Research Article

Guidelines of sustainable soil tillage system in Croatia (Contribution to sustainable land management in 2015 - international year of soils)

Abstract

Within soil degradation processes soil erosion is on the first place, as consequence of improper land man-agement, first of all soil tillage system and practices. Results of 10years (1995-2004) of our investigation (inves-tigation endure now 21st year) show guidelines in tillage practices. At first; traditional tillage practiced in this agricultural region up/down the slope on Stagnogley on slopes of 9% and more is unsustainable in growing of row crops-maize and soybean, because of disastrous or extreme soil erosion. But, in growing of crops of high density, like wheat this practice is sustainable. On the other side, No-tillage and contour tillage resulted in much lower water erosion in comparison with up/down the slope tillage. At the beginning of experiment in the first two years No-tillage as system was not sustainable. Stabilization of yields of growing crops on the level which is statistically the same or higher than on other tillage treatments on no-tillage plot started after ten years of no-tillage practice. These investigations suggest the conclusion that high density crops like winter wheat, spring barley and oilseed rape are relatively suitable crops for growing under reduced tillage systems. Soybean toler-ates no-till practices in climatically favourable years, but with higher risk in dry years. Maize was shown as a very risky crop without tillage even in climatically average years. We agree with assertion of Solbrig1 that no tillage is a process, a new philosophy and way of thinking in arable farming of Europe, and not a technology.

Keywords: erosion risk, sustainable intensification of agriculture, no-tillage

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Ferdo Bašić

Department of Natural Sciences, University of Zagreb, Croatia

Correspondence: Ferdo Bašić, Department of Natural Sciences, University of Zagreb, Faculty of Agriculture-Croatian Academy of Sciences and Arts, Zagreb-Zrinjskitrg 11, Croatia, Tel 00-385-98 416934, Email ferdo.basic1@gmail.com

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Abbreviations: EMS, erosion monitoring station; SU, sustainable; I, insignificant; ER, erosion risk; CS, conditionally sustainable; M, moderate; US, unsustainable; E, extreme; SOC, soil organic carbon; PET, potential evapotranspiration; RET, real evapotranspiration; D, water defficiency; S, water sufficiency; R, reserve of water; Ea, actual erosion-t; T, soil loss tolerant-t

Introduction

The International Year of Soil-2015 is an opportunity to remind that soil as a living media is the key media of a harmonious flow of matter and energy and maintenance of harmony and equilibrium of terrestrial and semi terrestrial ecosystems, including agricultural-agro ecosystems. In this role, as conditionally renewable natural resource[2] soil-pedo-sphere decisive influences and directs sustainable development of global economy, especially agriculture and environmental protection. Facing with climate changes, the revision and improvement of practiced system of land management and soil tillage in conventional agriculture is globally "requirement of the day". The aim is clear; higher food production on environmental-friendly way. The only way we see in sustainable intensification of land management and farming system which includes soil protection. In focus is necessary to put biological properties of soil, organic matter transformation, humus formation and conservation of humus as "fuel" of "biological fire" of soil biota, through farming system and crop rotation. Selection of cultivars as well as all treatments of crop in the future oriented to quality of crop residue on and in the soil as "row material" for humus, means basic component of soil on one, but source of CO_2 after mineralisation on the other side. The biodiversity in the soil in agro sphere is not of lower importance than above-soil one.

Our concept of soil conservation[3–7] is based on an integral approach. To explain it, follow USLE; R-rain factor is vis maior, cannot influence on rain intensity, but we can prepare soil surface for reception of rain drops; on vegetation cover (C factor) or on soil, to direct the water in the soil-infiltration or on surface run-off. On all factors influence on K-factor except of soil texture we can influence by arable farming practices (humus content, soil permeability) and change in desirable way. Both topographic factors we can change; L-factor by breaking the slope with grassed waterways like we made in Ethiopia,[8] but S factor by terraces, like we suggest on extremely erodible soils of Central Istria.[9]

