Главные редакторы: Виктор Г. Сычёв и Лотар Мюллер

НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том IV Оптимизация сельскохозяйственных ландшафтов

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NOVEL METHODS AND RESULTS OF LANDSCAPE RESEARCH IN EUROPE, CENTRAL ASIA AND SIBERIA

Monograph in 5 Volumes

Vol. IV Optimising Agricultural Landscapes

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Коллектив авторов и редакторов под руководством В.Г. Сычёва (Москва), А.Х. Шеуджена (Краснодар), Ф. Ойленштайна (Мюнхеберг).

Главные редакторы: Лотар Мюллер (Лейбниц центр агроландшафтных исследований, Мюнхеберг, Германия) и Виктор Г. Сычёв (Всероссийский научно-исследовательский институт агрохимии им. Д.Н. Прянишникова, Москва, Россия)

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Chapter IV/64: TILLAGE DEPTH AND CROP YIELDS: RE-EVALUATION OF LATE HOLOCENE SOIL TILLAGE TRIALS IN EASTERN AND CENTRAL EUROPE

Глава IV/64: Глубина обработки почвы и урожайность сельскохозяйственных культур: переоценка опытов по обработке почвы в Восточной и Центральной Европе в условиях позднего голоцена

Lothar Mueller1,2; Frank Eulenstein1,2,3; Blair M. McKenzie4; Uwe Schindler2,3; Wilfried Mirschel1
DOI 10.25680/1929.2018.23.16.329
* Email: agrarlandschaft@gmail.com; mueller@zalf.de
1. Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Muencheberg, Germany
2. Kuban State Agrarian University, 13 Kalinin Str., 350044 Krasnodar, Russia
3. Mitscherlich Academy for Soil Fertility, Prof.-Mitscherlich-Allee 1, 14641 Paulinenaue, Germany
4. The James Hutton Institute, Invergowrie, Dundee, DD2 5DA, UK

ABSTRACT. The need for soil tillage and its appropriate depth and procedures has been key questions of plant cropping and design of agricultural landscapes worldwide. We re-evaluated the largest series of international soil tillage trials, ever conducted. They were carried out on 50 locations in 8 countries of Eastern and Central Europe from 1955 to 1967. Framework conditions were Late-Holocene: Mechanized tillage and cropping technologies and organo-mineral fertilisers were available, whilst fungicides, herbicides, pesticides and hybrid seeds were little applied or not available during that time. Rotations were wide and balanced. These conditions come close to current organic farming systems. We analysed a multivariate set of more than 4,000 crop yield meta-data. Results revealed strong effects of soil fertility (as evaluated based on the Muencheberg Soil Quality Rating) and of organo-mineral fertilisation on crop yields, whilst soil tillage depth had lower and site-specific effects. Ploughing led to higher crop yields due to better suppression of weeds and mineralisation of plant nutrients. On humid sites in Europe without erosion risks, in a well structured agricultural landscape, the moldboard plough should be an inevitable part of productive and sustainable cropping systems.

Резюме. Необходимость обработки почвы, ее оптимальная глубина и приемы были ключевыми вопросами растениеводства и создания сельскохозяйственных ландшафтов во всем мире. Мы выполнили переоценку международной серии опытов по обработке почвы, крупнейшей из когда-либо проводившихся. Опыты были проведены в 50 географических точках в 8 странах Восточной и Центральной Европы с 1955 по 1967 гг. Рамочные условия – позднеголоценовые: использовались механизированные технологии обработки почвы и возделывания сельскохозяйственных культур, органические и минеральные удобрения, тогда как фунгициды, гербициды, пестициды и гибридные семена в то время применялись мало или отсутствовали. Севообороты включали широкий набор культур и были сбалансированными. Эти условия близки к современным системам органического сельского хозяйства. Мы проанализировали многометрический массив из более чем 4 тысяч метаданных, относящихся к урожайности сельскохозяйственных культур. Результаты выявили выраженные эффекты плодородия почвы (оцененного на основе Мюнхебергской системы рейтинга качества почвы), органических и минеральных удобрений на урожайность. Эффект глубины обработки почвы был ниже и зависел от местоположения. Вспашка повышала урожайность культур благодаря лучшему подавлению сорняков и минерализации питательных веществ в почве. В условиях влажного климата в Европе и отсутствия рисков эрозии, в хорошо структурированном сельскохозяйственном ландшафте, отвальный плуг должен быть необходимой частью продуктивных и устойчивых систем земледелия.

