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ORIGINAL ARTICLE

Herbological monitoring of efficiency of tillage practice and green manure in potato agrocenosis

Y.G. Mishchenko[1], E.A. Zakharchenko[1], S.I. Berdin[1], O.V. Kharchenko[1], E.R. Ermantraut[2], I.M. Masyk[1], V.S. Tokman[1]

[1]Sumy National Agrarian University, H. Kondratiev Str., 160, Sumy, Ukraine
[2]Bila Tserkva National Agrarian University, Soborna Sq., 8/1, Bila Tserkva, Ukraine.
E-mail: yrmis@ukr.net
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Weeds in potato crops have a negative effect on potato yield, especially in organic farming, so the present study aim find the most effective methods of reducing of weed infestation growing potato. A field experiment was conducted in the experimental plots at Sumy National Agrarian University in Northeastern Ukraine. Oilseed radish was grown for green manure use, after winter wheat harvesting, from August to October. Two methods of growing potatoes was studied-with application of green manure or without. In addition, four different types of tillage were studied: the control-moldboard ploughing at a depth of 28-30 cm, sweep ploughing at a depth of 28-30 cm, disking at a depth of 13-15 cm and 6-8 cm.
It was found that green manure made from oilseed radish significantly decreased weed infestations and weed weight, especially of early weeds and winter weeds. The largest reverse correlation was observed between phytomass of oil radish and weed infestation (r=-0.76 and-0.75) and weed weight in potato sowings (r=-0.59 and-0.55) with moldboard ploughing or sweep ploughing methods at a depth of 28-30 cm. A decrease in tillage depth led to a significant increase in weed infestation, in the weight of potato crops, and a decrease in tuber yield-1.8-6.2 t ha^{-1}. The method of tillage had a greater influence on the weed infestation-34 and 46% compared with the application of green manure-29 and 39%. According to data from the experiment, the application of green manure made from oilseed radish, along with the usage of sweep ploughing and disking, reduces the potential amount of weed seeds in the 0-30 cm deep root soil layer. The sweep ploughing at a depth of 28-30 cm with green manure application reduces the effect of potato overgrowth with weeds and helps to get the largest crop yield-up to 30.3 t ha^{-1}.
Keywords: Weeds; oil radish; *Solanum tuberosum*; tillage; weed infestation; tuber yield; green manure; disking; ploughing

Introduction

Crop productivity depends heavily on the state of agrocenosis. Weed control during the potato growth period is very important for obtaining a high yield of tubers. This is because potatoes crops slowly increase in phytomass in the initial stages of ontogenesis and can not compete with weeds for the main factors of life (Shuvar and Korpita, 2016). Weeds occupy the planted area because sprouts will slowly grow to the surface15-30 days after planting, and the distance between the rows is wide-70 cm. The massive appearance of weeds before the haulm meets in the rows not only prevents potatoes from using the main factors of life, such as light and moisture, but also increases the threat of disease and pests spreading in the crops. In addition, wild plants could become temporary transmitters (Bazdyrev et al., 2014; Zhukova 2015).
By suppressing and outgrowing the main crop, a specific group of autotrophic weeds comprised of wild plants develops in agrophytocenoses, which ultimately leads to a significant decrease in productivity and yield quality (Kyryliuk, 2013; Dvorak, 2015).
The economic injury level (EIL) of weeds on potato field is 5-12 plants m^{-2} of annuals and 2-4 plants m^{-2} of perennial weeds. Total losses in potato yield is caused by the presence of 50 weeds m^{-2} can reach 20 to 25%. The more weeds, the smaller the yield of tubers and a decrease in tuber quality is also common. Large quantities of weeds can lead to bigger losses-up to75% (Spiglova, 2014; Caldiz et al., 2016; Mehring et al., 2016).
Due to the uncontrolled development of weeds in potato agrocoenosis, especially in humid years, the costs of weed control are greatly increased (Price and Norsworthy, 2013; Petit et al., 2013; McErlich and Boydston, 2013). Highly competitive types of weeds such as Convolvulus arvensis L., Sonchus arvensis L., Chenopodium album L., and Atriplexpatula L. affect not only

