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Original Article

Soil Tillage in the Context of Sustainable Intensification of Agriculture and Global Warming

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Abstract

The long-term, poly-factorial, field experiment on Typical chernozemon the Balti steppe (Republic of Moldova) demonstrates the benefits of crop rotation that includes a perennial legume-grass mixture: higher crop yields; better accumulation of soil organic matter and nitrates, and uptake of soil phosphate; and more efficient use of soil water, especially on unploughed plots. The agronomic effect of soil tillage is determined by the interaction with crop sequence and fertilization in the crop rotation. The capacity of the soil to accumulate soil water and consumption of soil water are higher in crop rotation with perennial legumes and grasses, especially under the plough. Crop rotation with the mixture of perennial legume and grasses under ploughless tillage increases the accumulation of soil organic matter relative to other variants. By using a crop rotation with a mixture of perennial legume and grasses, farmers have real possibilities to decrease the dependence on industrial inputs.

Keywords: soil tillage, crop rotation, soil fertilization, soil fertility, field crops.

1. Introduction

Discussions about methods of soil tillage are the most contradictory in the scientific literature - and amongst farmers. No-till is especially contentious [3, 4, 5, 8]. There are very different opinions about its effects on yields, soil fertility and, especially, on the stocks of soil organic matter [5, 7]. This divergence of results and opinions on the effect of different tillage practices comes about because of the different soil and weather conditions in different geographical regions, and the lack of any systematic approach in the evaluation of farming systems - soil tillage included. Tillage cannot be evaluated separately from the other components of the farming system.

Our previous research suggests that, compared with the contributions of crop sequences in the crop rotation and fertilization, different tillage practices make insignificant contributions to yield formation for winter wheat, sugar beet and maize-for-grain [6]. Sustainable intensification of agriculture is unimaginable without Conservation Agriculture (CA) that comprises minimal or no-till, a diversity of crops in rotation, cover crops, and maintenance of ground cover by a mulch of crop residues [1, 2]. Integration of animals in the farming system is, also, beneficial for restoration of soil fertility. This article summarises data generated by a long-term field experiment evaluating the action and interaction between crop rotation, including crop rotation with the mixture of perennial legumes and grasses; different systems of soil tillage and different systems of fertilization; all without using chemicals for pest, disease and weed control.

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2. Material and Method

The long-term field experiment was established in 1995 at the Selectia Research Institute for Field Crops on the Balti steppe in the north of Moldova. The soil is Typical Chernozem: heavy clay with 4.5-5.0% humus; pH water 7.3, pH $CaCl_2$ 6.2; and total NPK of 0.20-0.25, 0.09-0.11 and 1.22-1.28%, respectively. The experiment includes two seven-field crop rotations, one with and the other without a mixture of perennial legume and grasses. There are two systems of soil tillage: ploughless tillage where the topsoil is not inverted; and alternation of ploughless tillage with the mouldboard plough which inverts the topsoil. The systems of fertilization are: 1) a control without fertilizer; 2) composted farmyard manure; 3) composted farmyard manure + mineral NPK fertilizer. The same amount of manure (10 t/ha) is used in both crop rotations but the amount of mineral fertilizers is different (N12.8P21.8K24.2 kg/ha in the rotation that includes perennial legumes and grasses, N38.6P24.2K24.2 kg/ha in the other).No chemicals are used for control of pests, diseases and weeds.

Each plot is 264m2 with three replicates, a total experimental area of 8.7 ha. Simultaneously, trials are conducted with continuous wheat, barley, sugar beet, maize-for-grain and sunflower under the two systems of tillage and three systems of fertilization, but without replication. This article includes experimental data for the last four years (2011-2014) during which the mean annual precipitation for this period at the meteorological station of Selectia RIFC was 489mm (44mm greater than the long-term mean) with the highest (705 mm) in 2013 and the lowest (348mm) in 2012; over this period, the mean annual air temperature was10.4°C (1.2°C above the norm).