KEYWORDS: soil tillage, tillage depth, ploughing, fertilisation, experiment, international cooperation

Ключевые слова: обработка почвы, глубина обработки почвы, вспашка, удобрение, эксперимент, международное сотрудничество

INTRODUCTION

Soil degradation by wind, water and tillage erosion often associated with soil compaction continues worldwide. Intensive and repeated soil tillage, and particularly the use of the moldboard plough, has been blamed for this damage [1]. European settlers transferred this plough from their homelands, which were
characterized by temperate humid and sub-humid climates, into drier regions of other continents, where soil erosion by wind, water and translocation of soils by the plough itself quickly destroyed fragile soils. In Europe, agricultural soils have a long cultivation history. Measures of humus enrichment and deepening of the humic layer were successful [2]. This was done by soil tillage and permanent input of organic material, mainly dung of animal husbandry. Nowadays, under the conditions of the mainstream agro-industrial production, which is typical for the beginning Anthropocene [3], the need for soil ploughing or soil tillage is generally questioned in Europe as well [4].

THE ROLE OF SOIL TILLAGE
Tillage has played a crucial role in soil and plant management. However, functions and specifics of tillage have changed. Across some centuries, tillage had four important functions: (i) creating a loose and crumbly seedbed of optimum soil physical and hydrological conditions for enabling seeders to put seeds into the desired depth, and to provide fast seedling germination and even emergence of crops, (ii) incorporation of plant residues, dung and other fertilisers into the topsoil, (iii) loosening the soil, thereby inducing mineralization of organic matter for plant nutrition, and (iv) suppressing competing plants (weeds) by burial. The moldboard plough seemed to be the optimum tool for fulfilling functions (ii), (iii) and (iv) in a basic tillage process, whilst tillage for function (i) was often done later in a separate work stage using special tools and implements (secondary tillage).

All these four functions are still desired in organic farming, many kinds of horticulture, and some subsistence and low-input systems. Contemporary conventional high-input farming systems including conservation tillage systems have replaced function (iii) by mineral fertilizers and function (iv) by herbicides. Sophisticated seeders are able to fulfill (i) without tillage, and they are able to operate whilst plant residues could stay above the soil surface (no need for (ii)) forming a shelter against erosive forces. Finally, tillage can be reduced in many cases of conventional farming and questioned at all in case of No-Till [5,6].

Conservation tillage e.g. ploughless tillage flanked by further principles of conservation agriculture like crop rotations and plant residue management [7,8] plays a crucial role in the concept of “sustainable intensification” [9,10]. Its climate-mitigating effects in many soils [5] and positive influence on soil biota [11,12] backed the image of ploughless agriculture as a sustainable and green technology [13].

IS CONSERVATION TILLAGE A SUSTAINABLE SOLUTION FOR EUROPE?
Conservation tillage can be applied successfully for mitigating or preventing soil erosion from large fields. Though slightly lower crop yields, under humid climate conditions in particular [14] it is a viable option for European agriculture from the viewpoint of agricultural productivity [15]. Positive effects on soil biota are evident. D’Hose et al. (2018)[16] extracted data from more than 60 European multiyear field experiments. They found that non-inversion tillage (tillage without ploughing) and organic amendments increased the presence of soil biota.

However, the success of reduced tillage and No-Till technologies largely depends on agrochemicals. Because of rapidly declining biodiversity in Europe, those measures have become under increasing public pressure. The case of glyphosate, an indispensable part of large-scale conservation tillage, viticulture, and pomiculture, has reached the level of political decisions [17]. Overall, the key position and effects of herbicides and other agrochemicals (stem-stabilizer, fungicides) in those systems remains underestimated. Because some weeds became resistant to glyphosate [18], application rates increase. For improving the performance of glyphosates against weeds, more genetically modified glyphosate-resistant crops were created, whose can also spray beyond agricultural lands [19]. Meanwhile, glyphosates have been detected in soil, water and the food web, influencing faunal communities and their metabolism [20, 21, 22, 23].