Taking in account the unpredictable, in fact chaotic climate changes we witness[2] it is impossible to predict potential impacts of climate changes on agro ecosystems. Agreed with this statement we suggest; in agriculture of 21st century sustainable intensification of arable farming as the only right way of development needs land reclamation and management on the way to be ready for water sufficiency, means accept and remove sufficient water by drainage, as well as for irrigation in the case of water deficiency (drought).[10]

Methods

For this work we use and summarized the results of long-term investigation in Department of General Agronomy of Faculty of Agriculture, University of Zagreb; data on the long term (1995-2004) stationary measuring of soil erosion by water on Erosion Monitoring Station (EMS) located in Blagorodovac, near Daruvar in central Croatia, in Central Pannonian agricultural sub region,[11] on Stagnosol albic. With about 580 000ha this soil type is after Luvisol the most widespread soil type in Croatia, usually described in Central European literature as Pseudogley and is generally known as unfavoured for arable farming without complex (three stage) amelioration. Also, experienced agronomists excluded this soil type from no-tillage practice, because of low content of humus, unstable structure caused by high content of silt, there is in this soil the tendency to crust formation. Especially high risk of crust formation is in the case of hard rain in F stage-on seed-bed prepared for sowing of spring crops, before germination which can be aggravated. The main indicators of climatic conditions are presented in Table 1.[12,13]

PET: Potential EvapoTranspiration in mm-quantity of water which could be evaporated and transpirated from soil if there is enough water in soil; R: Reserve of water in soil in mm; RET: Real EvapoTranspiration in mm-quantity of water; which will be really lossed by evaporation and transpiration in mm, D: Water defficiency in soil in mm; S: Water Sufficiency in mm

As visible, total water sufficiency is about 200 mm, mostly in winter and early spring period. The period of maximal risk is spring maximum of rain, which is usually in Mai and Jun in F stage of maize, when is the soil maximal sensitive, naked and opened without any protection. Because of surface layer-seed-bed is fertilized and treated by herbicides, erosional drift from such cropland is biocide and can damage water resources-underground water and water courses. Whether conditions in presented period 1995-2004., where in average, except of 2003, which was extremely dry and warm. Monitoring of eroded soil we made collecting erosional drift of soil from 6 iron sheet enclosed trial plots, according to the USLE,[14] viz. on a 9% slope, length 22.1m, width 1.87m.

Quantity and quality (intensity) of precipitation we register by ombrograph, installed on EMS. Soil loss tolerance (T value in USLE) for this soil type has been estimated at 10t/ha/annually[15] (Figure 1). Special equipment enabling separation and filtration of erosion drift, creation of Prof. O. Nestroy has been set up on the lower part of each trial plot. Clean water is collected in a separate container, while eroded drift remains on the cloth serving as filter. Based on quantity of dry soil collected on filter from plot of known area, registering of rain quantity and its intensity on ombrograph and clean water quantity in container, we calculate eroded soil/ha, run-of (as % of registered rain), but also humus, plant nutrients, heavy metals, etc in eroded soil. On plots of EMS crops are grown in the 3-field crop rotation: maize,-soybean-winter wheat. This rotation is usually practised in arable farming of this agricultural region, with the pressure and tendency to increase participation of maize, from narrowed crop rotation to monoculture. Monitoring of erosion started 1994.

Data on soil erosion are collected following crop stages according of USLE: F stage (bare fallow), SB (seed bed), Sta

ge 1 (up to 50% cover) Stage 2 (50-75% cover) Stage 3 (ripening and harvest) Stage 4 (plant residue). This (2015) year is 21st one. Till today there is change six rotations of three field crop rotation and will remain minimal yet one. Collected data on soil erosion are very rich.

The main indicator of soil erosion erosion risk (ER) has been calculated as criteria of evaluation of "con-servational effects" the investigated tillage practices:

on Risk (*ER*) =*Ea − Actual Erosion − Eroded Soil in tons of soil*/*haSoil loss tolerant* (*T*) *in tons of soil*/*ha*

For ER characterisation we use the criteria of Auerswald et al.,[16] but own criteria[3] for evaluation of sustainability of tillage practices, shown in Table 2.

