Review paper

Review of research and practice of production and tillage systems in Podravje region (Slovenia)

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Abstract

In the scope of production and tillage systems for Eastern part of Slovenia (Podravje region) we analyzed results of 4 research projects and two case studies: company Perutnina Ptuj ploughing and non ploughing tillage and farm Majerič used just conservation tillage in integrated production system in field crop and vegetable rotation. In case of comparison of grain maize yield between conventional tillage incl. sowing and direct sowing into cover crops the yields were not different in the case of use *Trifolium incarnartum*, but in the case of *Lollium multiflorum* was lower on sandy soils. On the slope field with clay soils comparisons between conventional tillage and sowing in cover crops resulted up to 3.5 t ha^{-1} of eroded soils. In two soil types between conventional and conservation tillage incl. ripping were not significant differences in crop rotation yields (maize, winter wheat and oilseed rape), but the yields decreased in direct sowing treatment. No significant differences were among content of humus, but CO_2 emissions differed just after tillage. The highest Ecological Foot Print was calculated in case of conventional tillage, and the lowest in case of conservation tillage and depending mainly on use of fuel. After 3 years trials no impacts were on the content of humus in the soil regards different tillage systems, but number and mass of living organisms and ecological foot print of crop and vegetable production differed significantly among production systems (conventional, integrated, organic and biodynamic). However, after 7-years crop rotation in different production systems show promising results about soil characteristics and yields. For those further research of tillage systems needs to be focused more interdisciplinary, especially on sustainable i.e. organic production systems.

Key words: production system, tillage system, organic matter, foot print, yield,

Introduction

Food, feed and energy production, their low prices and safety, rational use of energy, low environmental impacts on the soil characteristics and biodiversity are the main contradictions depending on production and tillage systems, mainly influenced by climate and type of soils. Innovative solutions with lot of 'Pro et Contra' arguments (Gomiero et al., 2011; Williams and Hedlunt, 2013) are only partly acceptable for producers because of lack of interest, machinery, profit, not clear long term effects on the soil, biodiversity and yields. Also public opinion is very often opposed to alternative tillage systems. Apparently good solutions like sowing clover into interrow space of maize and direct sowing of maize in the second year in Switzerland (Amon et al., personal communication Swiss federal agric. institute) have never been accepted in practice. In whole scale accepted USA practice of conservation tillage after soil erosion crisis of conventional produced maize in monoculture brings the new problems in weed resistance, increased pest damage and the negative effects on soil profile. Solutions like pest and Roundup resistant GMO plants are under debate in context of long term effects on environment and even food safety.

The problems in a long term acceptable production and tillage systems with strong influences to storage and supply of water, soil fertility, soil compaction, weed suppressing, yielding, use of energy, environmental impacts, etc. However, organic agriculture relies on a number of farming practices based on ecological cycles and aims at minimizing the environmental impact of the food industry, preserving the long term sustainability of soil and reducing to a minimum the use of non renewable resource (Gomiero et al., 2011). Even conventional researchers like Karlen et al. (2013) conclude that good nutrient management and crop rotation reflect in yield and soil fertility differences between no-tillage and more intensive tillage. Based on 9-year maize-soybean rotation average grain prices and yields was twice more profitable as continuous maize. The fact is that many factors like crop rotation and complete nutrition to meet requirements to help soil/plant system to resist harmful external stress has interdisciplinary co-effect on soil compaction (Hamza and Anderson, 2005). In this contexts conservation agriculture systems appear to be interesting options to achieve more sustainable and intensive crop production under different agro ecological environments because they use efficiently available resources and maintain soil fertility. However, this mostly results from the permanent presence of organic mulch on the soil surface and the incorporation of cover crops in the rotations. Such modifications require a significant reorganization of the production process at farm level, and when facing technical or socioeconomic constraints, most farmers usually applying only partially the three main principles (soil tillage reduction, soil protection by organic residues and diversification in crop rotation) of conservation agriculture. Investigating the consequences of such partial implementation of conservation agriculture principles on its actual efficiency and assessing the most efficient participatory approaches needed and adapt conservation agriculture principles to local conditions and farming systems (Da Silva et al., 2013).

