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The influence of basic soil tillage methods and weather conditions on the yield of spring barley in forest-steppe conditions

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Abstract. The research on the effect the main methods of soil treatment have on its hydrophysical properties was carried out as a stationary experiment at the National Scientific Centre, Institute of Agriculture NAAS. It included a grain crop rotation with the subsequent crop sequencing: winter wheat/grain maize/barley. In 2013–2015, the spring barley variety 'Solntsedar' was sown. Throughout the three years of research, the consistency of the effect of the main soil treatment methods on the overall yield stayed more or less the same. Reduction in barley grain yield against the backdrop of long-term disking at the depth of 10–12 cm is explained by the thickening of the 10–30 cm layer of soil to the critical level of 1.57 g cm^{-3}, moisture deficiency, as a result of the over-compaction of the root layer, and an increase in the amount of sterile spikelets. As the result of our research, we have come to a conclusion that for barley, soil disking at the depth of 10–12 cm is as good as ploughing if it is used as a part of differential treatment system, which includes ploughing at the depth of 28–30 cm or chisel tilling at 43–45 cm for its preceding crops. If disking was used for all crops of the grain crop rotation, a deterioration of hydrophysical properties was observed in the barley field, which can lead to a considerable reduction in the barley yield, especially in a dry cultivation year.

Key words: soil treatment, yield, barley, weather conditions, moisture accumulation, crop rotation, water consumption coefficient, vegetation period.

INTRODUCTION

Spring barley as a fodder-grain crop has the highest yield among first class grain crops. Cultivated areas of the forest steppes of Ukraine cover 15% of the crop rotation structure. In Ukraine, the average barley yield is 3.0–3.5 t ha^{-1}, while in good weather conditions and provided that high quality agricultural machines are used, it can reach 6.5–8.0 t ha^{-1} (Gorash, 2007; Gorash, 2012).

The analysis of weather conditions of the last decade, in particular of the years 2013–2015, indicates that spring grain crops, especially ones with a short vegetation period, are extremely sensitive to drought and high temperatures during the vegetation period.

Hydrothermal conditions, soil moisture in particular, are some of the main factors for yield formation, while the efficient use of available resources provides the minimum loss per yield unit. Water consumption during the vegetation period depends on weather conditions, biological peculiarities of the plant and their growth technology (Ehrenbergerová et al., 1999; Gorash, 2007; Lihochvor et al., 2010; Gorash, 2012).

Barley is a drought-tolerant crop, characterised by a highly efficient use of moisture needed to make a yield unit. Seeds require 45–50% of water of their dry mass to sprout (Kaminsky & Peter, 2003; Gorash, 2007; Lihochvor et al., 2010; Gorash, 2012). In spite of being highly moisture-efficient, the plants can still experience a deficit of water, especially at the start of the vegetation period. The reason for that is the insufficient development of root system. The critical period, in terms of water consumption, growth stages 4–6 of organogenesis (Ehrenbergerová et al., 1999; Lihochvor et al., 2010).

The total water consumption and evaporation characterizes the security of plants during separate development periods and their vegetation period as a whole. The evaporation process takes place under the influence of weather conditions: the income and loss of water in the 'soil-plant' system, the temperature of the topmost layer of soil, air and wind speed (Malienko, 2013).

Taking all of the abovementioned facts into account, the process of water accumulation in autumn and winter and the formation of a positive hydrophysical soil environment are the key measures for the formation of a high spring barley yield. This is why the search for a means of water preservation is an urgent scientific and production objective.

Purpose of the Research. To determine the influence of the basic soil tillage methods and weather conditions during summer barley vegetation period on its yield in the forest-steppe. To assess the provision of hydrophysical properties within the environment of the ploughing soil layer and its dynamics during plant vegetation.

