Piotr Jakubowski

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REDUCED TILLAGE REGENERATIVE CULTIVATION

CEE REGENERATIVE AGRICULTURE GUIDEBOOK

TERRA NOSTRA FUNDACJA

eit Food

Co-funded by the European Union

CEE REGENERATIVE AGRICULTURE GUIDEBOOK - REDUCED TILLAGE REGENERATIVE CULTIVATION

Author:
Piotr Jakubowski

Graphic design:
Maciej Wilgosiewicz
Piotr Krukowski
Agencja reklamowa Pixel Star

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The EIT Food Regenerative Agriculture Programme aims to support farmers across Europe in transitioning to regenerative agriculture. It promotes sustainable farming practices that not only positively impact soil quality but also contribute to the production of food with higher nutritional value. The EIT Food Regenerative Agriculture Programme includes on-site training for farmers, advising, as well as webinars and manuals on regenerative practices for specific crops, available to all interested farmers. Furthermore, we organise events promoting regenerative agriculture and carry out educational activities for consumers. Our approach is based on collaboration among various stakeholders, such as farmers, researchers, startups, the processing industry, and consumers, to jointly create beneficial and lasting conditions for the development of regenerative agriculture

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The Terra Nostra Foundation for Agricultural Development

The Terra Nostra Foundation for Agricultural Development was founded in 2019. Its aim is to promote the idea of regenerative agriculture as a holistic resource and environmental management system that takes into account the profitability and competitiveness of the agricultural business in the value chain.

The foundation's activities are based on the knowledge of practitioners and scientists who implement the Integrated Regenerative Production program. It is based on the conversion of farms to regenerative agriculture through training, practical support and the development of a thematic community. The result of the program is the Certificate for Integrated Regenerative Production, which is awarded by an independent certification body - Bureau Veritas. It serves as evidence of regenerative actions on the farm and a way to monitor the environmental benefits of agricultural management, respected by agri-food processors.

The Terra Nostra Agricultural Development Foundation is also the organizer of the International Forum for Regenerative Agriculture BIO_REACTION, which brings together an international group of experts, scientists, farmers and advisors from around the world.

More information at www.fundacjaterranostra.pl

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INTRODUCTION

(R)evolution in soil cultivation. Soil has been cultivated by humans since the beginning of time, however the tools and methods of soil cultivation have differed depending on the environmental and living conditions.

The differences in cultivation and difficulties related to it are a consequence of extreme diversity of soils, climates, soil profile, quality of subsoil, humus content, fertilisation and other factors. The constant search for ways to achieve the highest possible crop yields has contributed to the development of many technologies and methods of soil cultivation.

The history of soil cultivation started with a sokha, that is a two-arm tool with shares on ends, mixing organic residue and loosening the top layer in order to prepare it for sowing or planting the next plant. In time, after a widespread use of the next invention, which was the plough of various types, tillage had a number of negative consequences, the reversal of which turned out to be a recovery process taking many years. At the same time, around the world, as early as in the 19th century, more enlightened farmers started to search for no-tillage systems of soil cultivation. Practical experiments conducted in England by Alexander Beatson before 1828 mark the beginnings of shallow cultivation in place of tillage in agricultural production. In 1835 a Bohemian, Frantisek Horsky proposed a system of simplified cultivation in which he admittedly allowed the use of plough, but only if there was a need to turn fertile soil after soil components have been washed down into lower layers of soil. Apart from that, he recommended deeper loosening of soil without till at the depth of 15 cm, without turning the soil over.

At the turn of the 19th and 20th centuries in Poland Jan Owsiński, followed by other proponents of modern cultivation systems, described the effects of plant growth depending in the type of cultivation. As early as 120 years ago certain plant tropisms were described which indicated an increased potential of generative development in a controlled stress environment, i.e. in not fully ideal conditions, including cultivation conditions. A fully abundant environment leads to excessive overgrowth of plants through their vegetative development. In order to optimise the conditions to produce an increased number and quality of plant seeds it was recommended to use shallow cultivation and introduce strip and row sowing.

Since the end of the 20th century the Dry Farming system has been gradually implemented and spread in the United States, in which fields are ploughed once every two years at most in order to save the moisture in the soil. The experiments in France have also been striving for a few decades to cultivate only subsoil and reduce the cultivation of the whole topsoil. All these activities aim also to prevent soil erosion.