3. Results and Discussions

Water regime

Water is a limiting factor in yield formation on the steppe. Water-use efficiency for winter wheat and sugar beet, on average for 3 years, is represented in Tables 1-2. Under winter wheat sown after lucerne on the 3rd year after first cut, the stocks of soil water in spring are somewhat higher under combined ploughed/ploughless tillage compared with ploughless tillage. This applies to both the 0-100cm and 0-200cm soil layers and for both systems of soil fertilization (Table1). Under the combination of mouldboard and ploughless tillage, andunder both systems of soil fertilization, stocks of soil water in spring amounted to158-159 mmin the 0-100 cm soil layer and 319-331mm in the 0-200 cm layer. Under ploughless tillage in the same crop rotation, soil waterstocks in spring were 110-112 mm in the 0-100cm layer and 237-239 mm in the 0-200 cm layer. The trend towards greater spring accumulation of soil water in ploughed plots was also observed in the crop rotation without the mixture of perennial legume and grasses, excepting unfertilized, unploughed plots. After harvest, the difference in the stocks of soil moisture is less pronounced so the consumptive use of water during the growing period is higher on plots with the combined mouldboard plough/ploughless tillage than on plots with only ploughless tillage. The same applies to the crop rotation without the mixture of perennial legume and grasses. Change to less-intensive tillage requires conditions for the exploitation of water in deeper soil layers; and perennial crops are the most effective in this respect. Soil water is used more efficiently under ploughless tillage than under the combined ploughed/ploughless system, especially in the crop rotation with the mixture of perennial legume and grasses.

Consumption of water on unfertilized, unploughed plots in the rotation with the perennial legume and grasses was 292.3tonnes per tonne of grain, compared with 437.3tonnes/tonne grain under combined ploughed/ploughless tillage; fertilization also contributed to more-efficient water use of 229.3 and 360.7tonnes/tonne grain, respectively. The least efficient use of water was observed in winter wheat sown after maize silage on plots under the combined ploughed/ploughless system of tillage, especially on unfertilized plots. Under combined ploughed/ploughless tillage, there is a tendency for crops to take more water from the upper (0-100cm) soil layer, especially in crop rotation with the mixture of perennial legume and grasses. The corollary is that winter wheat, especially in rotation with a mixture of perennial legume and grasses, can use more water from deeper soil layers under ploughless tillage. This is crucial in drought conditions. Forsugar beet (Table 2), soil water stocks in spring are much the same under both systems of soil tillage in crop rotation with the mixture of perennial legume and grasses; and, also, under the rotation without the mixture of perennial legume and grasses, with the exception of unfertilized unploughed plot. At harvest, under the crop rotation with the mixture of perennial legume and grasses, soil water stocks are higher under ploughless tillage compared with the combination of ploughing and ploughless tillage, in both soil layers, and for unfertilized and fertilized plots. This indicates a significantly greater consumption of soil wateron plots with the combination of ploughing and ploughless tillage.

At harvest, under the rotation without the perennial legume and grasses, the stocks of soil water on unploughed plots were lower than under the other crop rotation, especially for the soil layer 0-100 cm, and for both systems of fertilization. Consequently, consumption of soil moisture was greater on plots with ploughless tillage. Soil water was used most efficiently in the crop rotation with the mixture of perennial legume and grasses, regardless of tillage and fertilization.

Furthermore, under the crop rotation with the mixture of perennial legume and grasses, more water is extracted from the deeper soil layers. On unfertilized plots, consumptive use of soil water per tonne of sugar beet roots, averaged over 3 years, was 73.8 tonnes under alternating ploughed and ploughless tillage; and 69.0 tonnes under solely ploughless tillage. On fertilized plots, the water consumption was 66.7 and 55.1 tonnes, respectively; we observe that fertilization made a greater contribution to efficient soil water use in the crop rotation without mixture of perennial legume and grasses.

