Study on Erosion Control Efficiency of Advanced and Unconventional System for Minimum Tillage at Growing Wheat on Slope Lands

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Abstract: *The advanced system for minimum and unconventional tillage for growing wheat on slope lands was developed in ISSAPP "N. Poushkarov" - Sofia in order to protect agricultural lands from soil degradation processes water erosion and loss of organic matter. It combines minimum tillage and direct sowing, soil conservation operation vertical mulching with compost. This paper consider some results of studies demonstrating erosion control and soil protective efficiency of these advanced technologies and unconventional minimum tillage when growing wheat on arable slope lands with an incline 5º (8,7%) in Carbonate Chernozem.*

Keywords: *water erosion, erosion control, loss of organic matter, minimum tillage, direct sowing, vertical mulching, compost*

INTRODUCTION

Specific natural and economic conditions in our country are a prerequisite for the emergence and development of degradation processes as water erosion and loss of soil organic matter. As a result of soil water erosion in Bulgaria from farmlands are exported over 100 million tons of fertile soil, 3.4 million tons of humus, about 200,000 tons of nitrogen and lose tens of millions of tons of all other nutrients annually, significant deterioration of the soil agrochemical properties, reduction of fertility, yields of growing crops and the quality of the received output (Onchev, 2001).

Reduction of soil organic matter is another degradation process with great importance in the world and in Bulgaria, which is related mainly to the removal of topsoil due to water erosion, oxidation of organic carbon, high aeration at intensive cultivation and degradation of soil structure (Rousseva S., 2010). The negative effects arising from the reduction of organic matter in the soil are significant deterioration of water holding capacity, soil structure and soil fertility.

In the world and in Bulgaria, are made a systematic efforts to limit those two degradation processes, mainly using agricultural erosion control measures, methods and technologies because of their advantages such as easy process of implementation, rapid soil protection effect and relatively low cost. Such a specialized technology was developed and tested in ISSAPP " N. Pushkarov" which combines minimum tillage and direct sowing with unconventional soil protection method vertical mulching with compost for growing wheat on slopes.

The purpose of this work is based on some results of studies to establish erosion control and soil protection efficiency of this advanced system of unconventional minimum tillage for growing wheat on slopes in conditions of carbonate Chernozem.

MATERIALS AND METHODS

The study was conducted in the village Trastenik, Ruse region, during 2013-2015 year, on soil carbonate Chernozem, on the slope lands with an incline 5^0 (8.7%).

Variants of the experiment are:

e_0 - sowing wheat grown by conventional technology applied along the slope - control;

e_1 - sowing wheat grown by conventional technology applied across the slope;

e_2 - sowing wheat grown on soil protection technology using surface mulching with compost across the slope;

e_3 - sowing wheat, grown on soil protection technology for minimum tillage (including technological operations vertical mulching with compost, direct sowing and plant protection operations for weed control) applied across the slope.

Advanced soil protection technology and unconventional minimum tillage when growing wheat on slopes, includes the following erosion controlling technological operations:

- vertical mulching with compost.
- direct sowing of the crop;
- perform all technological operations (processes) across the slope.

The realization of vertical mulching with compost was performed with the reconstructed machine breaker-dead furrower ЩН 2-140 (Fig. 1 and 2), which consists a frame, cuttings and molehills making working bodies, as well as bunker for plant residues. Aggregated with tractors rated power from 120 to 150 kW (DT-75m, T-150K, Claas - Ares 696 RZ, John Deer, etc.). When handling these machine-tractor units across the slope, two cuttings working body soothers, formed at a depth of 0,40 m slots with width 0,15 - 0,18 m and distance between them 1,4 m. In the slots is poured from the hopper of the machine compost, which in this case is used as a mulch material.

Fig.1 Device for vertical mulching with bunker for mulch

Fig. 2 A breaker-dead furrower ЩН-2-140

Direct sowing provides high quality sowing of cereals without complementary pre-sowing tillage. This type of sowing keeps the soil structure, slows mineralization of humus, improves the permeability of under plow layer and reduces erosion.

For the realization of direct sowing in our case we used specialized cultivator drill SKS - 2 (Fig. 3) making both tillage of sowing area and sowing.

Fig. 3 General view of sowing aggregate "Belarus 952" cultivator and planter SKS - 2

In uncultivated field this machine is performing four technological operations: pre-sowing tillage, sowing, introduction of granular fertilizers and rolling the planted rows.

Subsequent weed control, pests and plant diseases are carried out exclusively by chemical methods using plant protection products.