The effects of introduction and consistent application of reduced tillage cultivation are achieved as soon as in the first years after the change. Tests carried out in a farm after 10 years of reduced tillage show permanent changes taking place in the soil compared with the soil of neighbouring farms, practising traditional tillage system. The effect, which contributes to the increase of the production value of soil in a farm with reduced tillage, is a 2-9% increase in the ability of soil aggregates to expand, and thus an increase in sorption capacity of soil. At the same time, soils in traditional cultivation showed lower water holding capacity of capillaries by approximately 4%, which in the context of climate changes and availability of moisture in critical periods of the year may be of fundamental importance. The reconstruction of soil parameters increasing the flexible adaptability of crops and their adaptation to various conditions is otherwise known as regeneration. The ultimate objective we can achieve in this way is a safe level of productivity, while maintaining a uniform quality of healthy ingredients for food production.

Soil on a field cultivated in a regenerative system.
Photo credit: P. Jakubowski

Crops of cereals, papilionaceous plants (peas) and rapeseed in regenerative farms.
Photo credit: P. Jakubowski

2

TYPES OF SOIL

There is a wide variety of soil types in the world and they are distributed differently from region to region.

Their development was influenced by both geological changes which took place millions of years ago on the Earth, and the changes of the recent millennia and centuries, since historically humans started to use soil for production. Depending on the region, land topography, soil origin and type of management the diversity of properties influencing soil productivity changed over many years.

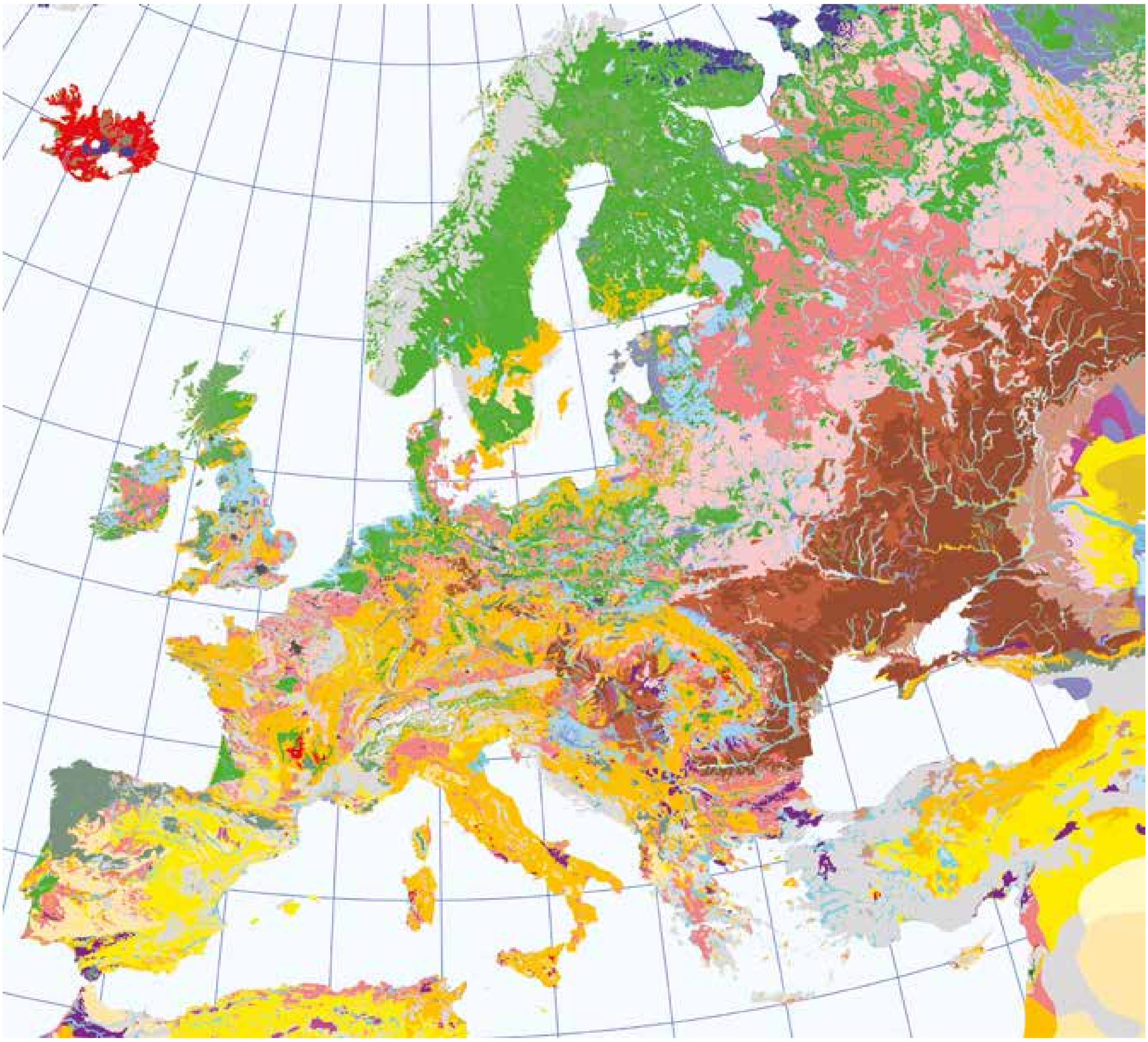
Zonal soils:	Azonal soils:
- Podzolic soils	**- black earths**
- luvisols	**- alluvial soils**
- brown soils	**- bogged soils**
- acid brown soils	**- rendzinas**
- czernozems	**- initial mountain soils**
	- anthropogenic soils