Table 1. Consumptive use of water by winter wheat in the Selectialong-term poly-factorial field experiment, 2011-2013

System of soil tillage	Fertiliza-tion	Soil layer, cm	Soil water stocks, mm			Share of water from soil layer 0-100 cm, %	Precipitation mm	Total water consumption mm	Yield t/ha	Soil water consumption (tonne) per tonne grain production	Total water consumption (tonne)per tonne of grain	Share of water from precipitation in total water consumption %
			Spring	Harvest	Soil water consumption mm							
Crop rotation with mixture of perennial legume and grasses												
Mouldboard plough + ploughless tillage	without fertilizer	0-100	158.7	61.3	97.4	48.0	261.5	464.4	4.64	437.3	1000.9	56.3
		0-200	331.1	128.2	202.9							
	Manure +NPK	0-100	157.7	64.3	93.4	53.3	261.5	436.8	4.86	360.7	898.8	59.9
		0-200	319.1	143.8	175.3							
Ploughless tillage	without fertilizer	0-100	111.7	54.0	57.7	44.9	261.5	390.1	4.40	292.3	886.6	67.0
		0-200	238.7	110.1	128.6							
	Manure +NPK	0-100	109.6	75.5	34.1	31.7	261.5	369.2	4.78	229.3	772.4	70.8
		0-200	236.5	128.9	107.7							
Crop rotation without mixture of perennial legume and grasses												
Mouldboard plough + ploughless tillage	without fertilizer	0-100	152.9	59.3	93.6	53.9	261.5	435.1	2.67	650.2	1629.6	60.1
		0-200	316.9	143.3	173.6							
	Manure +NPK	0-100	150.7	56.9	93.8	51.1	261.5	444.9	4.57	401.3	973.5	58.8
		0-200	309.8	126.4	183.4							
Ploughless tillage	without fertilizer	0-100	127.7	61.8	65.9	52.3	261.5	387.5	2.69	468.4	1440.5	67.5
		0-200	289.5	163.5	126.0							
	Manure +NPK	0-100	116.5	45.8	70.7	48.4	261.5	407.6	4.65	314.2	876.6	64.1
		0-200	237.4	91.3	146.1							

Table 2. Consumptive use of water by sugar beet in the Selectia long-term field poly-factorial experiment, 2011-2013

System of soil tillage	Fertiliza-tion	Soil layer, cm	Soil water stocks, mm			Share of water from soil layer 0-100 cm, %	Precipitation mm	Total water consumption mm	Yield t/ha	Soil water consumption (tonne) per tonne of grain production	Total water consumption (tonne)per tonne of beet	Share of water from precipitation in total water consumption %
			Spring	Harvest	Soil water consumption mm							
Crop rotation with mixture of perennial legume and grasses												
Mouldboard plough + ploughless	without fertilizer	0-100	121.3	24.6	96.7	47.5	272.1	475.8	27.6	73.8	172.4	57.2
		0-200	256.4	52.7	203.7							
	Manure +NPK	0-100	137.5	32.2	105.3	54.6	272.1	465.0	28.9	66.7	160.9	58.5
		0-200	274.7	81.8	192.9							
Ploughless	without fertilizer	0-100	137.4	58.0	79.4	50.0	272.1	430.9	23.0	69.0	187.3	63.1
		0-200	272.2	113.4	158.8							
	Manure +NPK	0-100	128.8	63.9	64.9	42.5	272.1	424.7	27.7	55.1	153.3	64.1
		0-200	259.1	106.5	152.6							
Crop rotation without mixture of perennial legume and grasses												
Mouldboard plough + ploughless	without fertilizer	0-100	127.3	14.4	112.9	55.3	272.1	476.4	19.5	104.8	244.3	57.1
		0-200	264.2	59.9	204.3							
	Manure +NPK	0-100	143.5	28.3	115.2	59.2	272.1	466.8	29.2	66.7	159.9	58.3
		0-200	268.6	73.9	194.7							
Ploughless	without fertilizer	0-100	148.2	48.0	100.2	56.7	272.1	448.7	16.3	108.3	275.3	60.6
		0-200	310.2	133.6	176.6							
	Manure +NPK	0-100	135.6	36.8	98.8	55.4	272.1	450.5	25.9	68.9	173.9	60.4
		0-200	279.8	101.4	178.4							