yields, but also the size of tubers and their marketability, and complicates mechanized harvesting, which increases losses (Mehring et al., 2016; Spiglazova and Dolmatova, 2014).
It is impossible to establish an effective and normal agrocenosis without identifying and eliminating the root cause of the weed infestation taking into account phytocoenic relationships between plants. Nowadays the distribution of weeds in crops is closely related to the potential reserves of the weed in the soil, which gradually increases in the conditions of the forest-steppe of Ukraine and can reach 3-4 billion psc.ha^{-1} in 0-30 cm soil layer (Santín-Montanyá et al., 2016; Shuvar and Korpita, 2016; Melander et al., 2017).
The stocks of weed seeds in crops could be reduced by some activities which provoke weeds to sprout and in the same time to intensify of biological destruction, increasing the soil microbiological activity (Gudz et al., 2010; Cordeau et al., 2017). These processes happen often when using ploughless tillage and when the upper soil layers are mulched with green manure (Kyryliuk, 2013; Peters et al., 2014; Romaneckas et al. 2015; Kunz et al., 2016; Kołodziejczyk, 2015).
Green manurealso decreases the density of vegetativebiennial weeds and prevents their reproduction (Jabran and Farooq, 2013; Jabran, et al. 2015; Jabran, et al., 2016). Incorporated phytomass of cover crops, due to the optimization of nutrient, water and air conditions, stimulates the growth and development of cultivated plants and favorsits successful survival in a competitive relationship with weeds (McGuire, 2012; Rostami, 2015; Kołodziejczyk, 2015).
Effective weed control in potato agrocenosis can be achieved throughusing several techniques in combination: using green manure on crops,and throughploughless tillage of soil. Therefore, the purpose of this study is to compare the results of herbological monitoring of the effectiveness of the application methods of the oil radish (Raphanussativus var. oliefera) asgreen manure on crops for the regulation of potential and actual weed infestation of potato crops.

Material and methods of research

The research was conducted in the conditions of the Left Bank forest-steppe of Ukraine in a stationary field experiment in the Department of Agriculture, Soil Science and Agrochemistry in the Educational Research and Production Complex of the Sumy National Agrarian University (50,881 ° N, 34,769 ° E).
The soil in the experimental plot is Chernozem typical medium-loamy low-humified on loess, humus content by Tyurin is 3.2%, medium content of available NPK: phosphorus 11.7-12.6 (P_2O_5), potassium (K_2O) 12.2-13.9 mg per 100 g of soil by Chirikov, hydrolyzed nitrogen by Cornfild in a Conway cup is 16.5 mg per 100 g of soil. The reaction of the soil solution is determined potentiometrically by Koppen and close to neutral (pH 5.9-6.2), the hydrolytic acidity is 1.2-1.4 meq. per 100 g of soil.
A split-plot experiment had three replications; the size of each plot was 56 m^{-2} (8 × 7 m). The research tasks included studying the potential weed infestation of typical chernozem and the actual weed infestation of potato crops after the application of oil radish as green manure, as well as using various methods of tillage.
The investigation was carried out as a two-factorial experiment.
Factor A had the following treatments carried out on the plot:
1. Control-without green manure;
2. Incorporation of oil radish as a green manure.
Factor B had 4 trials of tillage:
1. Control-moldboard ploughing 28-30 cm.
2. Sweep ploughing 28-30 cm.
3. Discing 13-15 cm.
4. Discing 6-8 cm.
Crop rotation was: buckwheat-winter wheat + oil seed-radish-potatoe-barley. Winter wheat left on the field 5.2 t ha^{-1} of residues (straw); with incorporated oilseed radish was left as additional 29.7 t ha^{-1} of phytomass. Oilseed radish had been sown (30 kg ha^{-1}) after the harvesting of winter wheat in early August, and was applied to the soil during the autumn treatments (flowering-pod formation phase), according to the experiment plan, at the end of October 2005-2009. Potatoes were grown in 2006-2010 according to the recommended technology for the experimental location and planted 3 t ha^{-1} in the first decade of May.
No herbicides were used, only loosening between the rows with hilling and manual weeding were carried out. Potential reserves of weed seeds were determined by washing the soil using sieves, and by the quantitative and weight method. Using auger of Kalentiev, soil samples are taken in fivefold replication at experimental splots. Soil samples for analyses were collected separately from five layers: 0-5 cm, 5-10 cm, 10-20 cm, and 20-30 cm. The samples were dried at room temperature, each was divided on two medium samples of 100 g and washed on 0.25 mm sieve.
The quantity and biomass of weeds and potential infestation were determined every year in third decade of October. The potential infestation was determined also every year in the second decade of April. The quantity and weight of weeds in potato crops was determined in dynamics after two months: 1. During planting (1 decade of May). 2. During the flowering of potatoes (1 decade of July). 3. Before harvesting potatoes (3rd decade of August). Fresh (wet) mass was collected on trial plots (each 1 m^2) in triplicate and weighed.
In the formed phytocoenoses during the vegetation of Solanum tuberosum L., according to the results of herbological monitoring, it has been established that the following species of wild plants are represented in the structure of annual and biennial weeds: early spring annual: *Echinochloa crus-galli L., Setaria viridis L., Amaranthus retroflexus L., Chenopodium album L.,*

Solanum nigrum L., wintering: Erigeron canadensis L., Dessurainia sophia L., Thalassa arvense L., and among perennial weeds Convolvulus arvensis L.) and *Sonchus arvensis L*. A similar type of weed infestation (root stock annual and biennial) is typical predominantly in cultivated crops (Holm et al., 1977).