MATERIALS AND METHODS

The experiment was started in 1969 on wet coarse silty slightly loamy forest soil with a low humus content – 1.08 or 1.29%, and a content of phosphorus: 7.1–7.9, and potassium: 7.0–8.3 mg (100 g)$^{-1}$ soil. The soil solution reaction is slightly acidic, pH_{KCl}: 5.1–5.2.

At the time of our research in the topsoil (0–45 cm) were gotten following results: humus content – 1.28–1.32%, phosphorus – 15.3–19.2 mg (100 g)$^{-1}$ and potassium – 14.9–17.7 mg (100 g)$^{-1}$. Method of Kirsanov is based on the extraction of mobile phosphorus and potassium compounds from the soil with a solution of hydrochloric acid (extraction solution), the molar concentration of 0.2 mole dm^{-1} and subsequent quantitative determination of mobile phosphorus compounds and potassium photoelectrocolorimeter – by flame photometer. The reaction of the soil was rNKCl – 5.7.

Coordinates to pilot area location: Kiev; Latitude 50°,35´; Longitude 30°,42´; Altitude 186 m. Tested soil groups by WRB classification WRB (World Reference Base): HE – 0–30 cm; I1 – 31–55 (60); I2–56 (61) – 85 (90); Ip – 91–125 (130); P – 126 (131).

The research has been carried out with grain crop rotation with the subsequent crop sequencing: winter wheat/grain maize/barley.

The barley fertilization system included the introduction of $N_{50}P_{40}K_{50}$ and the termination of all of the by-products of the preceding crop – 14.2 t ha^{-1} (maize stalks). Small potassium norm was used because during research potassium content in soil was already 14.9–17.7 mg (100 g)$^{-1}$.

The protection system has includes the use of the following herbicides and fungicides: against weeds – Agritox 500 water soluble granules: 1.5 l ha^{-1}, Nurelle-D emulsion concentrate: 1.0 l ha^{-1}, against diseases: Vitavax 200 FF 1.5 l ha^{-1}, and against pests – Bi-58 new emulsion concentrate: 1.0–1.2 l ha^{-1} (DSTU, 2004).

The scheme of long-term stationary experiment is represented by the main cultivation system of grey forest soil (Table 1).

Table 1. The scheme of the tested soil

The main soil treatment method system	Crop rotation crop		
	winter wheat	grain maize	spring barley
Ploughing at different depths (control)	Ploughing at the depth of 16–18 cm	Ploughing at the depth of 28–30 cm	Shallow ploughing at the depth of 10–12 cm
Flat-cut tilling at different depths	flat-cut tilling at the depth of 16–18 cm	flat-cut tilling at the depth of 28–30 cm	flat-cut tilling at the depth of 10–12 cm
Differential	disking at the depth of 10–12 cm	chisel ploughing at the depth of 43–45 cm	disking at the depth of 10–12 cm
Disking at one single depth	disking at the depth of 10–12 cm	disking at the depth of 10–12 cm	disking at the depth of 10–12 cm

Soil samples used in this analysis have been selected in accordance with standard DSTU 4287: 2004, and prepared in accordance with the requirements of DSTU ISO 11464-2007. The moisture content in the soil has been determined by thermogravimetric-gravimetric method using auger sampling in soil layer 0–100 cm, measurements were taken after every 10 cm in the three periods of time – in the phase of sprouting, flowering and at the time of full maturity of grain, with the transfer to general reserves of moisture soil accordance with standard DSTU ISO 11465-2001. Yielding capacity was determined via continuous threshing. The size of the area is 200 m^2, the used plot is 120 m^2, three replications, the placement of samples in the experiment is sequential.

RESULTS AND DISCUSSION

During the spring barley vegetation period in 2015, the precipitation rainfall norm was 30% of the average perennial rainfall norm, and its distribution in time was determined by using a histogram in the package Matlab application. The year was described as abnormal. It was made unique by the simultaneous display of three types of drought: soil, atmospheric, and hydrological drought. Weather conditions within this particular year and vegetation period had a negative effect on the growth and development of barley plants. The maximum precipitation deviation from the norm – by 48.6–63.2 mm – had fallen within the period of formation of the productive elements of the ear. On average, the moisture deficiency during the vegetation period had been 224 mm (Table 2).