Nutrient regime

Under winter wheat incrop rotation with a mixture of perennial legume and grasses, the content of nitrates in the soil was significantly higher than in the other crop rotation–throughout the growing season and in both the 0-20cm and 20-40 cm soil layers (Table 3). Fertilization increased the nitrate content more in the crop rotation without the perennial legume-grass mixture than in the rotation with the perennial legume and grasses. Ploughless tillage appears to stimulate a differentiation of nitrate content between the different soil layers, especially in the crop rotation without the perennial legume, and more especially on unfertilized plots. For example in spring, the nitrate content in unfertilized, unploughed plots under the rotation with the mixture of perennial legume and grasses, was 52.0 and 50.9 mg/kg soil for the 0-20 and 20-40 cm soil layers, respectively: but on the same variant in the crop rotation without mixture of perennial legume and grasses, nitrate content was 34.0 and 17.8 mg/kg, respectively.

Table 3. Nitrates under winter wheat in the long-term field poly-factorial experiment (mg/kg soil) average for 2010-2014

Period of time	Soil layer, cm	Crop rotation with mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses			
		Mouldboard plough		Ploughless		Mouldboard plough		Ploughless	
		without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK
New growth in spring	0-20	47.7	82.4	52.0	115.7	30.1	58.6	34.0	58.2
	20-40	63.2	86.5	50.9	78.4	13.0	55.3	17.8	46.6
	0-40	55.4	84.4	51.4	97.0	21.5	56.9	25.9	52.4
Harvest	0-20	67.4	83.5	70.5	85.9	23.9	66.2	22.6	80.6
	20-40	66.4	74.1	55.4	72.0	14.3	47.5	21.2	56.2
	0-40	66.9	78.8	62.9	78.9	19.1	56.8	21.9	68.4

Under sugar beet, the content of nitrates is, again, higher in crop rotation with the perennial legume mixture than without (Table 4). The content of nitrates in spring is higher for the 0-40cm layer on unploughed plots under both systems of fertilization compared with the ploughed plots - a consequence of a much-higher nitrate content in the 0-20 cm soil layer. At harvest, the difference is less pronounced.

We should mention that the main influence on the content of nitrate in the soil was biological nitrogen from lucerne crop residues – even though the amount of nitrogen applied as mineral fertilizers in the crop rotation without mixture of perennial legume and grasses was more than three times the amount applied to the crop rotation with the perennial legume.

Table 4. Content of nitrates under sugar beet (mg/kg soil) in the long-term poly-factorial field experiment, average for 2010-2014

Period	Soil layer cm	Crop rotation with mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses			
		Mouldboard plough		Ploughless		Mouldboard plough		Ploughless	
		without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilzer	manure +NPK
Spring growth	0-20	58.1	96.1	90.8	118.9	56.2	86.0	60.2	115.4
	20-40	61.1	89.4	69.9	106.9	41.2	82.6	47.6	81.7
	0-40	59.6	92.7	80.3	112.9	48.7	84.3	53.9	98.5
Harvest	0-20	61.0	74.5	56.4	83.2	63.5	85.7	54.1	91.9
	20-40	56.6	68.1	47.3	73.8	29.2	71.2	53.6	68.3
	0-40	58.8	71.3	51.8	78.5	46.3	78.4	53.8	80.1

Remarkably, under winter wheat, the content of mobile phosphorus for the 0-40 cm soil layer is higher throughout the growing season, and under both systems of fertilization, under the crop rotation without the mixture of perennial legume and grasses than under the rotation with the perennial legume/grass mixture especially on unploughed plots (Table 5). It appears that phosphorus is becoming less available in the soil under a crop rotation that includes perennial crops and we may suppose that it is being taken up by the crop. The open questions are: what forms of phosphorus (organic or mineral) and for how long a time?.