Analyzing the weather conditions in 2006-2010, it should be noted that the amount of precipitation per year was 575.5-689.2 mm with 570 mm of average annual amount. The wettest years were 2006 (May, August) and 2009 (May, July). There was not enough moisture during the growing season 2007 (April, May) and 2008 (June). The mean monthly temperature in the years of experiment was higher than the mean monthly (6.81 °C). So, in 2006 it was 7.81 °C, 2007-9.6 °C, 2008-9.42 °C, 2009-8.88 °C, 2010-9.47 °C. May was a bit cold in 2008 and August 2009.

The results were statistically elaborated using analysis of variance for two-factorial experiments by Statistica (Anova and Multiply regression) from Stat Soft (USA) (Borovikov, 2003).

Results and discussion

One of the main tasks of herbology is the determination of the weed infestation type, which depends on the previous crop. Winter wheat was the previous crop in this experiment, and after its harvesting and discing, before the main tillage, the type of weed infestation had been defined as short-lived-annual, biennial.The rate of early spring weeds increased and the winter annual weeds significantly decreased after green manure intercorporation-spring early weeds by number and weight (respectively, by 15 and 22%) and decreased wintering and perennial (11.5 and 22.0 and 2.0 and 2.3% respectively) (Figure 1). Compared with the control, under the cover of oil radish, the number of early weeds decreased by 4.2 plants m^2, and by weight-wintering-by 40 gm^{-2}, and the smallest number and weight of perennial weeds, respectively 2.4 plants m^{-2} and 13.4 gm^{-2}.

At the time of the growth recovery of weeds in the soil layer 0-30 cm deep after ploughing, we observed a proportional distribution of weed seeds within 30-40 % (Table 1). It has to say that potential infestation is the number of viable seeds in the soil and actual weed infestation is the number of weeds or their weight per unit area.

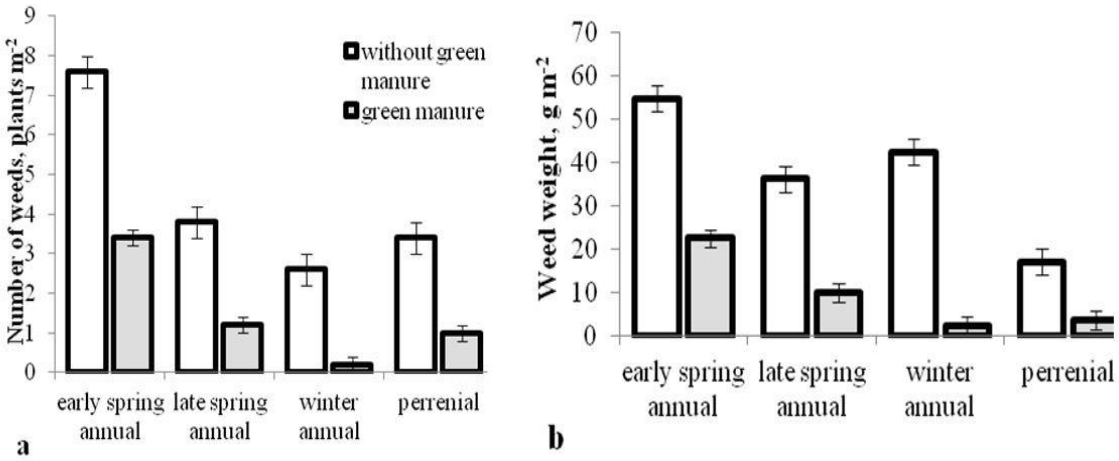

Figure 1. Amount and weight of weeds before the primary soil tillage (x ± SE, n=10). *difference between variant without the incorporation of green manure iand with is statistically reliable P<0.05.

Table 1. Potential weed infestation of soil after green manure incorporation and tillage (April 2006-2010), mln pcs.ha^{-1}.

Treatment		Soil layer, cm				Total
Green manure	Tillage system	0-5	43743	44105	20-30	0-30
without green manure	control (moldboard ploughing 28-30 cm)	20.8 ± 0.41	19.4 ± 0.28	36.7 ± 0.44	30.7 ± 0.24	107.6
	sweep ploughing 28-30 cm	24.5 ± 0.64*	35.1 ± 0.40*	25.7 ± 0.52*	21.9 ± 0.29*	107.2
	disking 13-15 cm	25.5 ± 0.33*	36.2 ± 0.36*	24.0 ± 0.34*	21.6 ± 0.18*	107.3

	disking 6-8 cm	28.1 ± 0.42*		35.0 ± 0.31*		22.6 ± 0.47*		21.5 ± 0.45*		107.2
green manureincorporation	control (moldboard ploughing 28-30 cm)	19.9 ± 0.25		18.8 ± 0.22		36.0 ± 0.40		30.1 ± 0.38		104.8
	sweep ploughing 28-30 cm	23.5 ± 0.40*		33.5 ± 0.26*		25.4 ± 0.33*		21.7 ± 0.46*		104.1
	discing 13-15 cm	24.5 ± 0.32*		35.3 ± 0.21*		23.1 ± 0.75*		21.4 ± 0.32*		104.3
	Discing 6-8 cm	26.8 ± 0.24*		33.4 ± 0.30*		22.4 ± 0.62*		21.2 ± 0.14*		103.8

*difference between variant without green manure and with is statistically reliable $p<0.05$.