Peigné et al. (2018) [24] found that under conditions of organic farming, tillage without plough (conservation tillage) had no positive effects on soil and biota. It led to soil compaction and limitations of rooting. Also creatures of higher positions in the food web like birds, cannot benefit from conservation tillage but suffer from damage of agrochemicals [25]. In major tillage trials in UK, characterized by a humid climate, no benefits of non-inversion tillage for crop yields and carbon sequestration were found [26]. Detrimental effects of non-inversing tillage on higher mycotoxin infestation of cereals as compared with ploughing, are evident for humid regions of Europe as well [27,28]. This requires more fungicides.

Monitoring and permanent thinking about the usefulness and sustainability of tillage systems is a need. This should include balances and risk assessment of all main elements of the agricultural system, aspects of design and function of the landscape included. Besides the mainstream of large-scale cropping systems
without ploughing (non-inversing tillage, reduced tillage, conservation tillage, no-till) the search for better solutions in order to achieving sustainability of cropping system in Europe should go on.

THE LARGEST SERIES OF INTERNATIONAL SOIL TILLAGE TRIALS, EVER CONDUCTED

Which tillage depth is optimum for cropping systems under the conditions of no herbicides, pesticides, and fungicides? Historical tillage trials could help to find answers.

The largest series of agricultural trials in Central and Eastern Europe was conducted during the years 1955-1967. Effects of different soil tillage depths and fertiliser rates were tested on 50 locations in 8 countries [29]. Trials were coordinated by the former “Institut für Acker- und Pflanzenbau” in Muencheberg, Germany. Results of these experiments were published in a report “International cooperation trials for deepening the soil’s A horizon (Internationale Gemeinschaftsversuche zur Krumenvertiefung [29]).

Each mentioned field trials contributed limited data but only a minority delivered statistically significant results. Any advantage of deepening the A horizon occurred on only a few soils, whilst positive effects of organic and mineral fertilisation were significant in most cases [29].

Table 1: Experimental locations

<table>
<thead>
<tr>
<th>Country</th>
<th>Location names</th>
<th>Range of Climate¹</th>
<th>Soils²</th>
<th>Range of M-SQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulgaria</td>
<td>Kostinbrod, General Toshevo, Gorni Lozen, Russe, Slovotin, Sofia, Stara Zagora</td>
<td>471-962</td>
<td>Chernozeems, Gleysols, Phaeozems, Luvisols</td>
<td>52-78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.0-12.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>Prag-Ruzyne, Bystrica, Piestany</td>
<td>490-864</td>
<td>Cambisols, Luvisols, Phaeozems</td>
<td>72-85</td>
</tr>
<tr>
<td>(East) Germany</td>
<td>Closewitz, Frauenprießnitz, Hirschfeld, Müncheberg, Seehausen, Siggelkow, Trossin, Troll, Wollup</td>
<td>470-671</td>
<td>Luvisis, Stagnosols, Albeluvisis, Arenosols, Cambisols, Gleysols</td>
<td>42-87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.9-8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>Brody, Chylice, Czeslawice, Dobrogostow, Laskowice Olawskie, Lawica, Lezany, Lipki, Malyszyn Wielki, Posorty, Swojec, Werbkowice</td>
<td>515-630</td>
<td>Cambisols, Phaeozems, Luvisis, Chernozeems, Albeluvisis, Fluvisols</td>
<td>51-96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.1-8.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romania</td>
<td>Cenad, Fundulea, Lovrin, Marculesti, Secuierii, Stefanesti-Arges, Suceava, Tartul Frumos,</td>
<td>491-950</td>
<td>Chernozeems, Phaeozems, Kastanozeems, Luvisis, Stagnosols</td>
<td>70-83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.9-11.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>Debrecen, Tregszemecse, Jak, Karac, Kenyeri, Kompolt, Mariettapuscza, Penyige, Szeged</td>
<td>541-769</td>
<td>Chernozeems, Gleysols, Solonetzes, Cambisols, Luvisis</td>
<td>52-87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.2-10.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia, Belorussia</td>
<td>Menkovo, Ustje</td>
<td>620-708</td>
<td>Albeluvisis</td>
<td>57-58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.1-5.1</td>
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</table>

¹ Annual precipitation (mm), average annual temperature (°C), ² Dominating Reference Soil Groups [30]

RE-EVALUATION OF THE HISTORICAL TRIAL SERIES

We created a set of more than 4,000 meta-data. Besides factors of tillage depth and fertilizer rates, the data set includes soil, and climate data, data for weeds and others. Soil and climate data enabled a bonitation of the overall soil quality as assessed by the Muencheberg Soil Quality Rating (M-SQR) [31, 32].

