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Phytosanitary state of pea agrophytocenoses under various methods of basic tillage

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Abstract

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As a result of the research, the formation of a different phytosanitary situation on pea (*Pisum sativum* L.) crops was revealed with various tillage methods using. The infestation of pea crops varied significantly depending on the growing season conditions. The introduction of disking and direct sowing increased the infestation of crops with annual and biennial weeds. Population density of yellow thistle and field horsetail increased. Favorable weather conditions can lead to a high spread of rust and gray mold on pea plants. The intensity of pathogen severity increased as the crop matured, regardless of the soil tillage. This indicator was the lowest with the use of disking. The density of the phytophage population also changed significantly depending on weather conditions. Moldboard tillage significantly reduced the population density of pea aphids and gamma armyworms compared to shallow tillage. Direct sowing also contributed to a decrease in the number of phytophages in pea crops.

The data obtained should be in demand in the development of an integrated system for the protection of peas from a complex of harmful organisms in the Non-Chernozem Zone of the Russian Federation.

Keywords: Pisum sativum; tillage,weed; pathogen; phytophagous insects

Introduction

The optimal phytosanitary state of agrocenoses can be formed with the complex implementation of farming system based on science approach (Vyugin & Vyugina 2012).

The phytosanitary principle in farming systems, starting from primitive forms up to the present, has not been decisive in their development and implementation. At the same time, there are a number of theoretical works that formulate the basic principles for optimizing the phytosanitary state of modern farming systems (Sokolov, 2007; Pavlyushin, 2011; Toropova et al. 2013; Ivashchenko, 2017).

The phytosanitary state of modern agrocenoses is deteriorating for a number of reasons. Firstly, a reduction in cultivated crops range and an increase in cereals share in crop rotations (Wenda-Piesik, 2021; Ratnadass, 2012). Secondly, an unreasonable transition to minimizing tillage. According to Zhuchenko (2004) and Sanin (2016), “no-till” cost-saving agriculture is accompanied by a deterioration of the phytosanitary situation. In the Russian Federation, in relation to the agricultural regions of the country, there are no studies, “which have such scientific proves as: in which regions, on which soils, which ploughland, using which methods and means of protection should be applied.” It is tillage, that largely determines the intensity of spread and harmfulness of plant diseases, insect pests and weeds in farming systems (Chulkina, 2000, Yakovlev, 2003).

Legumes in modern farming can help increase the resilience of agricultural systems (Pelzer, 2017). But a comprehensive study of their phytosanitary state under various production technologies is necessary. This article discusses the impact of basic tillage methods for peas on the harmful objects complex for crops.

Materials and methods

The studies were carried out in Non-Chernozem zone of the Russian Federation, Kovylkino district of Mordovia Republic (N 54°01′59″ E 43°55′00″), in a four-field crop rotation (pea-winter wheat-soybean-spring barley) in 2017-2019 in the second crop rotation phase. The main tillage for winter wheat and soybeans was based on disking, for peas and spring barley it was direct sowing.

The experimental factors were as follows:

1. Disking + deep mouldboard loosening to a depth of 22–25 cm with a PLN–5–35 plow (plowing).
2. Autumn disking to a depth of 10–12 cm (disking).
3. Direct seeding (no-till).

The experiment was carried out with 4-fold repetition, the plots were placed by the method of randomized repetitions. The experiment was carried out on leached chernozem with heavy loamy texture. Humus content varied from 5.8 to 6.5%, P_2O_5 from 148 to 169 mg/kg, K_2O from 163 to 182 mg/kg. The pH value of salt extract is 5.0–5.3. Saturation degree of soils with bases is high (86.4–88.4%). The variety Rocket was used in the experiment. Crop sowing dating was the 2-d and the 3-d decades of April. The seeding rate is 1 million germinating seeds per hectare.

During pea crop growing season, weather conditions varied significantly in different years of research **(Table 1).**

The species composition and weeds number were determined on plots of 1 m^2 in ten-fold repetitions, randomly selected at the end of the flowering phase (60-61 on the BBCH scale).

The prevalence and development of pathogens were determined in the following phases: the end of flowering (BBCH – 69), green ripeness (BBCH – 79), protein ripeness (BBCH – 85) and full ripeness (BBCH – 97).

The spread of pathogens was determined by selecting 10 plants at 20 points along the experimental plot diagonal. Disease development of plant was determined as a percentage according to the modified Cobb scale (Methodical ..., 2009).

