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Intensity of soil erosion on agricultural land under different of cropping systems and cultivation practices

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Abstract

Soil conservation practices and in particular soil tillage and crop cultivation patterns are becoming an important issue in agricultural production. Combating soil erosion and diminishing its negative impact on agricultural soil imposes as a matter of vital interest which gained even greater significance, in a pronounced negative impact of climate change. Main objective of the three-year research and monitoring program was to evaluate the effects of the easy-to-use adaptive measures on intensity of soil erosion, and soil properties considering to be of crucial importance on run-off velocity and sediment loss, like: soil structure stability, soil infiltration rate, soil organic matter and soil moisture conservation. The influence of soil tillage practices and different cropping systems on soil intensity and sediment loss, has been monitored on specially designed soil erosion fields with standard dimensions (20m length x 4m. width), on a sloppy terrain (12% slope). The experimental field is located on heavily textured Chromic cambisol on saprolite. This is the predominant soil type on the sloppy terrains in the country, usually under intensive agricultural activities Soil texture and physical characteristics were thoroughly investigated in order to determine the base soil conditions. The influence of downslope and contour ploughing on quantity of eroded sediment has been monitored in three consecutive years. The eroded sediment has been collected periodically on a weekly base and after intensive rainfalls. The intensity of soil erosion under most widespread cropping systems in the country, like: a) cereals as a monoculture, b) crop rotation, and c) perennial grass, was monitored as well. The collected sediment was examined in order to determine the quantity of soil organic matter and nutrient loss (nitrogen, phosphorus and potassium). Soil chemical properties are examined after each vegetative season in order to quantify the effect of tillage and cropping systems on soil properties. There are significant differences in the three years of investigations in terms to the quantity of eroded sediment within some of the variants, which is due to differences in the hydrological conditions, especially in 2014 and 2015. Also, there are substantial differences between variants (different systems of tillage and cultivation) as well. In the case of tillage systems these differences vary in a scale of 1: 6, 06 (in 2013) up to 1:13, and 33 (in 2015). Significant differences have been noticed between different cropping systems as well.

Keywords: sediment loss; tillage; adaptation measures; soil conservation; sol erosion

1. Introduction

Water and wind erosion are considered to be the dominant processes of soil degradation on agricultural land [21] affecting wide areas of high productive land. The problem of water erosion in the past decades was recognized as a global problem which cause the loss of the fertile topsoil, soil nutrients and water, pollutes surface waterways, constitutes and reduces agricultural and environmental productivity [1,19]. This type of land degradation is especially important for sub-arid and arid areas where intensive agricultural production is almost impossible without intensive irrigation [8.] High intensity rainfalls during the vegetation season becomes more frequent as a result of climate change, causing accelerated water erosion. The intensity of soil erosion is highly related to the geomorphology of the terrain and soil properties [15]. In such circumstances, the effects of different cultivation practices [7,9] and cropping systems [2, 16] becomes of crucial importance in the process of reduction of this type of degradation. In the past decades many authors gave a significant contribution to exploit the influence of different cultivation techniques on reduction of tillage erosion, and modeling of the translocation, dispersion and sedimentation of the eroded soil material [9, 10, 12, 13, 14, 17, 18]. Soil erosion is the most dominant type of land degradation in Republic of Macedonia. As a result of the improper management practices in agriculture and forestry and worsened climatic conditions, more than 33% of the country is affected with severe processes of water erosion. Till now, no specific research has been conducted, related to estimation of the influence of unsustainable management practices in agriculture to the intensity of soil erosion. Main objectives of our study was to quantify the influence of contour and up and down deep ploughing on soil sediment production and the influence of most prominent cultivation systems on soil erosion and soil organic carbon.

2. Material and Methods

The experimental site was established in autumn 2013 in the vicinity of Skopje, R. of Macedonia on the experimental fields of the Institute of Agriculture. The site is located on Cambic luvisol on saprolite (WRB), ona sloppy terrain (approx. 11%). For measurement of the influence of different cultivation methods and tillage on the intensity on soil erosion, the experimental site was divided in five experimental plots. The size of each plot is 22,1 m long and 5.61 m with, which were subdivided into 3 replications with width of 1,87 m each (Whichmaer and Smith 1978). Each experimental plot was fenced with thin-sheet tin to enable streaming of the run-off and sediment to the outlets. The tin fence was removed each season, before tillaging of the experimental site and re-installed. A special containers were installed on each outlet for collection of soil sediment. The intensity of soil erosion was monitored with five different cropping systems and tillaging methods, which are most commonly used in the country:

2.1. Deep Up-Downslope Pl)ughing (DUDP)

Ploughing (30 cm) was performed each vegetation season, in autumn and spring and the plot was left unsown, in order to monitoring the net effects of up-down slope cultivation on the intensity of tillage erosion and to compare it with the contour deep cultivation. The furrows formed with the deep ploughing were occasionally corrected manually, after heavy rainfalls.