Zonal soils are those the occurrence of which depends mainly on the climate conditions of an area, including, among other things, climate and vegetation zonation, including to a significant extent, precipitation and temperature.

Azonal soils are those which have not developed a soil profile and occur due to human activity, among other things. They include alkaline, fertile soils formed on the basis of limestone and carbonate rocks, characterised by a high humus content, and shallow mountain soils.

In the very long history of soil use the factors determining soil crop-yielding potential changed too. Animal husbandry contributed to the improvement in soil properties, as the production of manure or other natural fertilisers which ended up in the fields improved their fertility. The increase in soil organic matter occurred also through cultivation of a larger number of species, that is richer crop rotation, and leaving crop residues in the field. Soil organic matter comes mainly from the residues of plant and animal matter, processed through humification by microorganisms and decomposed under the influence of temperature, moisture and intra-soil conditions. Organic matter plays the main role in maintaining soil life due to its effect on soil structure and stability. It also influences water retention, soil biological diversity and is a source of nutrients for plants. The main component of soil organic matter is organic carbon. The level of organic carbon, however varies significantly.

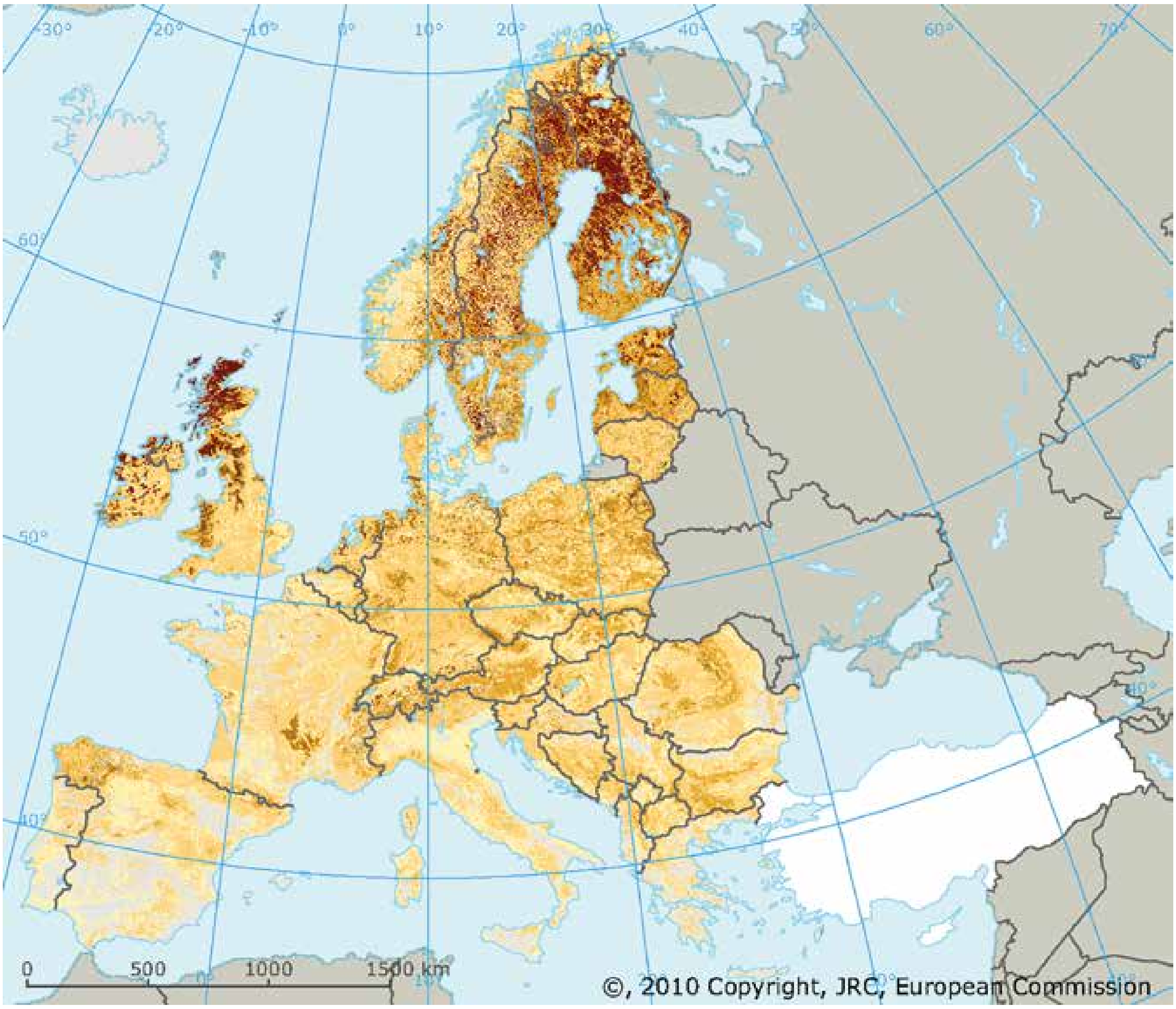
Map 1. The major soil types of Europe.



- **Albeluvisols:** *Acid soils with bleached topsoil material tonguing into the subsoil*