The number of pea aphids was taken into account by sweeping (10 swings at 10 points along the plot diagonal). The number of armyworms was counted on the ten chosen sites (0.5 × 0.5 m) (Monitoring..., 2002). The experimental data were processed by dispersion analysis method. Statistical analysis of the results was performed using the Statistica 10 program, highlighting the main effects and their pairwise interaction.

Results

The number of weeds varied significantly depending on growing season conditions **(Table 2).** Thus, in 2017, which was characterized by the highest amount of precipitation, the number of dicotyledonous annual and biennial weeds was higher by 64% compared to 2018 and by 37% compared to 2019. The indicator for perennial dicots was higher by 19 and 23% respectively. A similar trend has been established for monocot weeds.

Direct seeding contributed to increase in weed infestation with dicotyledonous annual and biennial species by 53% compared to plowing and by 27% compared to disking. The number of perennial dicotyledonous and monocotyledonous

Table 1. The mean air temperature (°C) and total rainfall (mm) in 2017-2019 peas vegetation as compared to the long term mean (LTM = 1980-2000)

Year	Month, decade											
	May			June			July			August		
	I	II	III	I	II	III	I	**II**	**III**	**I**	**II**	**III**
Mean air temperature (°C)												
Long term mean	12,0	13,7	14,6	15,5	17,4	18,4	18,5	19,4	19,0	18,6	17,4	16,4
2017	12,9	10,4	13,0	12,4	15,8	16,6	16,0	19,9	20,2	20,4	19,1	17,7
2018	15,5	17,3	14	12,3	15,9	22,7	22,9	21,9	21,4	20,9	19,5	18,7
2019	15,2	16,8	17,1	19,8	18,8	19,0	16,6	18,0	18,0	14,5	18,9	15,5
Total rainfall (mm)												
Long term mean	13	16	15	14	24	17	30	22	18	18	19	16
2017	7	21	20	23	19	12	73	16	15	5	1	9
2018	9	4	5	17	3	0	13	6	17	5	0	2
2019	8	2	6	6	2	31	26	25	32	14	35	3

Table 2. Influence of the main effects of factors on the weed density in pea crops, number/m^2

Treatment	Weeds		
	mono-cotyledons	dicotyledon-ous annual & biennial	dicoty-ledonous perennial
Year			
2017	5^{a*}	46^{a}	11^{a}
2018	2^{b}	17^{c}	9^{b}
2019	3^{b}	29^{b}	8^{b}
Tillage practice			
Direct seeding	7^{a}	45^{a}	12^{a}
Double disking	6^{a}	33^{b}	10^{b}
Plowing	2^{b}	21^{c}	8^{c}

* – here and further values with different indices significantly differ from each other at the level of $p = 0.05$, Tukey post hoc test

weeds was significantly higher without tillage. Significant dynamics of the species composition of weeds was noted in phytocenosis. The largest species diversity (33–38 species) was in 2017 (optimally moistened), the smallest (20–26 species) – in 2018 (extremely dry), also depending on soil tillage.

With direct sowing and disking, *Tripleurospermum inodorum* L. *Sch. Bip, Equiseum arvense* L., *Galium aparine* L., *Convolvulus arvensis* L., *Cirsium setosum (Willd.) Besser., Sonchus arvensis* L. had a significant population density exceeding the economic thresholds of harmfulness (ETH). During moldboard tillage, a number of weed species exceeded the economic thresholds of harmfulness, in particular, *Convolvulus arvensis*, *Cirsium setosum*, *Galeopsis tetrahit* L., *Chenopodium album* L, *Polygonum aviculare* L. At the same time, such species as *Sonchus arvensis* L., *Tripleurospermum inodorum* L., although were observed quite often, had a population density below the ETH.

Uromyces pisi (Pers.) de Bary was the dominant rust species in pea crops.

The prevalence of *Uromyces pisi* depended on weather conditions. The formation of primary infectious structures – germ hyphae – occurs in the presence of dripping water, with rain or dew. In 2017, due to high precipitation, the spread of the disease during the flowering phase was 44-53% higher compared to the drier 2018 and 2019 **(Table 3)**. By the phase of protein and full ripeness, the largest number of uredospores had been noted. This ensured a high density of propagules in the air and their uniform distribution on the plant. By the full ripeness phase, the spread of the pathogen was greatest, but the differences between the years of the study persisted.