Due to previously mentioned statements and findings, the aim of this contribution is research evaluation of production and tillage systems (done by University of Maribor) in Eastern part of Slovenia during past 15 years with focus to user area with critical assessment of the topic.

Methods

We have analysed situation in the Podravje region (Slovenia) and reviewed 4 national research projects:

a) Bavec F. et al. (1996-1998): L4-7408. Technological - environmental comparison of conventional and more environmental friendly maize production systems;
b) Bavec M. et al. (2008 – 2010): J4-9532 Quality of food depending on agricultural production system;
c) Stajnko D. et al. (2010-2012): V4-1042 Research of alternative soil tillage systems on better soil fertility, increasing of humus and decreasing of CO_2 emission;
d) Bavec F. et al. (2012-2014): V4-1137 Alternative crops in different production and crop rotation systems as a basic parameter for adaptation to climatic circumstances for food and feed supply.

Projects were provided by University of Maribor, Faculty of Agriculture and Life Sciences and also the newest research papers were analyzed. The aims of review are suggestions for further development of tillage and production systems.

Results and discussion

Ploughing vs. direct sowings into cover crops

In autumn sowing - biennial (rye, Italian ryegrass) and spring sowing - annual cover crops (phachelia, white mustard) decreased soil erosion for 90% during growth period of maize. On the other hand uncovered soils after ploughing decreased runoff surface water from 30 to 50%. Thus, covered field surface and the method of treatment or pre-sowing preparation are found as very important factors influencing the reduction of soil erosion. But opposite to the expectations, also in rye sowing comes to extremely high soil erosion immediately after sowing, when the pre-sowing preparation is very fine. In contrast, the unstructured soils or open soils boost erosion especially in slope land. Yield of silage maize is not reduced after dead cover crops, but it is reduced after rye. There has been delay of maize development in early growth stages, especially in case of incarnatum. The main reasons are low temperatures of soil under cover crops and in case of rye the content of N_{min} in the soil after different tillage systems. Mineralization processes were slower after rye compared to white mustard, N was used by competition for decomposition of plant rests and maize yields were reduced eventhough rye plants accumulated about 60 kg N ha^{-1}. Dead cover crops accumulated about 90 kg N ha^{-1} in the autumn, which was available for the plants in the spring.

After 439.6 mm of rainfall in the period from October to April in case of loam to clay soils at slope field up to 27%, the sum of eroded soils are follows: a) in the treatment of ploughed open furrow from 2900 to 3450 kg of dry eroded soil ha^{-1}, b) on untreated field 1550 to 2800 kg of dry eroded soil ha^{-1} and c) on the plots sown with rye from 174 to 200 kg of dry eroded soil ha^{-1} were found. In the case of plowed fields before sowing was 83.2 kg NO_3-ha^{-1} and after rye 42.7 kg NO_3-ha^{-1} on the slope part of fields, but under hill slopes 112.9 kg and 78.3 kg NO_3-ha^{-1}, respectively. Emergence of maize plants delay 7 days in rye comparing with ploughed field, but the final number of plants were similar among all treatments (81500, 82200 and 81000 plants ha^{-1}). Ploughed plots, untreated plots and rye treatments did not statistically differ in green mass yield (81.6, 83.7 and 81.0 t ha^{-1}) and grain yield (7.6, 7.6 and 7.3 t ha^{-1}), respectively.

In case of undersown clover into the maize plants in the heavy soils at University center the soil erosion was reduced, but due to the intensive growth of weeds (especially *Convolvulus* sp.) the system of undersown clover gave statistically lower yields and system was completely unsuccessful.