Using the data of Table 2, the guidelines for evaluation of each tillage practice are; Desirable tillage practice is the sustainable (SU) one, with insignificant (I) or small Erosion risk (ER) or conditionally sustainable (CS) with moderate (M) erosion risk. The unsustainable (US) tillage practice with high erosion risk (H) or extreme (E) should be avoided, which means in crop rotation to avoid crops with such erosion risk, like row crops (maize). The aim of investigation was to establish the optimal conservation tillage treatments, crop rotation and farming practices for our farmers in multipurpose land use; optimal for arable crops and farming, but reliable for soil and water resources conservation, on the line of sustainable agriculture.

Table 1 The basic long term indicators of the climate (Meteorological station Daruvar 1960-1999)

Months												**Annually**
I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	
Precipitations in mm												
55	47	58	73	88	97	85	82	88	70	83	63	889
Mean Air Temperature°C												
-0.4	1.9	6.3	10.9	15.5	18.9	20.6	19.9	15.9	10.9	5.7	1.6	10.7
Days with Precipitation ≥ 0,1mm												
12	11	13	13	14	13	11	11	10	9	13	13	143
Days with Precipitations ≥ 1,0mm												
8	8	9	9	10	10	9	8	7	7	9	10	104
Monthly[20] and annaually rain factor[22]												
43,2 perhumid	24,7 perhumid	9,2 humid	6,7 humid	5,7 semihumid	5,1 semihumid	4,1 semiarid	4,1 semiarid	3,9 semiarid	6,4 Semi humid	14,5 perhumid	39,4 perhumid	80 sem-hum
Balllanceof water calculated by method of thornthwaite												
PET*	0	0	24	52	91	115	132	110	76	42	20	662
R	100	100	100	100	93	79	44	26	15	36	100	893
RET	0	0	24	52	91	115	132	110	76	42	20	662
D	0	0	0	0	0	0	0	0	0	0	0	0
S	45	45	25	27	0	0	0	0	0	0	3	212

Table 2 Criteria of evaluation of sustainability of tillage practice

Sustainabillity of tillage practice[3]		**Erosion risk: ER=Ea/T***[14]		
Designation	**Abbreviation**	**Designation**	**ER**	**Abbreviation**
		Insignificant	< 0.20	I
Sustainable	SU	Small	0.21-0.50	S
Conditionally Sustainable	CS	Moderate	0.51-1.00	M
		High	1.01-2.00	H
Unsustainable	US	Extreme	2.01-4.00	E
Unacceptable	UA	Disastrous	> 4,01	D

*Ea, actual erosion-t of soil/ha/year; T, soil loss tolerant-t of soil /ha/year

Table 3 Indicators of soil erosion by different tillage practices on stagnogley of central croatia