Table 5. Content of mobile P under winter wheat in the long-term poly-factorial field experiment (mg/kg soil), average for 2010-2014

Period	Soil layer cm	Crop rotation with mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses			
		Mouldboard plough		Ploughless		Mouldboard plough		Ploughless	
		without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK
Spring growth	0-20	103.1	130.4	102.1	144.0	89.0	137.6	110.0	166.8
	20-40	74.9	88.8	73.0	90.6	71.5	102.5	95.8	114.2
	0-40	89.0	109.8	87.5	117.3	80.2	120.0	102.9	140.5
Harvest	0-20	99.2	133.8	101.9	118.9	94.0	136.6	113.6	153.5
	20-40	80.1	90.3	85.6	111.8	78.5	105.5	95.3	112.4
	0-40	89.6	112.0	93.7	115.3	86.2	121.0	104.4	132.9

The tendency fora lower amount of mobile phosphorusunder the crop rotation with perennial crops also holds for the next crop in crop rotation – sugar beet at harvest (Table 6).

Table 6. Content of mobile P under sugar beet in the long-term poly-factorial field experiment (mg/kg soil), average for 2010-2014

Period	Soil layers cm	Crop rotation with the mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses			
		Mouldboard plough		Ploughless		Mouldboard plough		Ploughless	
		without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK
Spring growth	0-20	94.9	157.9	105.5	172.2	119.4	157.9	112.7	192.8
	20-40	63.5	104.7	83.8	113.1	75.1	99.4	86.2	91.9
	0-40	79.2	131.3	94.6	142.6	97.2	128.6	99.4	142.3
Harvest	0-20	102.1	145.1	96.1	145.7	98.5	151.6	126.3	200.0
	20-40	78.3	94.0	78.0	94.2	87.4	107.7	91.9	124.4
	0-40	90.2	119.5	87.0	119.9	92.9	129.6	109.1	162.2

Productivity of winter wheat and sugar beet. Over the four years, the productivity of winter wheat in crop rotation with the mixture of perennial legume and grasses was practically the same on unfertilized and fertilized plots, under both systems of tillage: 4.40-4.64 t/ha on unfertilized plots, 4.78-4.86 t/ha on fertilized plots (Table7). The difference is significantly higher for winter wheat sown after maize silage in the crop rotation without the mixture of perennial legume and grasses:2.67-2.69 t/ha on unfertilized plots and 4.57-4.65 t/ha on fertilized plots.

Table 7. Productivity of winter wheat (t/ha) in crop rotations with different systems of soil tillage and fertilization, average for 2010-2014

Years	Crop rotation with mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses				DL05, t/ha
	Mouldboard plough		Ploughless		Mouldboard plough		Ploughless		
	without fertil.	manure +NPK	without fertil.	manure +NPK	without fertil.	manure +NPK	without fertil.	manure +NPK	
2011	5.83	5.82	5.73	5.72	2.78	5.47	2.74	5.44	0.25
2012	2.99	3.02	2.69	3.01	2.10	2.68	2.09	3.04	0.24
2013	5.11	5.73	4.79	5.62	3.12	5.57	3.24	5.47	0.32
2014	4.76	4.90	5.09	5.21	1.95	4.85	1.77	5.63	0.37
Average for 4 years	4.67	4.87	4.58	4.91	2.49	4.64	2.46	4.90	
Average for 3 years	4.64	4.86	4.40	4.78	2.67	4.57	2.69	4.65	

It is evident that the yield from the rotation with perennial legume and grasses can be equaled in the rotation without the perennial legume/grass mixture by applying a three-times-higher rate of nitrogen from mineral fertilizers - and in crop rotation with the mixture of perennial leguminous crops without fertilization. Fertilization is only effective in crop rotation without the perennial legume/grass mixture. And systems of soil tillage didn't influence the yields for winter wheat in either crop rotation. The experimental data for winter wheat indicate real possibilities for cutting expenditures on soil tillage and fertilization in crop rotation with the mixture of perennial legume and grasses.

Productivity of sugar beet (Table 8) followed the same track as for winter wheat.