With direct sowing, from the phase of protein ripeness, the prevalence of *Uromyces pisi* increased compared with disking and plowing. By the phase of protein ripeness, the difference between direct sowing and other options had been 2-3%, in the phase of full ripeness this figure was 6-7%.

The most pathogen severity was in time of excessive moisture in 2017. With a lack of moisture in 2018 and 2019,

Table 3. Influence of the main effects of factors on the prevalence and development of *Uromyces pisi*

Treatment	Growth stages			
	BBCH – 69	BBCH – 79	BBCH – 85	BBCH – 97
prevalence %				
Year				
2017	82^{a}	91^{a}	95^{a}	100^{a}
2018	29^{c}	44^{b}	54^{c}	61^{c}
2019	38^{b}	48^{b}	69^{b}	77^{b}
Tillage practice				
Direct seeding	51^{a}	62^{a}	75^{a}	84^{a}
Double disking	47^{b}	60^{a}	71^{b}	77^{b}
Plowing	50^{a}	61^{a}	72^{b}	78^{b}
development, %				
Year				
2017	4^{a}	31^{a}	55^{a}	65^{a}
2018	5^{a}	9^{b}	16^{b}	18^{b}
2019	2^{b}	4^{c}	10^{c}	20^{b}
Tillage practice				
Direct seeding	4	15	27^{a}	36^{a}
Double disking	4	14	25^{a}	29^{b}
Plowing	4	15	29^{b}	38^{a}

Table 4. Influence of the main effects of factors on the prevalence and development of *Botrytis cinerea Pers* of pea

Treatment	Growth stages			
	BBCH – 69	BBCH – 79	BBCH – 85	BBCH – 97
prevalence %				
Year				
2017	30[a]	43[a]	63[a]	74[a]
2018	7[c]	13[c]	16[c]	18[c]
2019	13[b]	20[b]	26[b]	34[b]
Tillage practice				
Direct seeding	17[a]	26[b]	36[b]	42[b]
Double disking	14[b]	20[c]	30[c]	38[c]
Plowing	18[a]	31[a]	39[a]	48[a]
development, %				
Year				
2017	4[a]	8[a]	17[a]	33[a]
2018	2[b]	4[b]	12[b]	12[c]
2019	4[a]	8[a]	16[a]	26[b]
Tillage practice				
Direct seeding	4[b]	6[b]	13[b]	24[b]
Double disking	3[b]	5[b]	11[c]	17[c]
Plowing	4[a]	8[a]	19[a]	30[a]

the development of *Uromyces pisi* by the green ripeness phase had been 22-27% lower, and by the full ripeness phase this figure had been 45-47% lower.

On average, over the years of research, it has been established that an increase in the pathogen severity above the economic harmfulness occurred in all variants of tillage, starting from the green ripeness phase. This indicator was minimal during disking, and maximal during plowing.

Botrytis cinerea Pers. is one of the harmful and common diseases of peas. It is found in agrophytocenoses all over the world. Some important field crops are severely damaged by gray rot. The most notable losses are in legumes in India, Bangladesh and Nepal (Pande, 2002).

The greatest distribution of *Botrytis cinerea* was noted during the experiment in 2017, in other years this figure was significantly lower **(Table 4)**. In experiments, necrotic spots were noted on pea stems in the lower and middle tiers. The maximum pathogen severity had been noted by the phase of full ripeness. In conditions of high humidity in 2017, this development was 40-56% higher compared to other periods.

The prevalence and intensity of *Botrytis cinerea* manifestation at the end of pea flowering with moldboard tillage, and without it did not differ significantly. With disking, these figures were 29 and 21% lower. In subsequent counts, the prevalence of the pathogen increased. Most of the plants with symptoms of *Botrytis cinerea* in the green ripeness phase were in plots, which were plowed. In plots with direct sowing, they were less by 17%, in plots with disking – by 36%. The intensity of *Botrytis cinerea* development approached the level of ETH only with plowing. The manifestations of stem blight in the subsequent phases of pea development during direct sowing were more influenced by the supply of dormant sclerotia present on plant residues. The increase in *Botrytis cinerea* manifestation during plowing is largely due to poor aeration of crops and high air humidity.

By the phase of protein ripeness, the number of affected plants had increased to the level of ETH in all variants, but the regularity of tillage methods influence remained. The minimal development of *Botrytis cinerea* was with disking and direct sowing. The amount of *Botrytis cinerea* was minimal during disking. With direct sowing, it was significantly higher by 18%, and with plowing it was 63% higher.