Factor analyses revealed strongest influence of the overall soil quality (M-SQR score) and of the organo-mineral fertilization on yields of all crops. This is also visible in Figure 1. It shall show general trends. Most important is the crop yield level not lower than 25 dt/ha in all fertilised variants.
Tillage depth had minor influence on yields. Without fertilization, a slight positive influence is visible, whereas there was no clear effect on fertilised plots. Inconsistencies are due to site-specific tillage implements and other factors. For example, in case of cereals shown here, deep tillage was a secondary effect in many cases. Variants tilled deeper than 25 cm experienced this deep tillage for the preceding root crop. Tillage depths of 25-30 cm were created by ploughs (deep blue bars) in the very most cases. This variant was best on the majority of soils, on good and very good soils in particular. The reason was effective weed control through ploughing, thus leading to increased crop yields. Root crops showed
positive correlations with deep and regular soil tillage. Experiments of Koch et al. (2009) confirmed this [33].

As poor sandy soils are easy to till and to manage, also intensive shallow tillage provided good weed control, whilst deep ploughing of 25-35cm brought up too much infertile subsoil into the seedbed zone. Without organo-mineral fertilisation this led to yield depressions over several years. Deepening the humic horizon or loosening the subsoil showed a tendency of yield improvement on a few sites. It should be noted that deep tillage is a special kind of tillage. Tillage depth exceeds the depth of the current ploughing (Ap) horizon in most cases. Stepwise deepening of the topsoil horizon by burial of organic material and compensation of this loss in the upper layer thru organo-mineral fertilisation could be an interesting option for carbon sequestration. Under typical humid conditions of Europe, not ploughless tillage, but casewise deep tillage could be a useful tool of climate smart agriculture. Technical solutions for the approach of “Partial deepening of A-Horizon” had been developed and tested already in the 1970s and 1980s [34, 35, 36]. A meta-data analysis of deep tillage trials conducted by Schneider et al. (2017) [37] on other sites in Europe revealed that mean deep tillage effects on crop yield showed huge variability but was slightly positive (+6%).

CONCLUSIONS
1. Analyses of long-term agricultural trials can be useful for defining horizons of future cropping systems. To understand consequences of limiting the use of herbicides, fungicides and other pesticides, the horizon of the 1950-1965 years could serve as a model.
2. This time period is close to the boundary between Late Holocene and Anthropocene. Trials under study fell into this period. Eastern European agriculture was characterised by mechanized soil and crop management, moderate field sizes, wide and balanced crop rotations, application of mineral and organic fertiliser, but only marginal application of herbicides, fungicides and pesticides at this time.
3. Mineral and organic fertilisation is essential for all soils to maintain soil fertility through compensating soil nutrient losses due to harvest withdrawals and leaching, and for maintaining the humus level, which has a complex function in soils.
4. Principles and procedures of soil tillage depend on site-specific factors. Erosion risk is a key criterion. If this risk is not evident or can be eliminated by landscape design, for example, by buffer strips or reducing field sizes, soil tillage is a proven method for achieving high soil productivity.
5. Soil diagnostic criteria such as strength, density and water status are decisive for the choice of basic tillage procedures and depth of tillage [38]. In the humid and sub-humid zones, the moldboard plough is a proven device for basic tillage. It is most effective for the suppression of weeds and reduction of fungi infestation in cereal-dominated rotations, and for providing a good soil structure for root crops.
6. Based on the status of soil and crop rotation, flexibility in the choice of tillage procedures is needed. Phases of reduced tillage or no-till can be included into rotations.

APPENDIX: PHOTOS OF TILLAGE AND ITS EFFECTS

Photo 1, 2 - Moldboard ploughing is a traditional technology of basic soil tillage. It was the dominating technology worldwide about until 1970. Due to accelerated soil erosion caused by ploughing and broad availability of glyphosate for weed control, ploughing is increasingly replaced by non-soil-inversing technologies, reduced tillage or No-Till. On soils without erosion risk, ploughing could experience a renaissance because of its effectiveness for mechanical weed and fungi control.
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