2.2. Contourcultivation (CC)

Ploughing (30 cm.) was performed across the slope in autumn and spring. This variant except the plowing direction is the same as DDP. In order to enable comparability, both variantswas established on a close distance, toeliminate any variations of slope or soil characteristics, which might influence tillage erosion intensity.

2.3. Crop rotation (CR)

The deep ploughing (30 cm.) and all other subsequent operations (disk cultivation, seedbed preparation, sowing) were performed up-down the slope. The cropping pattern was as follows: autumn weed, forage maize, oil seed rape as a cover crop (2013/2014), incorporation of oil seed rape as a green manure, maize, barley (2014-2015), fallow, oil seed rape, (2015-2016). Spring crops during summer month were regularly irrigated with low portions of furrow irrigation, except in 2016 when plot was sowed with Oil seed rape.

2.4. Mono-crop of cereals (MC)

All cultivation practices (deep ploughing, disk cultivation, seedbed preparation, sowing) were performed across the slope. The site was sown with: autumn weed (2013/2014), barley (2014/2015), fallow, spring barley, autumn weed (2015-2016).

2.5. Perennial grass (PG)

Perennialgrass was established at autumn 2013 as a mixture of Poaceae and Fabaceae grasses (Lolium perene, Trifolium repens, Lotus corniculatus, etc.). The grass was regularly moved and the bio-material was left on the surface as organic mulch. The plot was occasionally irrigated with low intensity micro-sprinklers. This experimental site was intended to demonstrate the benefits of conservation practices in reducing of sediment loss on sloppy terrains, like: cover crops, reduced cultivation, mulching of organic matter, water conservation etc. Before setting up of the experimental site, soil samples were taken for laboratory analysis of soil chemical properties: pH in KCl and H_2O, Soil Organic Matter Content (Tjurin method, Orlov and Grishina, 1981), the content of available phosphorus and potassium Egheer-Riehm method (Egner et al., 1960) and soil texture [1] in order to have an information for the initial status of the main soil properties. After establishing of the experimental site, soil samples for soil chemical analysis were taken every year from each experimental plot, at the end of vegetative season. Special attention is payed to the dynamics of soil organic carbon and nutrients: nitrogen, phosphorus and potassium. In the vicinity of the experimental site an automatic meteorological station is installed for recording of basic meteorological data, like: air temperature, air humidity, solar radiation, win speed and wind direction and quantity and intensity of the rainfalls. In all years of monitoring, soil sediment has been collected on a weekly base or day after intensive rainfall events. The collected material was measured and laboratory tested for the quantity of soil organic matter and nutrients. Statistical analysis of data was performed by statistical method, SPSS 20, 0. The analytical procedure is performed by a general linear model method and the results are tested on a probability level of $p < 0, 05$.

3. Results and Discussion

The experimental site was located on Chromic luvisol on saprolite (WRB). Average soil samples were collected from several points of the site up to 80 cm. depth for laboratory testing of the basic soil properties. Data from the laboratory tests are presented in Table 1 and 2. Out of the data, presented in Table 1 it can be seen that the soil have fine texture with domination of clay particles and fine sand. Clay content increases in the lower part of the soil horizon, with a maximum content of 56, 2% in (B)/C. Fine sand fraction has its highest content in the surface (Ap) horizon and subsurface horizon (B). Low content of coarse sand and skeleton fraction from 8.7% in hor. Ap up to 3.3% in C, indicates a possibility of infiltration rate of the top soil and possible high coefficient of erodibility. Due to the high clay content, all soil horizons according Scheffer & Schachtschabel are classified as loamy clay [1].

