in yield), SNPK.
- NPK (the rate of mineral fertilizers calculated for the planned increase in yield), NPK.

Factor C. Herbicide system:

- Free of herbicides, G0.
- With herbicides, in 2015 - herbicide Lintur (active ingredient: 659 g kg^{-1} dicamba 41 g kg^{-1} and triasulfuron); in 2016, 2017, 2018 no herbicides were applied - their aftereffect was studied, WG.

3. Results

Weed count and dry biomass of weeds.

The studied soil cultivation systems did not have a significant effect on the number and dry weight of weeds (table 1).

At the same time, non-moldboard treatments (STL, ST) were characterized by the highest indicators in terms of the number and dry weight of perennial weeds. SP ensured the formation of the number and dry weight of the most harmful perennial weeds at the MP level. It can also be noted that STL, SP, ST led to a decrease in the number (by 9.96-19.78 plants m^{-2}) and biomass (by 4.44-7.31 g m^{-2}) of annual weeds in the crops of the oat-vetch mixtures.

Table 1. Weed number (numerator, no. m^{-2}) and dry biomass of weeds (denominator, g m^{-2}) on average by factors (tillage, fertilizers, herbicides) and by crop groups for the period 2015-2018.

Variant	**Spring grains crops (2015, 2017)**			**Oat-Vetch Mixtures (2016, 2018)**		
	perennial weeds	annual weeds	total weeds	perennial weeds	annual weeds	total weeds
Factor A. Primary tillage system						
MP	4.3/4.2	54.8/28.0	59.1/32.2	19.90/27.74	108.82/28.63	128.72/56.37
STL	6.6/4.5	66.6/34.8	73.2/39.3	42.63/60.05	93.06/21.32	135.69/81.37
SP	4.2/3.9	66.8/33.4	71.0/37.3	26.07/33.54	89.04/24.19	115.11/57.73
ST	6.6/4.7	61.6/36.5	68.2/41.2	41.42/59.35	98.86/22.40	140.28/81.74
LSD_{05}	ns/ns	ns/ns	ns/ns	ns/ns	ns/ns	ns/ns
Factor B. Fertilizer system						
F0	6.0/4.2	56.8/25.3	62.80/29.5	41.53/50.93	81.19/21.08	122.72/72.01
N	8.2/5.3	74.1/31.2	82.30/36.5	35.33/42.81	104.90/20.67	140.23/63.49
S	8.0/5.9	56.1/22.5	64.10/28.5	53.13/66.62	105.13/14.00	158.26/80.62
SN	4.9/3.5	61.4/27.6	66.30/31.0	37.27/41.99	95.79/17.69	133.06/59.67
SNPK	2.2/2.6	67.1/43.6	69.3/46.2	16.78/25.73	94.25/36.33	111.03/62.06
NPK	3.4/4.4	59.0/49.0	62.4/53.4	16.96/42.84	103.67/34.64	120.63/77.48
LSD_{05}	2.0/2.0	ns/ns	ns/ns	16.9/ns	ns/14.33	ns/ns
Factor C. Herbicides system						
G0	5.7/4.5	65.6/35.6	71.3/40.1	36.72/41.32	96.61/24.56	133.32/65.88
WG	5.2/4.1	59.3/30.8	64.4/3.9	30.28/48.99	98.37/23.58	128.65/72.56
LSD_{05}	ns/ns	5.9/ns	5.7/ns	6.30/6.34	ns/ns	ns/ns

ns – not significant at $p<0.05$

The application of fertilizers to spring grain crops was accompanied by an increase in the number of annual weeds. However, these changes were not significant ($p>0.05$). The use of SNPK and NPK led to a significant decrease in the abundance of perennial weeds during the entire study period. At the same time, SNPK contributed to the least accumulation of perennial weed species both on spring crops (3.4 plants m^{-2}) and vetch-oat mixture (16.78 plants m^{-2}).

The use of S and N fertilizers on spring crops (2015, 20017) led to a significant increase in the number of perennial weeds (by 2.0-2.2 plants m − 2) with a slight increase in their weight.

During the research period, the herbicide was applied only once in 2015 in crops of spring barley. In 2016, 2017 and 2018 its aftereffect was studied.

The action of the herbicide in the spring grain crops contributed to a decrease in the number of annual weeds by 6.3 plants m^{-2} with an insignificant ($p> 0.05$) decrease in their dry weight. In the crops of the oat-vetch mixture (2016, 2018), the aftereffect of herbicides caused a decrease in the number (by 6.3 plants m^{-2}) with an increase in dry weight (by 7.67 g m^{-2}) of perennial weeds ($p <0.05$).

Crop yield.

With an increase in the number ($r = -0.61$; $p <0.001$) and dry weight ($r = -0.68$; $p <0.001$) of perennial weeds, a decrease in the yield of spring barley was observed (2015). When growing vetch-oat (2018), the number of perennials weed species was also inversely related to the crop yield ($r = -0.59$; $p <0.001$). At the same time, a stronger and more significant dependence was observed on plots with minimal treatment (STL, SP, ST) as compared to the MP.

The number and dry biomass of annual weeds in the cultivation of spring wheat (2017) and oat-vetch mixture (2018) was in direct proportion to the yield of field crops ($r = 0.48$-0.74; $p = 0.001$). At the same time, it should be noted that when growing the vetch-oat mixture (2018), a strong significant relationship between the accumulation of dry matter by annual weed species and yield was observed only on plots with minimum tillage (STL, SP, ST).