For reporting of erosion control efficiency of applied soil conservation technology was used stationary method with sites for collecting eroded sediment and surface runoff. Besides the measurement of the volume water flow and the quantity of eroded sediment, were measured the concentrations of available forms of nitrogen - ammonium and nitrate in the eroded soil, nitrate in surface runoff, also available forms of phosphorus and potassium after ammonia-acetate method as in liquid and in solid runoff and organic carbon content by the method of Turin. Based on the concentration of macronutrients and organic carbon in the surface runoff and eroded soil are calculated losses occurred in erosive rains in the observed period, as the average annual loss of macronutrients and organic matter from the soil.

RESULTS AND DISCUSSION:

The obtained results from the studies show that the lowest are the amounts of surface runoff and eroded soil in variant e_3, which utilized advanced erosion technology for minimum tillage of slope lands, including vertical mulching with compost compared with variants with traditional technologies applied along the slope and across the slope (Table 1). At this variant, the average annual amount of surface runoff for the study period 2013-2015 was 135,268 m^3/ha, and the average annual amount of eroded soil is 683,8 kg/ha. Relatively high are those quantities at variant e_2 with conventional tillage and surface mulch and conventional tillage conducted across the slope (e_1), where the results are respectively - annual average surface runoff 223,462 m^3/ha and 262,026 m^3/ha, and the annual average amount of eroded soil - 1377,3 kg/ha and 2435,7 kg/ha. The lowest effective for erosion control is variant with application of conventional technology, along the slope, where the average amount of surface runoff for three years is 369,092 kg/ha, and the annual average amount of eroded soil is 4357,1 kg/ha.

Table 1 Total volume of surface water runoff and eroded soil 2013-2015y.

Date	**Rain l/m²**	**Surface runoff m³/ha**				**Eroded soil kg/ha**			
		Variant				**Variant**			
		e_0	**e_1**	**e_2**	**e_3**	**e_0**	**e_1**	**e_2**	**e_3**
14.04.13	17.5	112.071	75.306	63.434	39.231	1327.9	700.8	406.9	204.5
12.06.13	28.0	101.143	74.289	63.253	37.633	1151.2	626.9	366.9	182.7
13.06.13	12.0	89.143	64.082	53.494	31.953	948.1	592.9	301.1	149.0
Annual sum	57.5	302.357	213.674	180.181	108.817	3427.2	1920.6	1074.9	536.2
14.05.14	18.0	137.442	106.192	92.913	55.455	1658.1	971.6	552.6	267.1
31.05.14	54.0	115.814	76.603	64.702	38.485	1368.2	716.1	415.9	209.8
18.06.14	30.0	126.628	88.767	81.206	46.667	1572.9	869.1	504.2	249.3
Annual sum	102.0	379.884	271.562	238.821	140.607	4599.2	2556.8	1472.7	726.2
26.05.15	16,0	165,985	128,000	103,794	64,483	1983,2	1181,9	640,8	315,0
10.06.15	18,0	140,584	93,895	80,643	50,344	1663,9	884,0	510,9	258,3
02.07.15	14,5	118,467	78,947	66,945	41,552	1397,9	763,9	432,7	215,7
Annual sum	48,5	425,036	300,842	251,384	156,379	5045,0	2829,8	1584,4	789,0
Average for 2013-2015г	69,33	369,092	262,026	223,462	135,268	4357,1	2453,7	1377,3	683,8

ANOVA: Surface runoff, $p<0.0001$ HSD[0.05]=22.9; HSD[0.01]=28.49, e_0 vs e_1 $P<0.01$, e_0 vs e_2 $P<0.01$, e_0 vs e_3 $P<0.01$, e_1 vs e_2 NS, e_1 vs e_3 $P<.01$, e_2 vs e_3 $P<.01$, Eroded soil, $p< .0001$; HSD[0.05]=241.15; HSD[0.01]=300; e_0 vs e_1 $P<0.01$, e_0 vs e_2 $P<0.01$; e_0 vs M4 $P<0.01$; e_1 vs e_2 $P<0.01$; e_1 vs e_3 P0<0.01; $e_2$vs e_3 NS

Advanced technology for minimum and unconventional tillage, including technological operations vertical mulching with compost and direct sowing applied across the slope, will help to reduce surface runoff and soil losses when erosive rains occurs. In its use in the variant e_3 values of surface runoff were lower in the years from 2.5 to 3.0 times, while those of the eroded soil from 6.2 to 6.5 times compare to the control e $_0$, this effect is maintained over the entire period of production cycle. Under the variant e_2 with sowing wheat grown on erosion control technology applied across the slope, using the method surface mulching with compost, anti-erosion effect is much weaker. In this variant reduction of runoff is from 1.5 to 1.8 times, and of eroded soil from 3.0 to 3.3 times compare with the control.