Table 8. Productivity of sugar beet (t/ha) in crop rotations with different systems of soil tillage and fertilization, average for 2010-2014

Years	Crop rotation with mixture of perennial legume and grasses				Crop rotation without mixture of perennial legume and grasses				DL05, t/ha
	Mouldboard plough		Ploughless		Mouldboard plough		Ploughless		
	without fertil.	manure +NPK	without fertil.	manure +NPK	without fertil.	manure +NPK	without fertil.	manure +NPK	
2011	27.8	28.5	14.8	28.2	14.3	28.2	11.3	18.8	2.31
2012	8.6	8.9	9.1	9.2	5.0	8.9	5.1	8.4	3.01
2013	46.3	49.4	45.2	45.7	39.1	50.6	32.6	50.5	1.92
2014	30.1	33.2	33.5	37.8	20.1	43.4	21.0	37.5	2.05
Average for 4 years	28.2	30.0	25.7	30.2	19.6	32.8	17.5	28.8	
Average for 3 years	27.6	28.9	23.0	27.7	19.5	29.2	16.3	25.9	

The poorest yields were from unfertilized plots in the crop rotation without the mixture of perennial legume and grasses: 19.5t/ha under alternating ploughing and ploughlesscultivation, and 16.3 t/ha under ploughless tillage; on fertilized plots in the same rotation, yields were 29.2 and 25.9 t/ha, respectively. By analogy with winter wheat, it is possible to cut production expenditures for sugar beet by reducing the rates of mineral fertilizers and by replacing ploughing with ploughless cultivation in the crop rotation with the mixture of perennial legume and grasses. Soil organic matter stocks (Table 9) summarises changes in soil organic matter over 15 years of the polyfactorial experiment (1999-2014). Under the crop rotation with the mixture of perennial legume and grasses, the stocks of soil organic matter for the 0-40cm soil layer have increased by 5.0t/ha on unfertilized, unploughed plots, and by11.2t/ha on fertilized unploughed plots. In plots under alternating ploughing and non-inversive soil tillage in the same crop rotation, change in soil organic matter ranged from (+2.2 to – 10.2 t/ha on unfertilized plots and from +1.3 to -6.9 t/ha on fertilized plots.

Under the crop rotation without the mixture of perennial legume and grasses with combined ploughing and ploughless tillage, the increase of soil organic matter was higher than on the plots in the crop rotation with the mixture of perennial legume and grasses.

On unploughed plots, stocks of soil organic matter for the 0-40 cm layer increased almost two times relative to the plot with alternation of ploughing and ploughless tillage, but has remained almost at the same level on fertilized plots. Comparing the difference in the stocks of soil organic matter between the two crop rotations, the rotation without the mixture of perennial legume and grasses does better under the alternation of ploughing and ploughless tillage, especially on fertilized plots. Under ploughless cultivation, there is a greater accumulation of soil organic matter under the crop rotation with the mixture of perennial legume and grasses, especially on fertilized plots.

Table 9. Stocks of soil organic matter (t/ha) under different crop rotations, systems of soil tillage and fertilization in the Selectia, long-term polyfactorialfield experiment, 1999- 2014

Soil layer, cm	Crop rotation with mixture of perennial legume and grasses (№1)				Crop rotation without mixture of perennial legume and grasses (№2)				Difference between variants in crop rotation №2 to crop rotation №1			
									Crop rotation №1		Crop rotation №2	
	Moldboard plough		Ploughless		Mouldboard plough		Ploughless		Mouldboard plough		Ploughless	
	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK	without fertilizer	manure +NPK
1999												
0-20	101.8	99.4	94.8	98.2	94.8	97.2	95.0	100.8				
20-40	95.2	102.4	93.9	95.9	96.7	100.4	97.5	97.8				
0-40	98.5	100.9	94.3	97.0	95.7	98.8	96.2	99.3				
2014												
0-20	98.2	108.2	99.6	107.8	96.0	107.0	97.7	109.7	-2.2	-1.2	-1.9	+1.9
20-40	101.4	107.4	99.1	108.7	99.8	111.0	103.2	107.1	-1.6	+3.6	+4.1	-1.6
0-40	99.8	107.8	99.3	108.2	97.9	109.0	100.4	108.4	-1.9	+1.2	+1.1	+0.2
Difference in time, ± t/ha												
0-20	-3.6	+8.8	+4.8	+9.6	+1.2	+9.8	+2.7	+8.9	-2.4	+1.0	-2.1	-0.7
20-40	+6.2	+5.0	+5.2	+12.8	+3.1	+10.6	+5.7	+9.3	-3.1	+5.6	+0.5	-3.5
0-40	+1.3	+6.9	+5.0	+11.2	+2.2	+10.2	+4.2	+9.1	+0.9	+3.3	-0.8	-2.1