Production systems

The project was carried out on University centre of the Faculty of Agriculture and Life Sciences in Pivola in Maribor where in field experiment were produced different field and vegetable crops in two rotations (1- usual in the region, 2 – alternative) in four production systems: conventional, integrated, organic and biodynamic and in the control plots. Yields were significantly different between production systems in wheat and spelt with higher yields in conventional and, b integrated out for cabbage, beetroot and cucurbits has been a noticeable trend of higher yields in alternative systems. In experimental plots earthworms were determined in rotation 1 in October 2009 and 2010 using the 'hot' mustard extraction. Earthworm populations and their biomass were significantly higher and similar levels of biodynamic and organic plots compared to conventional and integrated in all studied crops where the highest value were found on plots with oil pumpkins. The next section focuses on the environmental footprint, using the included fixing life cycle assessment (LCA - Life-Cycle Assessment), which is still under development for use in agriculture. For the purposes of the research for the calculation was used the Sustainable Process Index ® (SPI) – a tool created by the Technical University of Graz (TU Graz). SPI's methodology was adapted for use in agriculture (Turinek et al., 2010). Three-year (wheat and spelt) and one year (other crops) data from long term trials and the field results reflected the real situation data and production systems were analyzed. Ecological footprint of wheat and spelt of organic and BD was 6-8 fold lower compared to conventional and production systems, but ecological efficiency of organic and biodynamic was 5-6 fold higher compared integrated to conventional production systems. The majority of ecological footprint is in conventional and integrated due to the use of pesticides and mineral nitrogen using a lot of energy in their production. But in the case of biodynamic and organic the majority was due to use of mechanization. The basic issue was how to make more sustainable production systems, which are largely used today and how they can be improved in order to increase sustainable food production for future generations. However, we found that improvements are needed in the mechanization in all investigated systems and also better yield of organic system. We have projected the magnitude of the change if any current arable land intended for wheat and spelt switching to organic and biodynamic. The yield (taking into account the relatively low yields in the ecosystem in our study) would be reduced by almost a third and partial footprint and footprint by almost two thirds. As consequence, the environmental performance of production increased threefold. For potentially lower yields in the future solutions and improvements will be needed in production techniques (tillage, fertilization, etc.), land use change (food production, altered rotation, the question of energy crops and sealing the best agricultural land), as amended subsistence policy. The changes are necessary as fossil fuels on which today is almost exclusively based industrial agriculture subsidy, and are expected by the end of this century as well spent. We concluded that uncertainty about oil reserves, rising energy prices and the threat of harmful climate change effects has intensified the search for alternative farming systems that reduce negative environmental impact. Thus, organic and biodynamic farming systems present viable alternatives for reducing the impact of agriculture on environmental degradation and climate change. Nevertheless, possibilities for improvement exists in the area of machinery use in all systems studied and yield improvement in the organic farming system (Bavec et al, 2012). In the next step we studied the sensory quality of white cabbage and red beets in 2008 and 2009. A total of 167 consumers evaluated the four properties (color, smell, taste and willingness to buy) using a nine-point hedonic scale. The results show significant differences between the two PS vegetables; better evaluated was cabbage from integrated control treatment versus conventional model (biodynamic and organic samples were in between), biodynamic and control samples of red beet were evaluated better than the conventional and integrated samples (organic samples were between). In two consecutive years (2008 and 2009) have been measured major macro and micro nutrients in fresh samples of cabbage and beetroot. We have also analyzed different sugars, organic acids, total phenolic compounds and antioxidant activity in samples of beetroot and cabbage in 2009, using established methods. Statistically significant differences between production systems in red beets were found for the content of malic acid, total phenolic content and total antioxidant activity. Characteristically malic acid was present in samples from the control plots, which are followed by samples from biodynamic plots. Conventional, integrated and organic samples contained significantly less malic acid than samples from control. Excretion of malic acid through roots activates the bacteria living in the area around the roots and stimulates their interaction with plants. Plants of "friendly" bacteria also establishing resistance to a wide range of foliar diseases through the activation of plant defense systems. Furthermore, they have samples from a biodynamic and control plots significantly higher content of total phenolic compounds than samples from conventional plots. Even with antioxidant activity samples from biodynamic and control plots had higher values than samples from conventional plots. There is also a significant positive linear correlation between the total phenolic content and antioxidant activity (r^2 = 0.6187), which coincides with the results of studies in other vegetables. Finalizing work on the quality of beetroot, we researched, is presented the importance of the measured ingredients for human health, as well as the resilience and health of the plants and we put them in perspective for the future. In the growing seasons 2008-2010 we had a similar experiment at additional sites in the area Goricko Natural Park, but with less studied crops (wheat, cabbage, beetroot and oil pumpkins) and three production systems (conventional, integrated and organic) and a control treatment. Sensory quality of cabbage and beetroot were tested for processed products (sauerkraut and beetroot juice). Based on the results of this experiment the broader impact of different production systems were studied, namely, agronomic, environmental and economic efficiency of production systems, the impact on crop quality parameters and a framework of indicators which included agronomic, environmental, economic and social indicators were established. In 2010, we also conducted an epidemiological study in which the two test groups of people ate differently, ranging from 63 students 31 got organic and 32 conventional food diets for three consecutive days. The results have confirmed the hypothesis of the effect of diet on the presence of pesticides in human body fluids – students eating organic had less organophosphorous compounds in the urine.