By the phase of full ripeness of pea seeds, the maximum number of affected plants and the intensity of development of *Botrytis cinerea* were in plowing plots. The main reasons were high foliage, significant vegetative mass and poor aeration. The minimum damage to plants by the pathogen was in plots with disking, which is 41% less than in direct sowing plots and 76% less than in plowing ones.

An analysis of the data dispersion using the Dospekhov-Barov method indicates that the variation in the distribution of both *Uromyces pisi* and *Botrytis cinerea* in all phases of crop development depended to a greater extent on the conditions of the year **(Figure 1)**. The contribution to the total data dispersion for *Uromyces pisi* was 78–90%, for *Botrytis cinerea* was 73–93%.

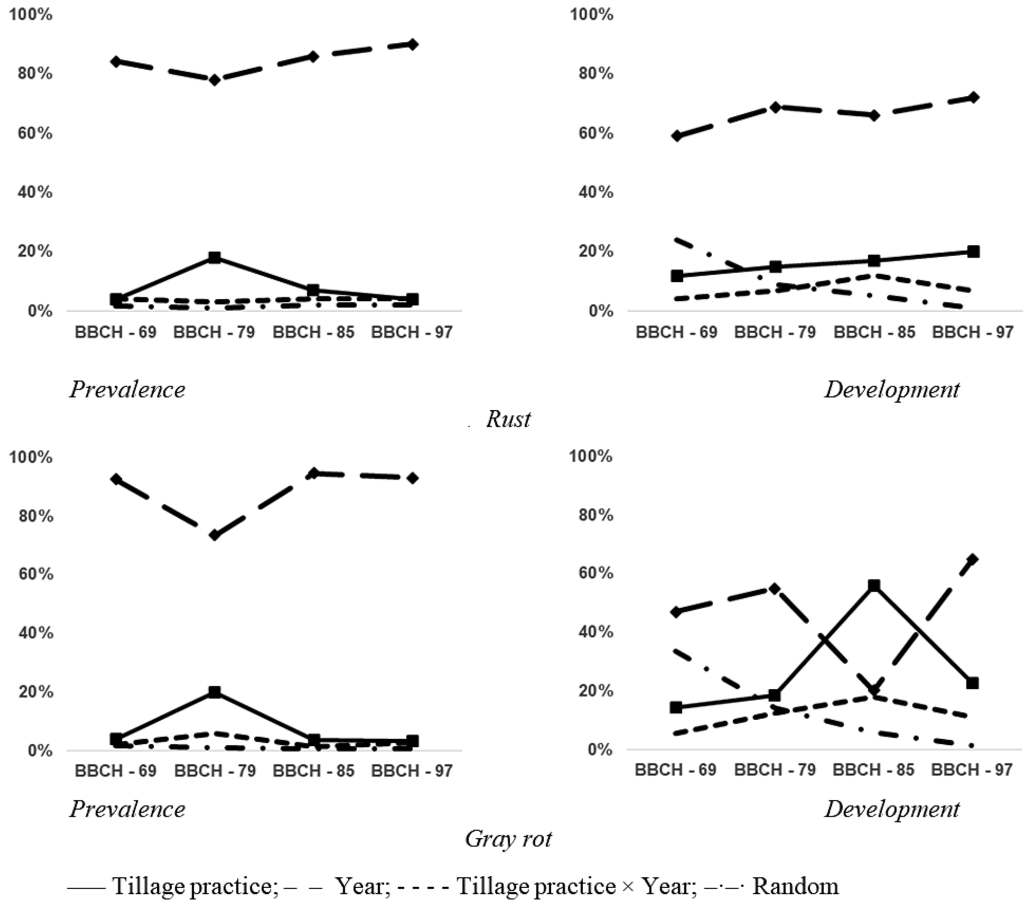

Fig. 1. The share of factors and their interactions in the experimental data dispersion of spread and development of pea diseases

The largest contribution of tillage method to the data dispersion was noted in the phase of green ripeness (18–20%). The share of factors interaction and random variation did not exceed 3%.

A greater share of tillage factor in the data dispersion was revealed for the pathogen severity indicator. With respect to *Uromyces pisi*, it increased from 12% at the beginning of flowering to 20% at full maturity. For *Botrytis cinerea*, the maximum influence of this factor was in the phase of protein ripeness – 56%.