Compared with moldboard ploughing, other methods significantly increased the amount of weed seeds in the soil layer 0-10 cm deep to 18.3-22.9 mln pcs ha^{-1}, and it was reduced appreciably in layers 10-20 and 20-30 cm deep (19.0-23.3 mln pcs ha^{-1}), due to the ploughless tillageand mixing of all root-containing soil layers 0-30 cm. Discing at 6-8 cm deepled to the accumulation of the largest reserves of weed seeds in the layer 0-5 cm deep-28.1 and 26.8 mln pcs ha^{-1}; the weed seeds reserve was smallest in the layers 10-20 cm deep and 20-30 cm deep-respectively 21.5-22.6 and 21.2-22.4 mln pcs ha^{-1}, because of non-disturbation of soil.

Discing at depth of 13-15 cm mixed, crumbled and mechanical loosened the soil layer, which resulted in a significant reduction of the amount of weed seeds in the soil layer 0-5 cm deep, respectively, at 2.6 and 2.3 mln pcs.ha^{-1} and an increase in layers 5-10 cm deep and 10-20 cm deep at 1.2-1.4 and 0.7-1.9 mln. pcs. ha^{-1}, respectively.

The sweep ploughingat a depth of 28-30 cm provided the smallest amount of possible weed infestation in the soil layer 0-5 cm deep-24.5 and 23.5 mln. pcs.ha^{-1}, which compared with discing was on 1.0-3.6 and 1.0-3,3 mln. pcs. ha^{-1} less. This tillage also increased the potential weed infestation in the soil layer 5-10 cm deep to 1.1 and 1.8 mln.pcs. ha^{-1}, compared with the discingat a depth of 13-15 cm.

Therefore, an increase in the depth of tillage leads to the reduction of the potential weed seed infestationsin the upper layers of the soil, and reduces the probability of weed seedling emergence, which also appears in the publications of a number of scientists (Kyryliuk, 2013; Scherner et al., 2016). In our studies, the depth of tillage without soil overturning closely correlated with the quantitative distribution of weeds seeds in the soil layers, so it was established an average inverse linear dependence ($r=-0.75$, $r^2=0.59$) in the spring in the soil layer 0-10 cm deep and a high direct dependence in the layers 10-20 ($r=0.97$, $r^2=0.95$) and 20-30 cm ($r=0.84$, $r^2=0.71$).

Oil radish green manure application on all types of soil tillage reduced the potential weed infestationat a depth of 20 cm to 0.2-1.6 mln. pcs.ha^{-1}. In the soil layer 20-30 cm deep, the potential weed infestation decreased by 0,6 million plants ha^{-1} only when using the method of green manure incorporation and conventional ploughing. Weed infestation was reduced by 2.8-3.4 mln.pcs.ha^{-1} in the soil layer 0-30 cm deep because of the use of green manure.

The actual weed infestation during the potato growing period determined the potential weed infestation in the upper layers of the soil (Scherner et al., 2016). The smallest amount of weed seeds in the upper layer was set in the plots with green manure, and the smallest amount and weight of weeds in the field was observed-10.6-20.8 plants m^{-2} and 132.4-728.0 gm^{-2} (Figure 2).

Based on data from the weed infestation, the result most similar to moldboard ploughing of 28-30 cm deep was sweep ploughing. The difference between these two methods in weed weight at the time of the seedlings emergence (1.3 gm^2) was not significant under the green manure application.

During the potato growing period using discing at a depth of 13-15 cm, the amount and the weight of weeds, compared with mouldboard ploughing and sweep ploughing methods on both nutrients backgrounds, substantially increased by 5.0-20.8 plants m^{-2} and 33.0-346.8 gm^{-2}, respectively.

The largest actual weed infestation was seen when discing at 6-8 cm; in comparison with other variants, the amount and weight of weeds increased significantly to 23.8-77.8 plants m^{-2} and 209.9-1089.8 gm^{-2}.

The smallest quantity of weeds were observed at the time of the potato harvest-10.6-36.2 plants m^{-2}, because it was the end of growing period. The smallest amount of weeds was observed at the sprouting of the potato seedlings-132.4-209.9 gm^{-2}. This could be explaind by the short vegetation period, which was interrupted by mechanical soil loosening.