Table 2 Soil chemical indicators inorganic nitrogen (mg/kg), available P_2O_5(mg/100g), available K_2O,(mg/100 g), electrical conductivity (µS/cm)

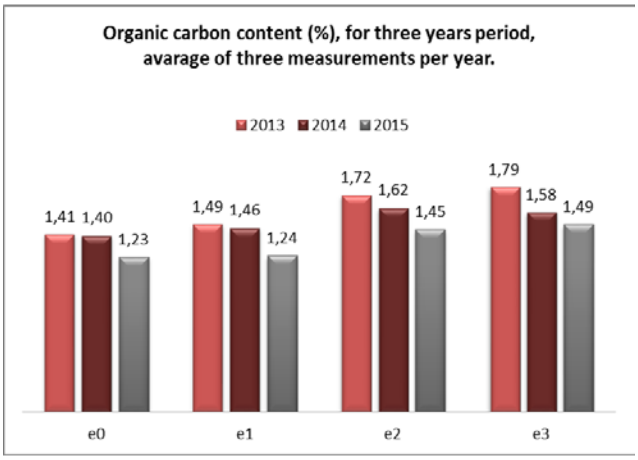
Year	Growing phases	Variants	Inorganic nitrogen, mg/kg	Available P_2O_5, mg/100 g	Available K_2O, mg/100 g	EC, µS/cm
2013	Sowing	e_0	37,71	10,31	17,84	247,50
		e_1	39,24	12,78	13,82	250,50
		e_2	44,07	15,11	22,82	403,00
		e_3	39,80	34,70	59,65	350,00
	Maximum growth stage	e_0	31,65	12,29	13,53	171,40
		e_1	35,54	12,52	16,69	247,00
		e_2	41,92	36,84	18,29	289,00
		e_3	37,03	30,11	24,05	340,00
	Harvesting	e_0	17,68	8,99	12,99	123,90
		e_1	20,96	13,64	14,22	135,45
		e_2	22,47	19,99	17,38	222,00
		e_3	23,53	20,91	17,38	311,00
2014	Sowing	e_0	29,89	10,27	40,27	204,00
		e_1	32,26	17,32	40,44	203,00
		e_2	48,60	52,55	51,31	270,00
		e_3	39,83	42,97	48,05	288,00
	Maximum growth stage	e_0	18,26	11,29	35,60	113,20
		e_1	36,08	12,14	35,56	114,00
		e_2	59,66	29,52	35,57	167,00
		e_3	53,47	22,60	38,23	171,50
	Harvesting	e_0	12,29	10,48	33,29	170,20
		e_1	15,80	14,46	34,68	174,00
		e_2	33,86	19,04	44,88	188,00
		e_3	34,05	21,84	54,88	220,00
2015 г.	Sowing	e_0	59,56	8,27	34,49	117,40
		e_1	58,23	8,56	37,29	167,80
		e_2	68,44	16,35	42,46	240,00
		e_3	85,42	14,24	49,97	284,00
	Maximum growth stage	e_0	63,29	8,99	34,87	140,40
		e_1	66,30	8,79	37,52	112,30
		e_2	85,87	10,80	45,76	126,50
		e_3	106,74	14,92	50,13	151,20
	Harvesting	e_0	15,35	8,85	29,76	117,90
		e_1	16,55	8,92	34,86	137,20
		e_2	17,84	10,32	35,92	155,10
		e_3	29,34	12,20	48,57	157,50
2013-2015 г.	Sowing	e_0	42,39	9,62	30.87	189,63
		e_1	43,24	16,89	30,52	207,10
		e_2	53,70	28,00	38,86	304,33
		e_3	51,68	30,64	52,55	307,33
	Maximum growth stage	e_0	31,07	10,86	28,00	141,67
		e_1	45,97	11,15	29,92	157,77
		e_2	62,48	25,72	33,21	194,17
		e_3	65,75	22,54	37,47	220,90
	Harvesting	e_0	15,11	9,44	25,35	137,33
		e_1	17,77	12,34	28,25	148,88
		e_2	24,72	16,45	32,73	188,37
		e_3	28,97	18,32	40,28	226,17