Growing season conditions can indirectly affect phytophagous insects by changing the composition of host plant tissues or by directly affecting population density. In 2018, hot and dry weather contributed to the massive emergence of pests. In 2017 and 2019 intensive moisture during the 2nd growing season and low average daily temperature reduced the number of *Acyrthosiphon pisum* zooids and *Autographa gamma* armyworms **(Table 5).**

Table 5. Influence of the main effects of factors on the population density of phytophagous insects in pea crops

Treatment	Phytophagous Insects	
	Acyrthosiphon pisum (for 10 swings)	*Autographa gamma* in m^2
Year		
2017	59[c]	11[b]
2018	106[a]	18[a]
2019	85[b]	11[b]
Tillage practice		
Direct seeding	71[b]	18[a]
Double disking	115[a]	14[b]
Plowing	64[c]	8[c]

With regard to the number of pea aphids, a clear pattern of growth in population density was traced in plots with disking. With plowing it was less by 38%, with direct sowing by 44%. With regard to the population of *Autographa gamma* armyworms, it was found that it was the largest with direct sowing. When plowing, the amount of the pest was less by 56%, while disking – by 22%.

Discussion

A large amount of research confirms the position that tillage significantly affects the phytosanitary condition of crops.

Changes in the tillage system lead to population density dynamics of individual weed species. (Locke et al., 2002; Feledyn-Szewczyk et al., 2020). Brainard et al. (2013) noted that the lack of mechanical pruning of root systems with a decrease in the intensity of tillage leads to a high density of perennial weed species. In the experiments of Woźniak et al. (2019) the largest number and air-dry mass of weeds were determined in traditional tillage, the smallest in minimum and no tillage systems. At the same time, with the introduction of direct sowing in the first rotations of crop rotations, according to a number of researchers, infestation with annual and biennial weeds increases (Kurdyukova, 2016; Kuzina, 2017; Ivchenko et al., 2018).

A similar trend has been established in our studies. Direct sowing contributed to an increase in the population density of annual and biennial weed species are typical for agrophytocenoses of the Russian Federation. The number of the most malicious perennial species also increased in comparison with plowing method. The weed species composition with different methods of tillage did not differ. Similar dynamics of weed species composition was revealed by Nikolsky et al. (2012). The authors noted that at the optimal level of moisture, a wider species composition and a high density of weed populations were noted. At the same time, the core of weeds, which are characteristic of a certain crop, has always been preserved.

According to Laptiev & Kungurtseva (2016), until recently, pathogens living in the soil, in particular Fusarium and ascochitosis, formed the basis of the pathogenic complex of peas. With the use of minimal methods of tillage, the development of *Uromyces pisi* and *Botrytis cinerea* increased. Our research confirms the position that, in relation to airborne phytopathogens, plowing is not an effective method to reduce their spread and development. Small-scale basic tillage in our studies significantly reduced the pathogens severity compared to other methods of tillage.

Since insects are poikilothermic organisms, the rate of their metabolism depends on the ambient temperature, which affects their development, nutrition, and population density in agrophytocenoses. (Régnière et al., 2012; Donatelli et al., 2017). This position was confirmed in our studies: under the conditions of accumulation of a larger amount of active temperatures (2018), phytophage insects spread more actively in pea crops.

Tillage is also a factor influencing the spread of phytophages. The presence of cereal straw on the soil surface leads to a decrease in soil temperature, which delays the development of immature insects and reduces their harmfulness in pea crops (Hanavan et al., 2012). In direct seeding, straw mulch is thought to interfere with the search for pea by aphid plants (Döring, 2004; Saucke et al., 2009). Mulch significantly suppresses pest population density when the crop is planted early. At the same time, the effectiveness of mulch with late seeding is significantly reduced (Saucke et al. 2009). Demkin et al. (2011) found that surface tillage to a depth of 12–15 cm is less effective in suppressing the number of pea aphids compared to deep moldboard tillage. The results obtained during our studies confirm the regularities of tillage methods influence on the number of phytophage insects. Shallow tillage contributes to an increase in the density of pest populations in pea agrophytocenoses.

Conclusion

The present study showed that the substitution of plowing with disking and direct seeding in the first rotations of the crop rotation increases the infestation of pea crops. The population density of perennial dicotyledonous species is increasing. Soil tillage practices have a lesser effect on the distribution and development of *Uromyces pisi* and *Botrytis cinerea*. To a greater extent, their dynamics is influenced by weather conditions. Direct sowing under the RF conditions reduces the population density of *Acyrthosiphon pisum* and *Autographa gamma* compared to minimal tillage, but is inferior in efficiency to plowing.

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