Table 1. Texture of Chromic luvisols on saprolite from the experimental site

Soil horizon	Depth (cm)	Skeleton (> 2 mm)	particle size distribution %				Texture
			Coarse sand (2-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Clay (<0.002 mm)	
Ap	0-23	8,78	8,7	35,2	16,4	39,7	Loamy clay
(B)	23-65	9,46	6,0	41,3	11,1	41,6	Loamy clay
(B)/C	65-89	6,24	3,5	27,7	12,6	56,2	Loamy clay
C	89-123	6,34	3,3	28,4	14,2	54,1	Loamy clay

The content of soil organic matter in all horizons is low and ranges from 2, 63 g kg^{-1} in the top layer up to 1, 09 g kg^{-1} in the substrate. The area where experimental site is located, previously was used for agricultural production, but for many years was abandoned and under natural vegetation, due to what a certain amount of organic matter is accumulated in the top layer. The content of total nitrogen is in optimum in hor. Ap and (B), while in hor. (B)/C and C the content of total nitrogen is low. Soil reaction is slightly acid and gradually decreases in depth in a line with the carbonate content. The content of easy available phosphorus decreases in depth of the soil profile and ranges from optimal level in hor. Ap to very low in hor. C (3, 3 mg 100 g^{-1}soil). The content of easy available potassium in the top layers is high while in the intermediate ((B)/C) and substrate C, the content of phosphorus is in the category of optimal content.

Table 2. Chemical properties of Chromic luvisols on saprolite from the experimental site

Soil horizon	Depth (cm)	Organic matter (g kg^{-1})	Carbonates %	Total nitrogen %	pH		mg $100g^{-1}$ soil	
					KCl	H_2O	P_2O_5	K_2O
Ap	0-23	2,63	0.33	0,15	6.4	7,3	8,7	35,2
(B)	23-65	1,88	0.38	0,11	6.4	7,7	6,0	41,3
(B)/C	65-89	1,27	0.30	0,07	6.3	7,8	3,5	27,7
C	89-123	1,09	/	0,06	6.1	7,2	3,3	28,4

3.1. Effect of tillage on soil loss

Soil loss has been monitored during three years (2014-2016) with particular focus on vegetative season from beginning of April till end of September, when most of the extreme events of intensive rainfalls occur. Main objective of this study was to quantify the effects of the direction deep tillage on soil sediment loss in relation to the extreme rainfall events. The first year of monitoring in terms of monthly averages and the distribution of the total quantities of rainfalls during the vegetative season (502.7 mm.), is much above the averages for region (238, 9 mm for period 1981-2010). In total, six intensive rainfall events were recorded during the vegetation season, but with most significant influence on sediment loss are rainfall events which occurred in three occasions in the period 17-20/6/2014, when the variant DUDP produced 3.957 t ha^{-1}, and rainfall events at the beginning of August and September 2014 with average production of sediment of 1, 0 t ha^{-1}, and 1,9t ha^{-1}, respectively. Out of the data presented in Table 3, a big difference in the production of soil sediment between variant DUDP and CC can be noted. Out of the data presented in Table 3 it can be noted that the reduction of soil loss in variant CC (contour cultivation) as a result to the direction of deep tillage is 6 times lower than variant DUDP (deep up-downslope cultivation). The difference in sediment loss among the variants, is result exclusively to the direction of the deep tillage, because both plots are on the same location, on same soil type and clear from vegetative cover.

Table 3. Effects of tillage and cropping systems on soil loss (t/ha) 2014

Date of rainfalls	Total event (mm)	Total month (mm)	Soil sediment t ha^{-1}				
			DUDP	**CC**	**CR**	**MC**	**PG**
19/04/2014	15,6	111,0	0,086	0,063	0,185	0,063	0,009
14-15/05/2014	17,2	85,4	0,170	0,110	0,100	0,085	0,021
17-20/06/2014	73,1	85,4	3,957	0,082	0,320	0,410	0,053
22/07/2014	13,4	47,9	0,125	0,068	0,110	0,263	0,020
07/08/2014	26,1	45,6	1,600	0,500	0,280	1,300	0,012
03/09/2014	60,4	167,5	1,900	0,470	/	0,459	/
			7,838 [a]	**1,293 [c]**	**0,995 [d]**	**2,580 [b]**	**0,115 [e]**

* values entitled with same letter are not statistically significant at the probability level $p < 0.05$

The second year of investigation was much drier than the previous one, with a total rainfalls in vegetative period of just 170.9 mm, which is three times lower than 2014. Only two rainfall events above 20 mm were recorded, but only the event on 21.09 2015 when high intensity rainfalls occurred, had a significant influence on soil sediment loss, with more than 11,8 t ha^{-1} in variant DUDP, which is much higher than in previous vegetative season. On the other side, in variant CC this event had an insignificant effect, hence the recorded sediment loss is lower (0.911 t/ha) than in the previous year of monitoring, which is most probably result to the low total quantity of rain water, despite its intensity. In such cases, rain water cannot make a breakthrough over the ridges formed with tillage perpendicularly to the slope and cause soil erosion.