ANOVA: Inorganic nitrogen (mg/kg); NS;P_2O_5, (mg/100 g) ; P=0.001887;HSD[0.05]=11.26; HSD[0.01]=14; e_0 vs e_1 NS; e_0 vs e_2 $P<0.05$; e_0 vs e_3 $P<0.05$; e_1 vs e_2 $P<0.05$; e_1 vs e_2 $P<0.05$; e_2 vs e_3 NS;K_2O, (mg/100 g) ; P=0.047449, HSD[0.05]=15.57; HSD[0.01]=19.37, EC (µS/cm), e_0 vs e_3 , $P< 0.006058$

The data in Table 2 shows the average levels for the period of study of mineral nitrogen, phosphorus and potassium in the initial phase, that are for variant e_3 are respectively 51.68 mg/kg, 30.64 mg/100g, 52.55 mg/100g while in control variant 42.39 mg/kg, 9.62mg/100g, 30.87 mg/100g. In phase maximum growth stage average of these levels of elements, for the three years are 65.75mg/kg, 22.54 mg/100g, 37.47 mg/100g, in variant e_2 they are 62.48 mg/kg, 25.72 mg/100g, 33.21 mg/100g, while at e_0 – 31.07 mg/kg, 10.86 mg/100g, 28.00

mg/100g. In the final phase the differences between the variants are smaller, with the highest values of these indicators are reported in variant e_3 – 28.97 mg/kg, 18.32 mg/100g, 40.28 mg/100g and variant e_0 grown by traditional technology along the slope mobile forms of nitrogen, phosphorus and potassium respectively – 15.11mg/kg, 9.44 mg/100g, 25.35 mg/100g

The content of organic carbon, respectively humus is lowest in variants with conventional tillage applied along the slope (e_0) and highest at e_3 with the implementation of minimum tillage (Fig. 4) and vertical mulching with compost. Higher is organic carbon (humus) content in variant with surface application of compost.



ANOVA	SS	Degr. of Freedom	MS	F	p
variant	0,51851	4	0,12963	5,915	0,001173
Error	0,67939	31	0,02192		

Fig. 4 Total soil organic carbon content (%).

Table 3 shows the concentrations of macronutrients and organic carbon in eroded soil and surface runoff. The highest concentrations of available forms of nitrogen, phosphorus, potassium and organic carbon in sediment are observed in variant with applying conventional technologies across the slope and surface mulching with compost. High are these values and in variant with minimum tillage with vertical mulching, because the minimum tillage leads to enrichment with organic residues of topsoil, which is most susceptible to erosion.

Table 3 Average content of $N\text{-}NH_4$ (mg/kg), $N\text{-}NO_3$ (mg/kg), P_2O_5 (mg/100g), K_2O (mg/100g), C (%) in eroded soil, $N\text{-}NO_3$ (mg/l), P_2O_5 (mg/l), K_2O (mg/l), C (mg/l) in surface water runoff, 2013-2015y.

Year	Variant	Eroded soil						Surface water runoff			
		$N\text{-}NH_4$	$N\text{-}NO_3$	inorganic N	P_2O_5	K_2O	C, %	$N\text{-}NO_3$	P_2O_5	K_2O	C
2013	e_0	15,987	16,673	32,660	9,980	56,763	1,348	10,447	5,210	4,600	4,400
	e1	15,720	11,883	27,603	9,733	59,593	1,244	13,360	5,760	4,867	5,633
	e2	23,540	9,013	32,553	14,737	100,197	2,437	17,863	5,970	7,393	9,100
	e3	18,330	7,377	25,707	9,160	69,553	1,719	17,840	5,363	4,900	5,967
2014	e_0	58,587	37,553	96,14	13,557	57,493	1,361	22,847	3,447	10,500	12,133
	e1	55,630	39,590	95,22	14,970	54,490	1,475	18,763	3,520	9,367	9,433
	e2	95,327	78,613	173,94	18,840	73,087	2,057	28,045	4,103	9,433	13,100
	e3	84,167	47,980	132,147	18,850	50,857	1,678	19,927	2,543	9,467	4,453
2015	e_0	40,970	27,143	68,113	13,640	78,853	0,950	46,650	2,907	7,433	5,453
	e1	42,557	27,360	69,917	13,550	82,453	1,163	48,250	2,993	7,333	5,590
	e2	60,907	40,333	101,24	16,800	119,157	2,245	72,910	3,827	11,700	8,700
	e3	72,727	51,497	124,224	17,707	101,800	2,170	55,410	5,697	13,533	4,263

Table 4 Losses of available forms of N ($N\text{-}NO_3^-$ + $N\text{-}NH_4^+$), P_2O_5, K_2O, organic carbon in eroded soil and surface runoff (kg/ha) with erosive rains for 2013-2015 y.