The deeper the tillage, the smaller was the infestation of weeds in the potato crops. This was confirmed by the inverse correlation dependence of the average force between the depth of ploughing and the amount and weight of weeds r=-0.68,-0.66.

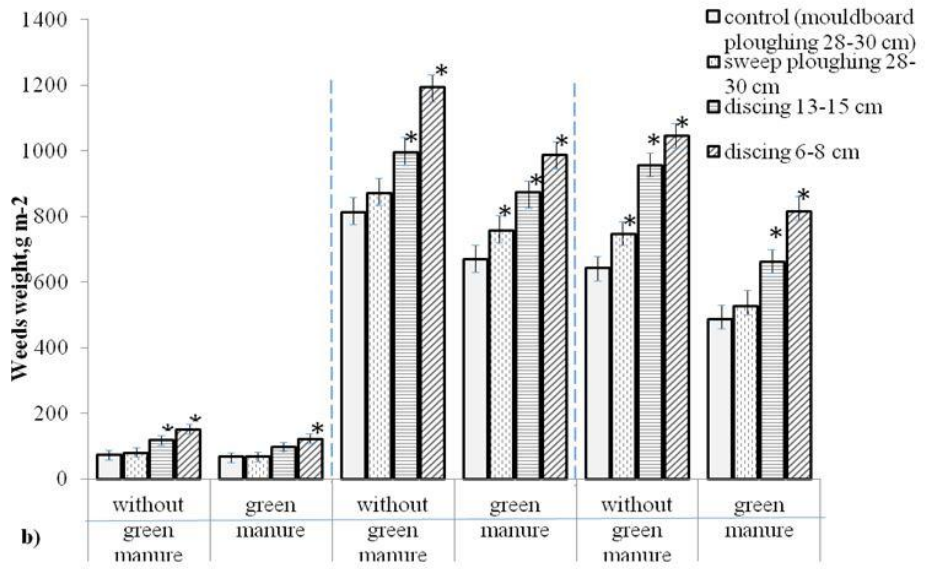

Figure 2. Impact of green manure and soil tillage on the dynamics of amounts and weight of weeds in potato crops.

Reducing the amount and weight of weeds during the potato's growing season had the largest effect on methods that involve an application of green manure in addition to the use of mouldboard ploughing and sweep ploughing at the same depth of 28-30 cm. The inverse correlation between application of green manure phytomass and the amount and weight of weeds in the potato crops was within r=-0.76 and-0.75,-0.59 and-0.55, respectively. Discing at the depths 13-15 cm and 6-8 cm was less effective in reducing the amount and weight of weeds; the proportion of the effect of phytomass green manure was 54-48 and 17-12%. The use of oil radish as incorporated green manure significantly decreased the number of biological groups of weeds and their mass during the potato growing period (Table 2).

Table 2. Distribution of biological groups of weed in agrocenosis Solanum tuberosum (x ± SE, n=15).

Treatment		**Biological group of weeds**			
Green manure incorporation	**Tillage system**	**Early spring**	**Late spring**	**Wintering**	**Pirennial**
Amount of weeds, plant m^{-2}					
Without green manure	control (mouldboard ploughing 28-30 cm)	13.7 ± 0.92	15.9 ± 0.44	2.6+0.24	2.2+0.22
	sweep ploughing 28-30 cm	18.3 ± 1.02*	16.2 ± 1.22	3.0 ± 0.12*	2.1 ± 0.16
	discing 13-15 cm	22.8 ± 0.88*	18.3 ± 0.90*	4.0 ± 0.12*	2.6 ± 0.44
	discing 6-8 cm	26.1 ± 0.89*	19.9 ± 1.06*	5.1 ± 0.52*	3.5 ± 0.47*
Green manure of oilseed radish	control (mouldboard ploughing 28-30 cm)	8.7 ± 1.08	7.9 ± 0.76	1.73 ± 0.21	1.7 ± 0.25
	sweep ploughing 28-30 cm	12.5 ± 0.58*	7.1 ± 0.82	1.5 ± 0.36	1.3 ± 0.24
	discing 13-15 cm	17.5 ± 0.92*	9.4 ± 0.94*	2.6 ± 0.28*	1.9 ± 0.32
	discing 6-8 cm	20.5 ± 1.11*	12.3 ± 1.06*	3.3 ± 0.22*	2.7 ± 0.34*
Weight of weeds. g m^{-2}					
Without green manure	control (mouldboard ploughing 28-30 cm)	196.0 ± 9.6	298.2 ± 10.2	25.5 ± 2.5	47.9 ± 1.2
	sweep ploughing 28-30 cm	253.9 ± 8.4*	302.1 ± 11.6	34.4 ± 1.8*	48.4 ± 1.5
	discing 13-15 cm	328.4 ± 10.6*	350.7 ± 6.3*	45.1 ± 1.4*	65.3 ± 2.0*
	discing 6-8 cm	380.1 ± 8.6*	373.1 ± 6.5*	53.2 ± 2.1*	77.9 ± 3.2*
Green manure of oilseed radish	control (mouldboard ploughing 28-30 cm)	133.3 ± 9.0	237.1 ± 9.2	17.2 ± 2.0	21.7 ± 1.0