Grown crop year actual erosion-ea erosion risk-ER		**BF**	**PUDS**	**NT**	**PAS**	**VDPAS**	**SSPAS**	**RANGE Min-Max***
		UP/Down The slope			**Across of slope – CONTOUR tillage**			
Maize 1995	Ea-t/ha	146.32	38.54	22.86	11.65	21.12	2.99	2,9-38,5
	ER	14,2- D	3,85- E	2,29- E	1,16- H	2,11- H	0,30- S	S-E
Soybean 1996	Ea-t/ha	110.14	38.18	13.53	5.35	5.26	2.90	2,9-38,2
	ER	11,01- D	3,82- E	1,35- H	0,53- S	0,53-M	0,29- S	S-E
Wheat 1997	Ea-t/ha	86.77	0.54	0.22	0.07	0.30	0.13	0,1-0,5
	ER	8,68- D	0,05- I	0,02- I	0,00- I	0,00- I	0,01- I	I
Oil rape 1998	Ea-t/ha	54,10	0,40	0,34	0,13	0,17	0,08	0,1-0,4
	ER	5,41- D	0,04- I	0,03-I	0,01- I	0,02- I	0,00- I	I
Doub.crop**1999	Ea-t/ha	36,50	6,55	0,26	0,18	0,23	0,15	0,1-6,5
	ER	3,65- E	0,65- M	0,03-I	0,02- I	0,02-I	0,01-I	I-M
Maize 2000	Ea-t/ha	141,41	26,06	0,56	8,37	6,61	6,02	0,6-26,6
	ER	14,1-D	2,61-E	0,06-I	0,84-M	0,66-M	0,60-S	I-E
Soybean 2001	Ea-t/ha	26,77	5,10	0,13	2,00	0,20	0,10	0,1-5,1
	ER	2,68-E	0,51-S	0,01-I	0,20-I	0,02-I	0,01-I	I-S
W. wheat 2002	Ea-t/ha	62,70	0,46	0,03	0,12	0,12	0,02	0,0-0,5
	ER	6,27-D	0,05-I	0,00-I	0,01-I	0,01-I	0,00 I	I
Oil rape 2003	Ea-t/ha	7,96	0,14	0,00	0,02	0,002	0,002	0,0-0,1
	ER	0,80-M	0,01-I	0,00-I	0,00 I	0,00 I	0,00 I	I
Double crop 2004	Ea-t/ha	49,50	20,60	0,40	10,40	8,40	6,60	0,4-20,6
	ER	4,95-D	2,06-H	0,04-S	1,40-H	0,84-M	0,66-M	S-H
Average	Ea-t/ha	65,74	12,60	3,75	3,85	3,31	2,27	2,3-12,6
	ER	6,57-D	1,26-H	0,38-S	3,85 S	0,33 S	0,23-I	I-H

*Standard plot is not included, **winter burley sown in autumn with soybean sown in spring

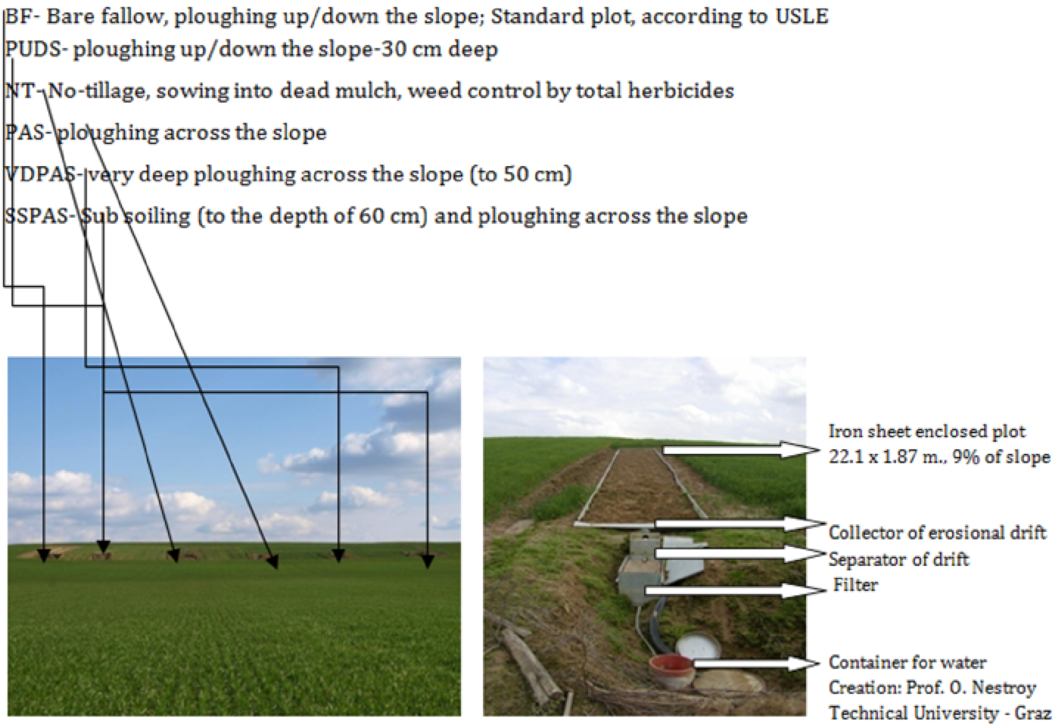

Figure 1 The field of EMS in Blagorodovac-Daruvar. Trial plots with wheat in 1997., are visible. Right; Details of trial plot construction (photo: Kisić).