Comparison of ploughing, conservation tillage and direct sowing

In three year field experiment with three treatments, the ploughing and conservation tillage incl. ripping did not result in significantly different yields, but direct sowing reduced the yield of rotated crops (corn-wheat-rapeseed). The values of humus in both locations in all three treatments increased, but between treatments were not shown statistically significant differences. In experiments the organic matter transported to the fields was estimated and share of accumulated carbon was 10-15% higher, which is less than was found in the literature without removal of crop residues, which increased organic matter in the soil for 21 and 7%. The most important results are direct measurement of CO_2 emissions from the soil by plants using LC PRO + ECHO. The highest CO_2 emissions of 13.94 μmol $m^{-2}s^{-1}$ were measured immediately after treatment of the soil with a plow during the first 24 hours. Followed by treatment with loosening where we measured the maximum value of 11.54 μmol $m^{-2}s^{-1}$ CO_2 also immediately after treatment. In the next days emissions were equal to the emissions in the raw soil and reach values 3.54 to 6.32 μmol $m^{-2}s^{-1}$ CO_2), partly due to dehydration of the surface layer of soil and unexplained causes. These findings are partly consistent with literature where the highest recorded emission was almost 15 days after disc harrows without tillage. The dynamics of CO_2 emissions in the Slovenian agro-ecological conditions are mostly affected by fluctuations in temperature, which match with the reporting of Bruce et al. (1999). Lack of rainfall was correlated with reduced emissions only in extreme summer droughts. In contrast to some other experiences we have in the winter mostly positive measure CO_2 emissions, but do not exceed 0.29 μmol If the ground was frozen for several days in a row, has been measured negative CO_2 flux $m^{-2}s^{-1}$ with a maximum of 0.12 μmol. Different systems had significantly different fuel (plowing + pre-sowing preparation of 23 l ha^{-1}, loosening 13.60 l ha^{-1}, direct sowing of 21 l ha^{-1}), but the savings in fuel and working time can be quickly lost due to the increased application of herbicides. We found that for the production of rapeseed and ecological footprints left by the plow treatment (4.25 ha), followed by ripping (3.75 ha) and direct sowing of 1.95 ha. Even in the cultivation of maize direct sowing resulted in foot print of 1.85 ha, while the largest footprint re-calculated in the conventional treatment (4.15 ha). The most objective assessment (expressed in ha/t crop) showed that the production of one t of oilseed rape left the biggest footprint (9.2 ha/t of grain) left the conventional cultivation of oilseed rape, the smallest (2.86 ha/t) conservation tillage of maize. Ecological footprint of production of one t of above-ground biomass fraction is significantly greater in the conventional production of rapeseed (4.14 ha t^{-1} of grain), followed by production of winter wheat and maize with absolute minimal footprint (2.86 ha t^{-1}) in conservation tillage (Stajnko et al., 2010-2012).