4. Conclusions

The agronomic effect of soil tillage is determined by the interaction with crop sequence and fertilization in the crop rotation. The capacity of the soil to accumulate soil water and consumption of soil water are higher in crop rotation with perennial legumes and grasses, especially under the plough. Consumption of water per tonne of grain is least in the crop rotation with the mixture of perennial legume and grasses under ploughless tillage. The same tendency was found for sugar beet.

The share of soil water from the upper (0-100cm) soil layer in the total consumption of water is less in crop rotation with the mixture of perennial legume and grasses than in the rotation without the legume/grass mixture; the root system can use water from deeper in the soil in the crop rotation with the mixture of perennial legume and grasses. The nitrate content of the soil is higher in the crop rotation with the perennial legume/grass mixture.

The content of mobile phosphorus in the soil is higher in crop rotation without the perennial legume/grass mixture, for both winter wheat and sugar beet. This suggests that crops in the rotation with perennial legumes and grasses have a better ability to take up phosphorus.

The productivity of winter wheat and sugar beet is similar under different systems of tillage and fertilization in the crop rotation with the mixture of perennial legume and grasses. Productivity of winter wheat and sugar beet is influenced to a greater extent by fertilization in the crop rotation without the mixture of leguminous crops and grasses, but systems of soil tillage don't affect crop yields.

Crop rotation with the mixture of perennial legume and grasses under ploughless tillage increases the accumulation of soil organic matter relative to other variants.

By using a crop rotation with a mixture of perennial legume and grasses, farmers have real possibilities to decrease the dependence on industrial inputs.

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References

[1] Jules P., Z. P. Bharucha, 2014, Sustainable intensification in agricultural systems. Annals of Botany, Oxford University Press, 1-26.

[2] Tara G., C., Godfry, 2012, Sustainable intensification in agriculture. A report on a Workshop, Oxford University Press, 51.

[3] Soane B.D., B.C. Ball, J. Arvidsson, G. Basch, F. Moreno, J. Roger-Estrade, 2012, No-till in northern, western and south-western Europe: A review of problems and opportunities for crop production and the environment. Soil and Tillage Research, 118, 66-87.

[4] Gonzalez-Sanchez E.J., O. Veroz-Gonzalez, G.L. Blanco-Roldan, F. Marquez-Garcia, R. A. Carbonell-Bojollo, 2015, Renewed view of conservation agriculture and its evolution over the last decade in Spain. Soil and Tillage Research, 146, 204-212.

[5] Cameron M. Pittelkow, Xinqiang Liang, Bruce A. Linquist, Kees Jon van Groenigen, Juhwan Lee, Mark E. Lundy, Natasja van Gestel, Johan Sih, Rodney T. Venterea, Chris van Kessel, 2014, Productivity limits and potentials of the principles of conservation agriculture. Letter, Nature, Macmillan Publishers Limited, 4.

[6] Boincean B.P., 2013, Soil tillage for sustainable farming systems. ProEnvironment. Journal of Documentation, Research and Professional Training. The 7th International Symposium Soil Minimum Tillage Systems, Cluj-Napoca, 2-3 May, 2013, 194-198.

[7] Boincean B.P., 2011, Soil tillage – trends and perspectives. Chisinau, Akademos 3(22), 61-68.

[8] ***, 2014, Why do we need to standardize no-tillage research? Letter to the Editor. Soil and Tillage Research, 16-22.