Year	Variant	Eroded soil				Surface water runoff				Total losses			
		N	**P**	**K**	**C**	**N**	**P**	**K**	**C**	**N**	**P**	**K**	**C**
		kg/ha	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**	**kg/ha**
Sum for 2013 y.	**e0**	0,112	0,342	1,945	46,186	3,159	1,575	1,391	1,330	3,271	1,917	3,336	47,517
	e1	0,053	0,187	1,145	23,890	2,855	1,231	1,040	1,204	2,908	1,418	2,184	25,094
	e2	0,035	0,158	1,077	26,192	3,219	1,076	1,332	1,640	3,254	1,234	2,409	27,832
	e3	0,014	0,049	0,373	9,217	1,942	0,584	0,533	0,650	1,956	0,633	0,906	9,866
Sum for 2014 г.	**e0**	0,269	0,623	2,644	62,603	8,679	1,309	3,989	4,609	8,949	1,933	6,633	67,212
	e1	0,142	0,383	1,393	37,719	5,095	0,956	2,544	2,562	5,238	1,339	3,937	40,281
	e2	0,140	0,277	1,076	30,297	6,698	0,980	2,253	3,129	6,838	1,257	3,329	33,425
	e3	0,061	0,137	0,369	12,188	2,802	0,358	1,331	0,626	2,863	0,494	1,700	12,814
Sum for 2015 г.	**e0**	0,313	0,627	3,627	43,692	17,722	1,104	2,824	2,072	18,035	1,732	6,450	45,764
	e1	0,179	0,346	2,108	29,744	13,103	0,813	1,991	1,518	13,282	1,159	4,100	31,262
	e2	0,149	0,247	1,755	33,059	17,412	0,914	2,794	2,078	17,562	1,161	4,549	35,136
	e3	0,090	0,129	0,739	15,759	7,791	0,801	1,903	0,599	7,881	0,930	2,642	16,311
Average for 2013-2015 y.	**e0**	0,232	0,530	2,738	50,827	9,853	1,330	2,734	2,670	10,085	1,859	5,472	53,498
	e1	0,125	0,304	1,551	30,451	7,018	1,000	1,858	1,761	7,142	1,304	3,409	32,212
	e2	0,108	0,227	1,302	29,849	9,110	0,990	2,126	2,282	9,218	1,217	3,429	32,131
	e3	0,055	0,106	0,494	12,388	4,178	0,581	1,256	0,625	4,233	0,686	1,750	13,013

ANOVA: For total losses C, p=0.001320, HSD[0.05]=19.67; HSD[0.01]=26.89; for total losses P, p= 0.013197; HSD[0.05]=0.62; HSD[0.01]=0.85; for total losses K, p=0.043723; HSD[0.05]=3.33; HSD[0.01]=4.56

The losses of available forms of nitrogen, phosphorus, potassium and organic carbon in variant with minimum tillage and vertical mulching with compost are 2.38, 2.71, 3.11, 4.11 times lower than in variant e_0 with conventional tillage along the slope. In the variant with surface mulching (e_2) are observed lower losses of nutrients and organic matter compared to e_0. Losses of nitrogen are higher in e_2 in comparison with e_1, but the losses of other elements between e_1 and e_2 are nearly equal. Losses of inorganic nitrogen in e_2 are 1.09 times smaller compared to e_0, the available forms of phosphorus 1.53 times, potassium - 1.60 times, the total organic carbon - 1.66 times. In variant e_1 losses of available forms of nitrogen, phosphorus and potassium in comparison with the control are respectively -1,41, 1.43, 1.61 and 1.66 times lower.

CONCLUSION:

1. In application of advanced soil protection technology for growing wheat on slopes, with minimum tillage, vertical mulching with compost and direct sowing, surface runoff decreased from 2.5 to 3.0 times and eroded soil from 6.2 to 6.5 times, compared to variants with conventional tillage.

2. For the study period in variant with application of advanced technology for minimum and unconventional tillage, losses of mineral nitrogen, available forms of phosphorus and potassium, and organic carbon from the action of water erosion are 2.38, 2.71, 3.11, 4.11 times lower compared to the losses of those elements in growing wheat on slopes by conventional technology applied along the slope.

3. When applying soil protection technology with conventional tillage and surface mulching, losses of eroded soil are 3.0 to 3.3 times and the volume of surface runoff is 1.5 to 1.8 times lower in comparison with control tilled along the slope. The decrease of losses of mineral nitrogen, available forms of phosphorus and potassium, and organic carbon from the water erosion are respectively 1,09, 1,53, 1,60 and 1.66 times lower in comparison with conventional technology of growing wheat along the slope.

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