The use of SP and ST contributed to a significant increase in the yield of spring barley (2015) by 2.64 and 2.02 centners ha^{-1}, respectively (table 2). In 2016 and 2017, the studied processing systems did not affect the yield of the oat-vetch mixture (2016) and spring wheat (2017). The use of STL reduced the yield of the oat-vetch mixture (2018) by 30.8 centners ha^{-1}.

Table 2. Crop yield (centners ha^{-1}) on average for the studied factors on average by factors (tillage, fertilizers, herbicides) from 2015 to 2018.

Variant	Spring barley, 2015	Oat-Vetch Mixtures, 2016	Spring wheat, 2017	Oat-Vetch Mixtures, 2018
Factor A. Primary tillage system				
MP	17.44	348.6	21.29	236.0
STL	18.32	349.06	21.83	205.2*
SP	20.08*	349.68	22.32	258.3
ST	19.46*	341.58	22.90	242.6
HCP_{05}	1.46	ns	ns	25.2
Factor B. Fertilizer system				
F0	14.53	328.48	17.38	205.4
N	16.69**	323.57	23.27	220.5
S	17.23**	359.98**	22.11	201.9
SN	18.04**	357.75**	21.25	202.6
SNPK	23.42**	368.15**	25.55	289.5**
NPK	23.03**	345.44	26.25	293.3**
HCP_{05}	1.98	28.99	2.85	20.0
Factor C. Herbicides system				
G0	17.56	340.59	22.24	235.9
WG	20.09***	353.87	23.03	235.2
HCP_{05}	1.11	ns	ns	ns

ns – Not significant at P<0.05

The use of fertilizers, and especially SNPK and NPK, led to a significant increase in field crop yields during the entire study period.

The use of the herbicide Lintur in crops of spring barley (2015) led to a significant increase in yield by 2.53 centners ha^{-1}. In 2016 and 2016, the aftereffect of the herbicide led to an insignificant ($p> 0.05$) increase in the yield of the vetch oat mixture (2016) and spring wheat (2017).

4. Discussion

Effects of tillage system, fertilizers and herbicides on weed number and dry biomass.

The results of these studies indicate that the use of minimum tillage (STL, SP and ST) does not lead to a significant increase in the number and dry weight of weeds. At the same time, non-moldboard treatments tended to increase perennial weeds, which is associated with less effective suppression of vegetative reproductive organs in the soil. On the other hand, non-moldboard treatments (STL, ST) provided better conditions for provoking seeds of annual weeds after harvesting spring cereals, which led to a decrease in their number and weight when growing the oat-vetch mixture. Our research has shown that the use of SP, where surface treatment is alternated for 3-4 years and moldboard plowing for 4-5 years. SP provides partial provocation of weed seeds by surface treatment in the first 3-4 years. After 4-5 years, moldboard plowing is carried out, which embeds the accumulated weed seeds into the lower soil layer, and the lower layer of the arable horizon, cleared of weeds, rises upward. Plowing after several years of surface treatment in the system (SP) also creates the best conditions for controlling perennial weeds.

The use of fertilizers stimulated the germination of seeds of annual weeds, but it was not significant. SNPK promoted the least accumulation of perennial weeds through better growth and development of field crops, the root systems of which competed with the root system of perennial weeds. Unbalanced nutrition based on S and N backgrounds led to an increase in perennial weeds due to the following species: *Stachys palustris L., Convolvulus arvensis L., Equisetum arvense L.*

The application of the herbicide Lintur led to a decrease in the number of annual weeds in the cultivation of spring barley (2015). The aftereffect of the herbicide was manifested in a decrease in the number of perennial weeds. At the same time, the preserved weeds formed the largest dry biomass.

Effects of tillage system, fertilizers and herbicides on the crops yield

The results of our research show that perennial weeds have the most significant impact on crop yield when minimal tillage (STL, SP and ST) is applied. Carrying out MP to a greater extent suppressed the growth and development of perennial weed species due to a more intense effect on the vegetative reproductive organs located in the soil, which was observed in crops of oat-vetch mixture (2016, 2018). This led to a decrease in the relationship between perennial weed species and yield. This led to a decrease in the relationship between perennial weed species and yield.

The highest yield of crops was determined by the use of SP by creating better conditions for the destruction of perennial weeds. When growing vetch-oat mixture (2018) on plots with SP, a strong negative relationship was found between the number of perennial weeds and yield ($r=-0.90$; $p<0.001$), while on MP this relationship was not significant ($r=-0.21$; $p=0.507$).

The application of fertilizers, and especially SNPK and NPK, led to a significant increase in yield. The effect of the herbicide on yield was observed only in the year of application. The aftereffect of herbicides, although it affected the abundance of weeds, did not have a significant effect on crop yields.

5. Conclusion

Our studies indicate that the application of minimal tillage does not increase the abundance of weeds. SP provides better weed management conditions resulting in higher yields. The introduction of SNPK and NPK contributed to a decrease in the abundance of perennial weeds, which to a greater extent determined crop yields. The herbicide had a positive effect on yield and reduction of perennial weeds only in the year of application.

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