During their active development period, the plants were suppressed; their growth was stumped as the days of vegetation with the long-term soil drought and air heat predominated

During 20–30 April and 1–20 June there was no precipitation, and the period without rain lasted for 30 days (Table 2).

Table 2. Hydrothermal conditions of spring barley vegetation period, 2013–2015

Year	Income of heat and moisture	Month				April-July**	Hydrothermal index
		April	May	June	July		
2013	actual*	10.5	18.7	21.5	20.3	2057	0.48
		18.5	26.6	49.6	4.0	98.7	
	deviations from	+1.8	+3.6	+3.3	+1.0	+9.7	-1.07
	the norm, ±	-30.5	-25.4	-23.4	-84	-163	
2014	actual*	10.5	18.7	21.5	20.3	1974	1.45
		28.8	167	50.2	41.2	287	
	deviations from	+1.6	+1.7	0.0	+2.7	+6.0	-0.1
	the norm, ±	-20.2	+115	-22.8	-46.8	+25.2	
2015	actual*	10.4	19.1	20.8	20.1	1958	0.51
		5.6	44.8	9.8	39.2	99.4	
	deviations from	+1.7	+4.0	+2.6	+0.8	+9.1	-1.04
	the norm, ±	-43.4	-7.2	-63.2	-48.8	-162	

*In the numerator—the average monthly air temperature, °C; in the denominator—the amount of precipitation per month, mm ** in the numerator—the sum of annual daily temperatures over 10°C within the vegetation period of the plants; in the denominator—the total amount of precipitation during the same period, mm.

Throughout the years of research the precipitation fell unevenly in different seasons and months, which has had an impact on moisture accumulation in autumn and winter, as well as on the deposits of moisture in soil during the plant vegetation period. The years 2013 and 2015 were critically dry. The amount of precipitation during vegetation was 98.7 and 99.4 mm respectively, hydrothermal index was 0.48 and 0.51. 2014 was very advantageous in terms of crop formation, as 287 mm of precipitation fell and the hydrothermal index was 1.45.

In 2013–2015, the average daily air temperature increased during the whole vegetation period. In May and June, it exceeded the norm on average by +3.8 and +3.0 °C respectively. The maximum deviation from the norm was registered in May 2015, and its absolute value exceeded the average perennial norm by + 4 °C and was accompanied by the reduction in the amount of precipitation at the level of 27.0 mm in comparison to the average perennial norm.

According to the Ukraine National Science Center, Institute for Agriculture NAAS given research area corresponds to the norm of the hydrothermal index 1.55.

Elevated air temperatures and virtually no atmospheric precipitation in 2015 led to a shortened ear flowering period, premature drying and dying of lower leaves, which, in turn, affected the size of assimilation surface and the spring barley grain yield (Table 2, 4).

The research carried out by the Department of Soil Treatment and Weed Control of the 'Institute of Agriculture NAAN' on grey forest soils revealed that in optimal soil density of 1.30 g cm^{-3}, the deposits of moisture in the 0–20 cm layer make up 56 mm, at 0–30 cm – 84 mm, and with the moisture of stable withering – 13 mm (Gordienko, 1998; Yatchuk, 2008; Zvezdenyuk & Boris, 2015).

According to this data (Gordienko, 1998; Yatchuk, 2008; Zvezdenyuk & Boris, 2015; Eshchenko, 2011), the grey forest soil can contain about 70% of annual precipitation in the 0–100 cm layer, which translates into 452 mm for the research area.

Autumn-winter of 2012–2013 had the largest amount of precipitation, a total of 316 mm, which surpassed the average perennial amount by 48 mm (18%). However, during the same period in 2013–2014 and 2014–2015, the moisture deficiency was 82.0 mm (31%) and 112 mm (42%) respectively.