Results and discussion

"Requirement of the day" is clear; higher food production on environmental-friendly way. The only way we see in sustainable intensification of land management and farming system which includes soil protection. For this aim, in focus is necessary to take biological properties of soil, organic matter transformation, humus formation and conservation of humus as "fuel" of "biological fire" of soil biota, through farming system and crop rotation. The main soil degradation processes within EU are: erosion (by water and/or wind), soil organic matter decline, soil compaction, salinisation, landslides, contamination and soil biodiversity decline. In agricultural soils of Croatia we estimate the next sequence of soil degradation processes:[8,11]

Erosion (water, wind, tillage)>Organic matter decline>Soil compaction>Soil sealing>Salinisation>Landslides>Soil contamination>Decline of soil biodiversity

Out of any question is the fact that soil erosion is on the first place. Origin of most of degradation processes, including of soil erosion is improper land management; first of all soil tillage system and practices in concrete agro ecological condition-agricultural region.

Our concept of soil conservation[3–7] is an integral approach, based on intervention in all steps of process of erosion following USLE; R-rain factor is vis maior, we cannot influence on rain quantity and intensity, but we can prepare soil surface for reception of rain drops on soil surface and direct to infiltration or in run-off. All properties influenced on K-factor (humus content, texture, structure, soil permeability) except of soil texture, we can change in desirable way by farming practices. Both components of topographic factors we can change too-L factor by breaking the slope with grassed waterways like we made in Ethiopia,[8] but S factor by terraces, like we suggest on extremely erodible soils on flysh of Central Istria.[9]

Results of 10years (1995-2004) of our investigation (investigation endure now 21st year) in the form of some indicators of soil erosion on Stagnosol albic are presented in Table 3. Presented results define guidelines in tillage practices. At first; in the case of BF as standard plot according USLE, the soil is exposed to disastrous erosion, which is absolutely unacceptable practice on Stagnogley on slopes of 9% and more. Second, and very important; on the same slopes PUDS as traditional tillage practiced in this agricultural region is unsustainable in growing of row crops-maize and soybean, because of disastrous or extreme soil erosion. But, in growing of crops of high density, like wheat this practice is a sustainable one. On the other side, PAS-contour ploughing is sustainable for all grown crops, in maize growing ER is the highest one but is moderate. This practise is optimal one in actual situation. VDPAS and SSPAS reduce soil erosion for crops of high density, but not for row crops, like maize in some years with rainfall of high in-tensity. The most important shortcoming of these two variants of tillage is to high price, high consumption of energy-fuel, means money, high CO_2 emission, costs of enriching of topsoil by humus, soil compaction by heavy machinery, etc. No-tillage and contour tillage resulted in much lower water erosion in comparison with up/down the slope tillage.

Modern concept is No-tillage, or direct drilling in mulch of plant rests. For this practice there is modern, very efficient mechanization. Let us to analyse this variant in our trial (Table 3). At first, at the beginning of experiment in the first two years this practice was not sustainable one, because of influence of past long-term tillage practices on soil properties, but after restoring of equilibrium of processes at first enriching by soil biota and state in the soil, means stabilization and high conservative effect of mulch on soil erosion. In first years, on the beginning of trial, winter wheat shows significantly lower yield on NT variant, but later differences between yields were not significant, when winter wheat was sown again in crop rotation. Indeed, the 2006 yield in NT treatment was slightly higher compared to some other treatments. Similar situation was recorded in spring barley growing. Oilseed rape was found to be the most rewarding crop with respect to reduction of the number of tillage practices. Yields of oilseed rape achieved under NT in the three years were in the range of yields in other tillage treatments. For this reason, no significant differences in yields were determined among investigated tillage treatments. Stabilization of yields on the level which is statistically the same or higher than in other treatments followed after ten years of NT practice. Means if no surprise, no-tillage system has a good future. For conclusion; we agree with opinion that no tillage is a process, a new philosophy and way of thinking in arable farming of Europe, and (yet) not a technology.[1]