Crop rotation in different production systems

The study of rotation in different production systems incorporating alternative crops shows significant differences among yields in conventional, integrated and organic treatments. Till now we can conclude that chemical composition of dwarf French bean (*Phaseolus vulgaris* L.) cv. Top Crop was compared among five production systems: conventional, integrated, organic, and biodynamic production systems and the control. Determination of sugars and organic acids was performed with a HPLC system, and identification of individual phenolic compounds using HPLC-MS. The chemical composition of the beans was unaffected by the production systems; however, levels of individual compounds contents were changed. The pods from integrated production contained the lowest levels of glucose and sucrose and the highest levels of catechin, procyanidin dimmers and a vanillic acid derivative. The control treatment, organic and biodynamic production systems, positively affected the levels of sugar content and caused a lower content of catechin and *trans-p*-coumaroylaldaric acids. Beans from the conventional production system contained the lowest levels of fructose, glucose, ascorbic acid, and many phenolics from various groups (Jakopič et al., 2013).

Situation in practice

In flat Eastern part of Slovenia in Podravje and Prekmurje region production system was changing from conventional to integrated (about 25%) and organic (7%), where tillage system is still based on ploughing and separate pre-harvest treatments. But, 30-40 years ago, the systems like direct sowing and similar concepts of 'conservation' tillage were not accepted by professionals. Because of the costs, the company Perutnina Ptuj, started with no-ploughing tillage for winter cereals, and even with spring glyphosate treatments before sowing (it was not allowed in integrated system). Two framers started with direct sowing (one in maize, one in sugar beet). For now is only one who represents success of direct sowing with special activities (crop rotation, deep ripping, care for organic matter, weeding) in the scope of soil conservation.

If we compare upper results (3.1-3.5) with recent literature we can agree that reduced tillage systems have been proposed to prevent soil erosion while the present increase of no-till is motivated mostly because of the decrease of production and mechanization costs. However, the efficiency of the numerous no-plough tillage systems on erosion control is not systematic. The soil must be sufficiently covered by crop residues and the infiltration rate has to remain high enough (Roger-Estrade, 2011). Conservation tillage is a system of management that leaves at least 30% of the soil surface covered by residue between crop harvests and planting, which increases bulk density in the absence of cultivation and may lead to decreases in soil aeration, increases soil organic carbon (SOC) at or near the surface of the soil profile and increases soil microbial biomass and diversity (Page et al., 2013). The soil biological activity depends on the organic matter supply. In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates and improves the water holding capacity of soil. Most soils contain 2 to 10% organic matter. However, even in small amounts, organic matter is very important. Tillage is one of the major practices that reduce the organic matter level in the soil. Each time the soil is tilled, it is aerated. Soil enzymes act as biological catalysts of specific reactions that depend on a variety of factors, such as the presence or absence of inhibitors, tillage and fertilization, and can be considered as early indicators of biological changes (Mohammadi et al., 2011). But, the presence of plant diseases and weeds may also increase, where crop disease and weed growth, a lack of plant available nutrients, and/or adverse soil structure limit plant development, lower yields may also be observed (Page et al., 2013). According to Scopel et al. (2013) conservation agriculture has been promoted as a way to reduce production costs, soil erosion and soil fertility degradation. However, these effects are mostly result of the permanent presence of organic mulch on the soil surface and the incorporation of cover crops in the rotations. Such modifications require a significant reorganization of the production process at farm level, and when facing technical or socioeconomic constraints, most farmers usually decide for applying only partially the three main principles (Da Silva et al., 2013) of conservation agriculture. Investigating more fully the consequences of such partial implementation of conservation agriculture principles on its actual efficiency and assessing the most efficient participatory approaches needed to adapt conservation agriculture principles to local conditions and farming systems are top priorities for future research (Scopel et al., 2013).