The autumn-winter moisture accumulation in the 0–100 cm soil layer during the years of research with the long-term ploughing at different depths was on average 20 mm (11%) higher in comparison to moisture deposits that accumulated with long-term disking at the depth of 10–12 cm. The moisture accumulation during the same period within the years of research has mostly been dependent on the main soil treatment system, and especially on the weather conditions of that year (Table 3).

Table 3. The influence of the main soil treatment system on the productive moisture accumulation at the start of the spring barley vegetation period, 2013–2015

The main soil treatment method system	Soil layer, cm	Moisture deposit, mm				Non-productive moisture loss during vegetation, mm
		crop maturing	barley sprouts	moisture accumulation		
		2013–2014	2014–2015	mm	%	
Ploughing at different depths	0–20	27	46	19	41	183
at 10–30 cm (control)	0–100	114	163	49	30	153
Flat-cut tilling at the depth	0–20	31	42	11	25	191
of 10–30 cm	0–100	121	161	40	25	162
Differential at	0–20	33	45	12	27	190
10–45 cm	0–100	123	160	37	23	165
Single-depth	0–20	35	42	7	17	195
disking at 10–12 cm	0–100	129	158	29	19	173
HCP $_{0.05}$	0–20	2.87	4.11	-	-	-
	0–100	3.02	6.13	-	-	-
	0–20	3.89	2.41	-	-	-
	0–100	8.13	5.24	-	-	-

Notes: *the amount of precipitation from the time of maize harvesting to the start of barley sprouting in 2013–2015 has on average been 202 mm, which make up the non-productive loss, namely the precipitation and accumulation in autumn-winter.

Our research has shown that the non-productive moisture loss during vegetation in 2013–2015 were the highest in long-term disking at the depth of 10–12 cm. In the latter case, the loss of moisture in the 0–20 cm layer in comparison to the control plot has been 12 mm (6%), and 20 mm (10%) in the 0–100 cm layer (Table 3).

The largest moisture deposits were in the control plot, and throughout the years they exceeded the amount of moisture deposits of long-term flat-cut and single-depth disking plots by 147 and 223 m^3 ha^{-1} respectively. Moisture deposits with differential treatment were on the same level as the control plot. During the barley sprouting period, the moisture deposits throughout the research years were sufficient for efficient development of the plants in the first half of vegetation (Table 4).

In particular, this trend in moisture depositing while using different main soil treatment methods remained constant throughout the years.

In 2015, long periods without rain lasted for 48 days, i.e. about 50% of the duration of the vegetation period of spring barley. In June and I–II decade of July - with the amount of precipitation of 10 mm moisture reserves decreased to a value close to the withering point.

The maximum air temperature in the ear flowering and grain filling period was 37–39 °C. In the soil at the depth of 0–5 and 10–15 cm it was 26–28 and 23–25 °C respectively, and 35–37 °C above the surface of the crop, which had a negative impact on barley plants.

An increase in the air and soil temperature to the critical level during barley vegetation is undesirable; especially critical is the period of the leaf-tube formation/grain filling development at the 8–10th stages of organogenesis (Lihochvor et al., 2010; Gorash, 2012). The optimum temperature for plant growth and development during vegetation is +18 °C. The maximum temperature that barley can withstand for the first 25–35 hours is + 38–40 °C. A temperature increase by 1 °C leads to a decrease in yield by 4.1–5.7% (Schelling, 2003; Váňová, 2006; Lihochvor et al., 2010).

In 2015, during barley earing, there was a sharp decrease in the moisture deposits in comparison to the deposits formed in 2014. Such a sharp decrease in the amount of moisture available for the plants can firstly be explained by its intensive use and the critical stage for yield formation, and secondly by a small amount of precipitation in April and May (Table 2).