Table 4. Effects of tillage and cropping systems on soil loss (t ha^{-1}) 2015

Date of rainfalls	Total event (mm)	Total month (mm)	Soil sediment t ha^{-1}				
			DUDP	**CC**	**CR**	**MC**	**PG**
06/04/2015	22,8	33,2	0,069	0,044	0,058	0,051	/
08/05/2015	7,6	20,4	0,141	0,073	0,024	0,039	/
21/06/2015	14,2	43,8	0,240	0,104	0,045	0,069	/
11/07/2015	1,6	5,0	0,184	0,063	0,115	0,420	/
17/08/2015	9,1	10,6	0,054	0,027	0,174	0,471	/
21/09/2015	23,6	57,9	11,200	0,600	4,543	1,000	0,012
			11,888 [a]	**0,911 [d]**	**4,959 [b]**	**2,050 [c]**	**0,012 [e]**

* values entitled with same letter are not statistically significant at the probability level p <0.05

In the third year of investigations, the total precipitation in the vegetative season was higher than 2014 but still below the average of the region. During the vegetative season in total, six events of intense rainfalls were recorded, with one extreme at the beginning of August when within 5 hours, more than 92.5 mm of rainfalls were recorded. As a result of this extreme, more than 32 t ha^{-1} of sediment loss were recorded on variant DUDP. Significantly high amount of sedimented material was recorded on the variant CC (10,358 t ha^{-1}) as well. It should be noted that contour cultivation reduces runoff by increasing surface roughness perpendicular to the slope, increased surface roughness reduces velocity of surface water, providing more time for infiltration and reducing erosion rates [9]. But, in a cases of heavy and intense rainfall, the tillage ridges, cannot collect and redirect the whole quantity of surface rain water which appears in a short period of time, due to what a downslope surface flow occurs, which resulted in significant amounts of soil loss in variant CC. In this year, the ratio between variants DUDP and CC, as a result of this phenomena is only 1:3 in favor of CC, which is lower than in 2014 and 2015 when it was 1:6 and 1:11, respectively.

Table 5. Effects of tillage and cropping systems on soil loss (t ha^{-1}) 2016

Date of rainfalls	Total event (mm)	Total month (mm)	Soil sediment t ha^{-1}				
			DUDP	**CC**	**CR**	**MC**	**PG**
26/04/2016	9,3	19,1	0,023	0,029	0,019	0,034	/
02/05/2016	22,30	66,50	1,240	0,420	0,055	0,514	/
04/06/2016	21,00	33,30	0,850	0,360	0,020	0,360	/
16/07/2016	34,40	63,40	1,113	0,549	0,120	0,412	/
07/08/2016	92,90	96,50	32,300	9,000	0,510	0,706	0,113
			35,526 ^{a}	**10,358 ^{b}**	**0,724 ^{d}**	**2,135 ^{c}**	**0,113 ^{e}**

* values entitled with same letter are not statistically significant at the probability level p <0.05

3.2. Soil loss under different cropping systems

Soil sediment loss was measured under different cropping systems, which are most common for the agricultural production in the region. Main objectives was to evaluate the influence of the crop and the applied management practices on soil sediment loss intensity. Data from the three years monitoring are presented in Tables 3, 4, and 5. In all three years of investigation the highest quantities of sediment loss were recorded in variant MC with an average of 2.255 t ha^{-1} sediment loss. In 2015 CR (crop rotation) shoved its highest values (4.959 t ha^{-1}), as a result of the hot and dry period in August and September, maize plants were intensively irrigated. The variant PG in comparison to the other two cropping systems, shows the lowest production of sediment in all three years of investigations. This is result of the good coverage of the surface with vegetative mass, which slow down surface water velocity, buffers the destructive effect of rain drops and increases soil infiltration rate. In the first and third years of investigation, the total soil loss in variant PG was in the ranges of 0.113-0.115 t ha^{-1}. The higher amount in the first year is result to the insuvicient develpment of sod, whill in the third yaer the higher ammountis result to the extreme rainfall events that occurred during the summer period. Based on the data presented Tab. 3,4 and 5, it can be concluded that in all years of investigation, DUDP variant with downslope tillage and cultivation, has the significantly highest values (with an average of 18.417 t ha^{-1}) of soil loss, compared to the other variants. The variant PG, in all three years, has the lowest production of soil sediment (0.080 kg ha^{-1}) with statistically significant difference at $p < 0.05$ level. Out of the results presented, it can be noted that the amount of sediment in CR variant in 2015 has significantly higher production of sediment, compared with the amount of soil sediment measured in 2014 and 2016. As previously mentioned this difference is result to the intensive furrow irrigation of maize in 2015 due to the dry and hot summer period. The most significant difference between variants DUDP and CC was observed in 2015, while the lowest difference was detected in 2016, which is as previously explained, result to the specific hydrological conditions in both years of monitoring.