As we found by analyzing foot prints, we agreed that adoption of recommended management practices is crucial to reverse the environmental footprint of agriculture and its impact on climate change. Regarding croplands, these practices can include reduced tillage systems, crop residue management, improved management of nutrients and pests, cover cropping, agro forestry, and utilization of precision agriculture technologies. Judicious implementation of related policies would be crucial for promoting the required links between agricultural production and environmental sustainability (Stavi and Rattan, 2013). There is a trend world-wide to grow crops in short rotation or in monoculture, particularly in conventional agriculture. Numerous factors have been hypothesized as contributing to yield decline, including biotic factors such as plant pathogens, deleterious rhyzosphere microorganisms, mycorrhizas acting as pathogens, and allelophaty or autotoxicity of the crop, as well as abiotic factors such as land management practices and nutrient availability. Despite long-term knowledge of the yield-decline phenomenon, there are few tools to reverting longer crop rotations or break crops. Alternative cropping and management practices such as double-cropping or inter-cropping, tillage and organic amendments may improve the negative effects seen when crops are grown in short rotation (Bennett et al., 2012). Karlen et al. (2013) conclude that with good nutrient management, crop rotation and yield; soil fertility differences between no-tillage and more intensive tillage systems can be minimized and that no-till production can be profitable on glacial till derived soils. Žugec et al. (2006) concluded that under hypogley soil and certain environmental conditions it is possible to apply reduced soil tillage and moderate N fertilization in maize and soybean as previous crop. Jug et al. (2011) found that tillage systems had significant effects on the yields and plant characteristics of wheat and soybean depending on year. Alternative tillage systems compared with conventional tillage gave similar or slightly better 1000 grains weight represents as an even - handed replacement for conventional soil tillage with alternate ploughing for previous crop or with autumn disc harrowing + chiselling.

Organic farming is conserving and utilizing soil, supports ecosystem services, and is more sustainable method of food production than conventional farming. However, conventional farms had significantly greater yield than organic farms, and there was no apparent trade-off between increasing yield and the level of supporting ecosystem services. The organic farms in this study appear to have been intensively managed, with a straight substitution of organic inputs for chemicals but little other efforts to enhance soil fertility. For example, the organic farms applied large quantities of manure compared to conventional farms but conducted mechanical weeding (harrowing), whereas conventional farms applied herbicides (Williams and Hedlund, 2013). Organic agriculture relies on a number of farming practices based on ecological cycles, and aims at minimizing the environmental impact of the food industry, preserving the long term sustainability of soil and reducing to a minimum the use of non renewable resources. Furthermore, organically managed soils have a much higher water holding capacity than conventionally managed soils, resulting in much larger yields compared to conventional farming, under conditions of water scarcity. Because of its higher ability to store carbon in the soil, organic agriculture could represent a means to improve CO_2 abatement if adopted on a large scale. Furthermore, the impact on biodiversity is highlighted: organic farming systems generally influence larger floral and faunal biodiversity than conventional systems. Gomiero et al. (2011) outline energy use in different agricultural systems: organic agriculture has higher energy efficiency of (input/output) but, on average, exhibits lower yields and hence reduced productivity (Gomiero et al., 2011).

Conclusions

Based on the review of analyzed projects and the newest literature we can conclude that sustainable production and tillage systems needs to be interdisciplinary researched and involved into the practice. There is no general rule for tillage systems because of soil texture and their physical conditions associated with climate differences. We suggest that optimal tillage and production systems need to be evaluated based on many impacts like energy use, energy costs, foot prints, environmental pollution, food safety, etc. and not just according to amount of yield for every region, soil type and farm.

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