	sweep ploughing 28-30 cm	202.6 ± 8.4*	248.72 ± 8.5*	14.4 ± 3.4	21.5 ± 2.5
	discing 13-15 cm	247.4 ± 8.6*	265.3 ± 9.8*	24.6 ± 3.1*	32.4 ± 0.7*
	discing 6-8 cm	283.2 ± 9.3*	280.9 ± 10.2*	29.6 ± 3.8*	45.5 ± 2.2*

*-significant at p<0.05.

The use of green manure cover crop effectively reduced the amount and weight of early and late spring weeds during the cultivation of potatoes-by 5.0-5.8 plants m^{-2} and 51.3-96.9 g m^{-2}, respectively, and the difference with the method without green manureby wintering weeds was the smallest-0.9-1.5 plants m^{-2} and 8.3-23.6 gm^{-2}.

Replacing conventional ploughing with sweep ploughing and disk ploughing led to an increase in the weed infestation in the potato crop, primarily in the early spring group-3.8-12.4 plants m^{-2} and 57.9-184.1 gm^{-2} respectively. There was an insignificant change in the amount and weight of the late spring and perennial weeds when usings weep ploughing at a depth of 28-30 cm. Discing at 13-15 cm caused an insignificant increase in the amount of perennial weeds, compared with mouldboard ploughing. The amount and weight of all biological groups of weeds significantly increased in both nutrients backgrounds under discing at 6-8 cm.

The application of oilseed radish as green manure contributed to a significant reduction in the amount of weed seeds in the root soil layer at a depth of 0-30 cm to 3.3-4.0 million plants ha-1during the potato growing period; the reduction in potential weed infestation is not significant; only in the 20-30 cm deepsoil layerunder sweep and discing (Table 3).

Table 3. Potential weed propagation on harvest potato time, million pcs ha-1 (x ± SE, n=10).

Treatment		**Soil layer, cm**				**Total**
Green manure incorporation	Tillage system	0-5	43743	44105	20-30	
Without green manure	control (mouldboard ploughing 28-30 cm)	19.9 ± 1.01	18.2 ± 1.04	36.0 ± 0.56	30.3 ± 0.65	104.4
	sweep ploughing 28-30 cm	23.5 ± 0.98	33.8 ± 1.81*	25.0 ± 0.36*	21.6 ± 0.52	103.9
	discing 13-15 cm	24.4 ± 0.90	34.8 ± 0.96*	23.4 ± 0.45*	21.4 ± 0.50	104
	discing 6-8 cm	26.9 ± 1.0*	33.6 ± 2.00*	22.1 ± 0.86*	21.2 ± 0.8*	103.8
Green manure ofoilseed radish	control (mouldboard ploughing 28-30 cm)	18.7 ± 0.97	17.7 ± 1.52	35.1 ± 0.74	29.6 ± 0.38	101.1
	Sweep ploughing 28-30 cm	22.3 ± 0.82	32.5 ± 1.22*	24.1 ± 0.44*	21.3 ± 0.44	100.2
	discing 13-15 cm	23.1 ± 0.74	34.0 ± 1.20*	22.1 ± 0.26*	21.1 ± 0.81	100.3
	discing 6-8 cm	25.3 ± 1.01	32.0 ± 1.35*	21.6 ± 0.33*	20.9 ± 0.74	99.8

*-significant at p<0.05.

Between the phytomass of radish oilseed and the amount of weed seeds from all methods of soil tillage a close-to-value strong inverse correlation dependencies was found-r=-0.76-0.7 with probability 70-76 %.

Tillage without soil overturning also contributes to reducing the total amount of weed seeds in the soil layer 0-30 cm deep. But the difference in the potential weed infestation compared with mouldboard ploughing was significant by discing 6-8 cm, conducted in conjunction with the application of oilseed radish green manure and was 1.3 million plants per hectare.

As the soil layers 0-30 cm are not intensively mixed when using sweep ploughing and discing, a significantly smaller amount of weed seeds were observed compared with the mouldboard ploughing technique in soil layers 10-20 cm deep-by 11.0-13.9 million psc. ha-1 and 20-30 cm-at 8.3-9.1 million psc. ha-1 for both backgrounds. Using ploughless tillage contributes to a concentration of substantially larger amounts of weed seeds in the upper layers-0-5 and 5-10 cm deep to 3.6-7.0 and 14.3-16.6 million $psc.ha^{-1}$, respectively.

A close inverse correlation was determined between the increase of the depth of tillageand the amount and weed seeds in the soil layer 0-10 cm deep (r=-0.71), and the straight line correlation was set in the lower layers 10-20 and 20-30 cm deep (r=0.96, and 0.64).