Is not visible from Table 3, but the highest erosion intensity was recorded in spring in F stage of crop, especially if a spring row crop was grown and up/down the slope. Yet one aspect of tillage is very important. In spite of suspicion on theory of anthropogenic influence on climate changes and modern interpretation of results of CO_2 efflux, we comment results of field measuring of CO_2 concentration on the same tillage variants using static method by transportable infra-red detector of CO_2 Gas AlerMicro5 IR. These measuring we made in the period 2011-2014, means after 20years of described tillage treatments.[17] At first; the range of soil total carbon content varied from 19 083, 7kg/ha at BF treatment up to 31 073, 6kg/ha at SSPAS treatment. Means; after 20years, content of C in the case of SSPAS is 60% higher than in BF treatment. Similar is with CO_2-C efflux; the average CO_2-C efflux at BF treatment was in average 7, 9kg CO_2-C/ha/day. The treatment with the highest average CO_2-C efflux was NT. Range of CO_2-C efflux at NT treatment varied from 7, 8kg CO_2-C/ha/day up to 65, 8kg CO_2-C/ha/day. Daily soil total carbon loss by soil respiration ranged from 0, 04% at BF treatment up to 0, 9% at NT treatment. Soil CO_2-C efflux was fully positively correlated with soil total carbon content (r=0, 91). After all mentioned, it can be stated that in these agro-ecological conditions, best tillage practice in sustainable plant production in terms of the lowest daily soil total carbon loss (0, 06%) by soil respiration is ploughing to 30cm (PUDS and PAS).[17,18]

Taking in account the unpredictable, in fact chaotic climate changes we witness[2] it is impossible to predict potential impacts of climate changes on agro ecosystems. Agreed with this statement we suggest; in agriculture of 21st century sustainable intensification of arable farming as the only right way of development needs land reclamation and management on the way to be ready for water sufficiency, means accept extremely high (torrential) rain by drainage, as well as for the case of water deficiency (drought). It is necessary to remark; climate changes will influence on soil properties much more and in short-term period than we expect. Namely, according our observation, extremely high soil temperature in 2003 caused some processes in colloidal complex of soil (coagulation of some ampholitoides?) resulted by change of structure and higher permeability of former impermeable soil horizons. In the background of most processes of degradation of agricultural soils of Croatia is unfavourable organic carbon cycling. Decline of soil organic carbon (SOC) content is the main driving force of the most degradation processes of agricultural soils.[19,20] There is an urgent need to create farming system which will be humus-accumulation oriented. The sources of SOC for most of soils were crop residues plough in, and infrequent green manure. There is necessity to change these unfavourable practices, especially in Pannonian region, with long-term, traditionally intensive arable farming.