3.3. Soil organic matter depletion under different tillage and cropping systems

Soil organic matter is of a crucial importance for soil sustainability to water erosion and tillage. By strengthening of soil structure and its capability for infiltration of run off water, soil organic matter increase resistance of soil to water erosion. Soil organic matter was continuously monitoring in the trial period in order to quantify the effects of different cropping systems and tillage techniques on soil organic matter content. Our research showed that, the variation of soil organic matter is significantly related to the type of cultivation, as presented in Table 6. The presented data indicates a significant negative influence of the applied downslope cultivation practices on sol organic matter. At the first year of investigation, the DUDP variant has the lowest content of organic matter, and its quantity continuously decreased during the monitoring period, from significantly 2.290 to 1.107 g kg^{-1}. In variant CC, the organic matter also continuously decreased, but with significantly lower intensity compared to variant DUDP. This difference is most probably result to the lower intensity sediment loss in the top soil of this variant, which has highest content of soil organic matter. Unlike, variants DUDP and CC, the content of organic matter in the variants significantly increased, as a result of applied different cropping systems. Positive influence of cropping system practices on soil organic matter content is most significant in variant PG. This is result not just to the reduce soil loss, but also to the continuously mulching of mowed organic mass from perennial grass, during the trial period. In the other two variants there is slight increasing organic matter which is result to the incorporation of vegetative mass of oil seed rape in variant CR as a green manure and incorporating of organic remains after the cereal harvest.

Table 6. Soil organic matter content dynamics with different cultivation and cropping systems

	Soil organic matter content g kg^{-1}			
Year	2014	2015	2016	average
Variant				
DUDP	2.290 ^{d}	1,843 ^{e}	1,107 ^{e}	1.746 ^{d}
CC	2.920 ^{b}	2,630 ^{d}	2,487 ^{d}	2.679 ^{c}
CR	3,110 ^{a}	3,550 ^{c}	4,940 ^{b}	3,867 ^{b}
MC	2,497 ^{c}	4,173 ^{b}	4,447 ^{b}	3,706 ^{b}
PG	2,620 ^{c}	5,107 ^{a}	5,307 ^{a}	4,344 ^{a}

* values entitled with same letter are not statistically significant at the probability level $p < 0.05$

4. Conclusions

- Two different tillage and three cropping systems were included in this research to investigate their influence on soil erosion intensity. These variants were: 1. Deep Up-Downslope Ploughing (DUDP), 2. Contour cultivation (CC), Crop rotation (CR), Monocrop of cereals (MC) and Perennial grass (PG).
- Direction of tillage and cultivation processes have significantly high influence on the intensity of soil erosion. During the three years of monitoring, the highest erosion was recorded in variant DUDP, where the total year quantiles in all three year were: 7.838 t ha^{-1} (2014), 11.888 t ha^{-1} (2015), 35.526 t ha^{-1} (2016),
- Cropping system applied influences the intensity of soil erosion. Significantly lowest production of sediment in all three years of investigations were recorded in variant PG with: 0,115 t ha^{-1}(2014), 0,012 t ha^{-1}(2015), 0,113 t ha^{-1} (2016),
- The intensity of rainfalls or irrigation applied, significantly affects the production of soil sediment in variants where downslope cultivation was applied, like variants DUDP and CR,
- In all years of investigations, significant differences between variants DUDP and CC were notices, as a result of the intensity and quantity of rainfalls. Deep tillage ridges, can collect and redirect the rain fall water to certain extent, after which downslope run-off occurs.
- The highest values of soil organic matter was detected in variant PC (perennial crop) due to the low soil loss intensity and continuous mulching of the moved bio-material,
- The lowest values were observed in variant DUDP, which is result to the intensive erosion of the top soil reach with organic matter, as a result of the tillage system applied.

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6. References

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