Tillage impact on the actual weed infestation of potatoes crop was in range 34-46% and has to be said the influence of different methods of tillage on the amount of weeds was larger than on its weight (Figure 3).

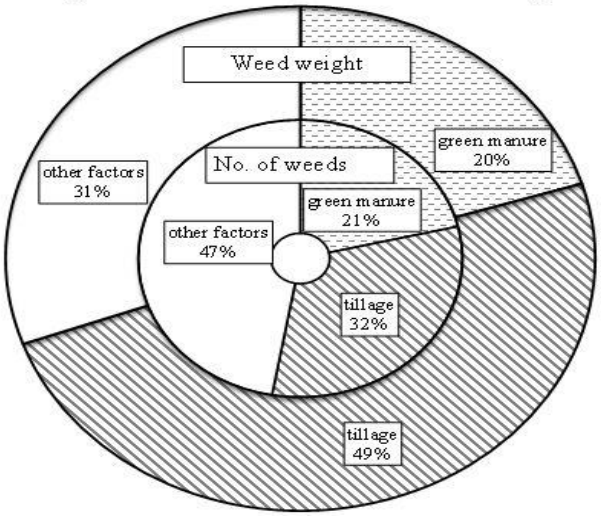

Figure 3. Impact fraction of green manure and method of tillage on weed infestation in potato crops.

Green manure made from oilseed radish plants also had a higher impact on the number of weeds-39% than its weight-29%. The primary tillage technique had the largest impact on the potential weed infestation in the layer 10-20 cm deep (66.4%), and the least-0-10 cm deep (46.1%). But method of application of green manure from oilseed radish had a larger impact on the potential weed infestation of the entire soil root layer 0-30 cm deep than the different methods of tillage. The green manure incorporation had a larger effect on the number of weed seeds in the upper soil layer-0.81% more than in the deep layers-0.43 and 0.2% (Figure 4).

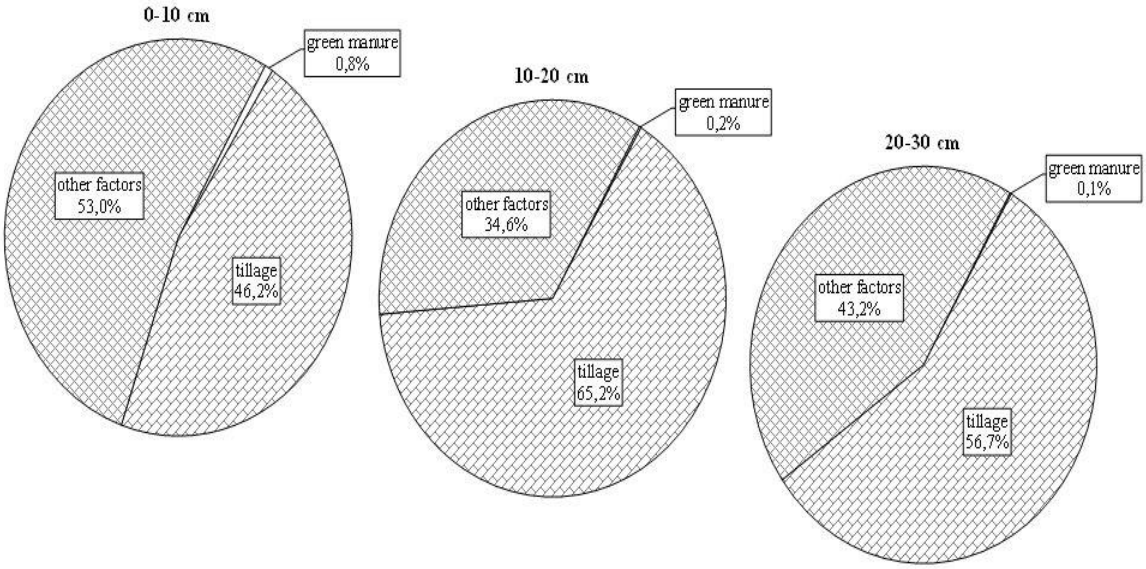

Figure 4. Impact fraction of tillage and oilseed radish incorporating on the potential weed infestation in the soil layers 0-30 cm (average for 2006-2010).

The growth of the smallest amount of weeds produced the highest yields of 30.3 t ha^{-1} using the green manure application method and ploughless tillage method 28-30 cm deep (Figure 5).