Apart from soil properties and soil type as consequence of soil forming factors content of soil organic carbon is determined by soil use, climate conditions and soil moisture regime. Soil organic carbon as source of food (energy) for soil micro flora and fauna contributes to reach soil life and (pedo) biodiversity. Therefore follows the task of scientists in agriculture to create and establish farming and tillage system which would open the process of CO_2 sequestration, enrichment of soil by organic carbon (humus), increase soil fertility and stabilization of yields of all crops in crop rotation on high level. The mean foreseen change is reduction of soil tillage: over tillage, and/or tilled surface area, and/or number of tillage operations, which in some cases leads to no-tillage system.[21,22] In every case, tillage system has to be adaptive one, climate-change and soil type-oriented. If so, there is no place for uniform solution, because of different soil types-agro ecological condition in agricultural region/sub region and erratic-unpredictable climate changes. The higher biodiversity and luxuriance above-and bellow-of soil surface (rizosphere) means the higher biological activity of soil, higher CO_2 emission, but at the same time higher CO_2 sequestration! Consequently; the more intensive photosynthesis means sequestration of more CO_2 in biomass of crop. Selection of cultivars started with the beginning of agriculture, till today aiming quantity (yield) and quality of harvested crop. Especially care in future will be quality of plant residues for desirable pedo- micro flora, participated in genesis and transformation of humus in soil. Therefore, organic and even more integrated and/or sustainable agriculture, as an alternative to intensive one, relies on the natural fertility of the biological component, which is of key importance of emission of CO_2 from cultivated soil. It is possible to minimize the total loss of soil organic matter, slow the excessive soil mineralization and increase terrestrial carbon sequestration and soil fertility. Furthermore, it is crucial to know to adapt tillage practices in certain agro ecological conditions with crop rotation on well-defined type of soil with knowledge of requirements of crop that we want to grow in order to favourably affecting all biological, chemical and physical parameters of soil fertility. It is a right way to maintain or even increase soil fertility, reduce risks to soil and environment degradation and realise food security and safety in satisfactory agricultural production!

Conclusion

Presented results of long-term trial (1995-2014) as well as experiences allow us to define some guidelines in tillage practices; On Stagnogley on slopes of 9% and more, ploughing up/down the slope as traditional tillage, practiced in Central Pannonian agricultural sub region is unsustainable in growing of row crops-maize and soybean, because of disastrous or extreme soil erosion. But, in growing of crops of high density, like wheat this practice is sustainable. On the other side, contour ploughing is sustainable for all grown crops, as the practise optimal in actual situation. Very deep ploughing and sub soiling reduce soil erosion for crops of high density, but not for row crops, like maize in some years with rainfall of high intensity. The most important shortcoming of these tillage variants is to high price, high consumption of energy-fuel, means money, high CO_2 emission, costs of enriching of topsoil by humus, soil compaction by heavy machinery, etc.

Modern concept is No-tillage, or direct drilling in mulch of plant rests. At the beginning of experiment, practically ten years was necessary for restoring of equilibrium in soil on the level of yields of conventional tillage practices. Stabilization of yields on the level which is statistically the same or higher than in other treatments followed after ten years of no-tillage practice. Results of measuring of CO_2 concentration in the period 2011-2014, means after 20years of described tillage treatments show the range of soil total carbon content varied from 19 083,7kg/ha at bare fallow treatment up to 31 073,6kg/ha at variant with sub soiling. Means; after 20years, content of C in the case of sub soiling is 60% higher than in bare fallow. Similar is with CO_2-C efflux; the average CO_2-C efflux at bare fallow treatment was in average 7, 9kg CO_2-C/ha/day. The treatment with the highest average CO_2-C efflux was no-tillage. Sustainable intensification of arable farming as the only right way of development in 21st century needs land reclamation and management on the way to prepare the soil to be ready for water sufficiency means accept extremely high (torrential) rain by drainage, as well as for water deficiency (drought) and irrigation. In the background of most processes of degradation of agricultural soils of Croatia is unfavourable organic carbon turnover cycling.

There is an urgent need to create farming system which will be SOC or humus-accumulation oriented. Because of SOC is the main factor of stable soil structure which improves physical, chemical and biological properties of soil, especially physical environment for root penetration through the soil, it improves hydrothermal regime, increases water retention capacity, reduce run-off and erosion, enhances permeability of soil and increases cation exchange capacity. Therefore follows the task of scientists in agriculture to create and establish farming and tillage system which would open the process of CO_2 sequestration, enrichment of soil by organic carbon (humus), increase soil fertility and stabilization of yields of all crops in crop rotation on high level. The higher biodiversity and luxuriance above- and bellow- of soil surface (rizosphere) means the higher biological activity of soil, higher CO_2 emission, but at the same time higher CO_2 sequestration!

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Conflict of interest

The author declares no conflict of interest.

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