The 2015 moisture deposits in the 0–100 cm soil layer during harvest in barley field, which amounted to 450 m^3 ha^{-1}, were the lowest ever, lower than moisture deposits during harvest in 2013 and 2014 by 421 m^3 ha^{-1} and 924 m^3 ha^{-1}respectively.

In the water year 2014, the pattern of moisture distribution, both in terms of time and soil profile, was different from 2013 and 2015. On average, the amount of precipitation during vegetation exceeded its average perennial norm by 25 mm, with the hydrothermal index of 1.45, which is 0.10 lower than the norm (Table 2).

Weather conditions in 2013 and 2015 were not typical for the right-bank forest steppe, the hydrothermal index was lower than the average norm by 1.07 and 1.04 respectively, and in the main spring barley yield decreased in comparison to 2014 by 2.75 t ha^{-1} on the average (Table 4).

During the spring-summer vegetation, the amount of productive moisture in the soil decreased considerably, its lowest values were during the stage of complete ripeness of the grain (Table 4).

Table 4. The consumption of productive moisture in 0–100 cm soil layer, depending on the main soil treatment method, 2014–2015, m^3

The main soil treatment system at the depth, cm	Moisture deposits for the time period		Moisture consumption	*Water consumption	Yield		WCC*	
	Sprouts	Harvesting			$t\ ha^{-1}$	**± to control plot	$m^3\ t^{-1}$	***± to control plot
2013								
Ploughing at different depths, 10–30 (control)	1,620	902	718	1,707	2.44	-	700	-
Different depths, flat-cut 10–30	1,330	915	415	1,404	2.02	-0.42 -17	695	-4.6 -1
Differential, 10–45	1,589	904	685	1,674	3.07	0.63 26	545	-155 -22
Single-depth disking, 10–12	1,171	762	409	1,398	1.99	-0.45 -18	702	2.6 0.4
$HCP_{0,05}$	4.79	5.01	-	-	0.12	-	-	-
2014								
Ploughing at different depths, 10–30 (control)	1,706	1,320	386	3,636	5.28	-	688	-
Different depths, flat-cut 10–30	1,516	1,357	159	3,409	5.32	0.03 1	641	-47 -7
Differential, 10–45	1,630	1,343	288	3,409	5.59	0.31 6	610	-78 -11
Single-depth disking, 10–12	1,499	1,477	22	3,538	4.82	-0.46 -9	734	46 7
$HCP_{0,05}$	6.13	6.70	-	-	0.26	-	-	-
2015								
Ploughing at different depths, 10–30 (control)	1,582	476	1,106	2,049	3.05	-	672	-
Different depths, flat-cut 10–30	1,621	443	1,178	2,121	2.47	-0.58 -19	858	186 28
Differential, 10–45	1,567	450	1,116	2,059	2.88	-0.17 -5	715	43 6
Single-depth disking, 10–12	1,571	431	1,139	2,082	2.40	-0.65 -21	869	197 29
$HCP_{0,05}$	5.24	2.17	-	-	2.40	-	-	-

Notes: *WCC: water consumption coefficient, $m^3\ t^{-1}$; *amount of precipitation during vegetation 2013: 989 m^3; 2014: 3,250 m^3, 2015: 940 m^3. ** in the numerator, ± compared to control plot, $t\ ha^{-1}$; in the denominator ± compared to control plot, %; *** in the numerator ± compared to control plot, $m^3\ t^{-1}$; in the denominator ± compared to control plot, %.

Our research has revealed that in 2013, the main spring barley yield was between 1.99–3.07 $t\ ha^{-1}$. With the differential soil treatment, where chisel ploughing was done at the depth of 43–45 cm during the preceding crop, and disking was done at the depth of 10–12 cm immediately before sowing barley, the grain yield was 26% (0.63 t) higher than on the control plot (Table 4). The barley yield with ploughing at different depths (control plot) at the 10–30 cm layer was 0.45 t ha^{-1}, or 18% higher than the results with single-depth disking (Table 4).