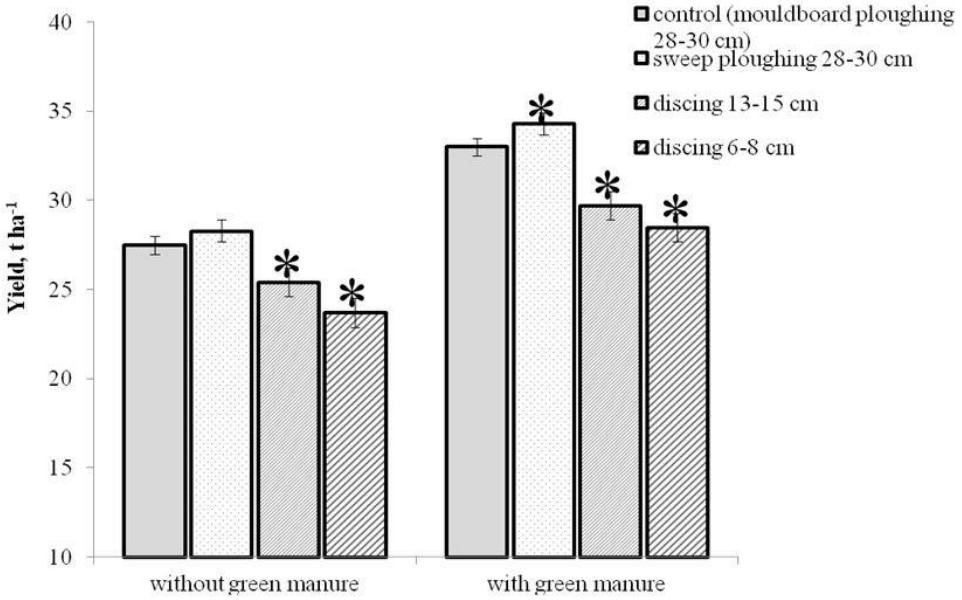

Figure 5. Influence of green manure incorporation and methods of tillage on potatoes yield, t ha-1 (average for 2006-2010). *-significant at $p<0.05$.

Reducing the depth of plougless tillage and the non-application of green manure significantly reduced the yield of potato tubers-by 1.8-5.1 tha^{-1}, and 3.9-6.2 t ha^{-1}, respectively.

Discussion

A highly allelopathic effect of oilseed radish crop and mulch was found in numerous studies (Lawley et al., 2011; Pupalienė et al. 2015; Kołodziejczyk, 2015). Scientific publications by numerous scientists (Chauhan and Mahajan, 2014; Kyryliuk, 2013; Cordeau et al., 2017; Melander et al., 2017) substantiate the application of ploughing as an effective element of crop cultivation technology, which evenly distributes weeds seeds in the soil layers. Long-term ploughless tillage concentrated more weed seeds closer to the soil surface. In particular, the shallow tillage by dick implements results in the accumulation of weed seeds mainly in the 0-5 cm soil layer, and the deep loosening by sweeps contributes to its partial inclusion in deeper layers (Titenko, 2010).

Using solely ploughing techniques, the amount of weeds was insignificant and it led to germination later than using ploughless tillage. However, this is only helpful in the first stage of the tillage system, because it significantly limits the effectiveness of agrotechnical direct weed control. Timely removing of weeds by plougghless methods make conditions for more intensive reducing of potential weed infestations, which subsequently affects the actual weed infestation in cultivated crops (Shikula et al., 2000; Van Der Weide et al., 2008; Scherner et al., 2016).

It was found that infestations increased in the middle of the growing period after appearing of next generation of sprouts. The same results were obtained by other scientists (Armengot et al., 2016; Dvořák et al., 2016). This is due to the low competition between potato crops and weeds in the first half of the growing season.Optimal moisture and heat conditions favor the emergence and development of weeds in the forest-steppe zone of Ukraine.

The obtained data indicated decrease in the number and weight of spring weeds when using green manure.This change in the growth of weeds can be explained, as green manure made from oilseed radish is part of the Brassicaceae family, and contains compounds of glucosinolates that are hydrolyzed to make toxins that effect annual and biennial weeds (Haramoto and Gallandt, 2004; Jabran, et al. 2015).

Significantly higher yields of potatoes using deep ploughless methods, after incorporation of green manure made from oilseed radish, is due to the formation of the most optimal soil agrophysical properties, compared with ploughing, which is confirmed by studies from a number of authors (Shikula et al., 2000; Huwe, 2002; Sorokina, 2016); and recorded in our previous publications (Mischenko, 2012; Mischenko, 2015).

Conclusions

Based on the of herbological monitoring of potato crops, the most effective method of weed control is using green manure made from oilseed radish incorporation in addition to sweep ploughing at a depth of 28-30 cm. Using these methods, potential weed infestation in the soil layer 0-30 cm deep has been reduced overall, and the smallest amount of weed seeds was observed in the soil layer 0-10 cm deep, compared with other ploughless treatments. Quantitatively-weighed weed infestation under sweep ploughing was similar to the mouldboard ploughing method. The highest potato tuber yield 30.3 t ha^{-1} was obtained under the incorporation of oilseed radish green manure and using of sweep ploughing at 28-30 cm deep.

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