In the conditions of the 2014 vegetation period, with sufficient moisture both during sowing and plant vegetation, the barley seed yield was very high: 4.82–5.59 t ha^{-1} (Table 4).

In comparison to the previous year (2013), it was on average 2.87 t ha^{-1} (55%) higher against the backdrop of the main treatment method. The yield was 0.46 t ha^{-1} (9%) lower when long-term disking at the depth of 10–12 cm was used, compared to the control plot. In 2015, long-term single-depth disking produced the lowest yield, 0.65 t ha^{-1}, or 21% lower than the control plot (Table 4).

In our opinion, such a low yield in 2013 and 2015 was caused by the physical condition of the soil, and insufficient moisture provision to the plants—deficiency of available moisture, high temperatures of air and the layer of soil where most of the roots were located.

Weather conditions in 2013–2015 were contrasting in structure and distribution, which provided us with a possibility to fully assess their importance and impact on yield formation and achieving the genetic potential of spring barley. In autumn and winter of 2013–2014, the amount of precipitation (in the form of snow and rain) from the moment of harvesting the preceding crop (grain maize) to the start of spring barley vegetation, was 186 mm, while its amount in 2014–2015 was 16% lower. In 2013–2013 and 2014–2015 the amount of precipitation was lower than the average perennial norm by 82.0 (31%) and 112 (42%) mm respectively. During the years of research, moisture deficiency in autumn and winter has been approximately 97.0 mm (36%) (Table 2).

Vegetation periods of 2013 and 2015 were dry. They were characterized by precipitation deficiency and a heightened total sum of active air temperatures. Moisture deficiency was typical of the entire barley vegetation period, and in different months it was 43 mm or 89% (April), 63 mm or 45% (June), and 84.0 mm or 95% (July) of the monthly rate. This period coincided with the formation of barley yield (Table 2).

Vegetation period in 2014 was characterized as satisfactory. During the vegetation period, 287 mm of precipitation fell, and moisture deficiency during ear flowering (-22.8 mm) was unnoticeable due to May precipitation, since its amount was 115 mm higher than the norm (Table 2).

Throughout the three research years, the consistency of the effect of the main soil treatment methods on the yield of the main crops remained more or less the same.

Decrease in the spring barley grain yield against the backdrop of long-term disking at the 10–12 cm depth is explained by the thickening of the 10–30 cm soil layer to the critical level of 1.57 g cm^{-3}, water deficiency, as a consequence of over-compaction of the root layer, and an increase in the number of sterile spikelets.

CONCLUSIONS

1. The largest moisture accumulation in soil necessary for spring barley plant development takes place in autumn and winter using the differential soil treatment method, which in the case of grain crop rotation includes ploughing at 22–24 cm for soy, disking at 10–12 cm for wheat and barley, and chisel ploughing at 43–45 cm for maize.

Decline in the moisture schedule of grey forest soil using small-scale and non-inversing tilling is explained by an increased density in the lower part of the cultivated layer.

2. Summer precipitation, in particular in 2013 and 2015, was insufficient for achieving the full potential of the plants, while their duration and amount mostly did not live up to the requirements. The main amount of moisture, which was concentrated in the 0–20 cm layer, was expected to intensively evaporate.

3. Non-productive moisture loss in the 0–20 cm layer throughout years has been the highest when using flat-cutting at different depths and single-depth disking – 191 and 195 mm, or 95% and 96% of the moisture deposits that had accumulated in autumn and winter.

4. Disking at 10–12 cm for barley is as good as ploughing if it is used in the differential soil treatment system, which includes ploughing at 28–30 cm and chisel tilling at 43–45 cm for preceding crops. If disking was used for all crops of the grain crop rotation, a deterioration of hydrophysical properties was observed in the barley field, which lead to a considerable reduction in the barley yield, especially in a dry cultivation year.

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