- **Andosols:** *Young soils developed in porous volcanic deposits*
- **Arenosols:** *Soils developed in quartz-rich, sandy deposits such as coastal dunes or deserts*
- **Calcisols:** *Soils with significant accumulations of calcium carbonate*
- **Cambisols:** *Young soils with moderate horizon development*
- **Chernozems:** *Dark, fertile soils with organic-rich topsoil*
- **Cryosols:** *Soil influenced by permafrost or cryogenic processes*
- **Fluvisols:** *Stratified soils, found mostly in floodplains and tidal marshes*
- **Gleysols:** *Soils saturated by groundwater for long periods*
- **Gypsisols:** *Soils of dry lands with significant accumulations of gypsum*
- **Histosols:** *Organic soils with layers of partially decomposed plant residues*
- **Kastanozems:** *Soils of dry grasslands with topsoil that is rich in organic matter*
- **Leptosols:** *Shallow soils over hard rock or extremely gravelly material*
- **Luvisols:** *Fertile soils with clay accumulation in the subsoil Phaeozems: Dark, moderately-leached soils with organic rich topsoil*
- **Phaeozems:** *Dark, moderately-leached soils with organic rich topsoil*
- **Planosols:** *Soils with occasional water stagnation due to an abrupt change in texture between the topsoil and the subsoil than impedes drainage*
- **Podzols:** *Acid soils with subsurface accumulations of iron, aluminium and organic compounds*
- **Regosols:** *Young soils with no significant profile development*
- **Solonchaks***: Soils with salt enrichment due to the evaporation of saline groundwater*
- **Solonetz:** *Alkaline soils with clayey, prismaticshaped aggregates and a sodium-rich subsurface horizon*
- **Stagnosols:** *Soils with stagnating surface water due to slowly permeable subsoil*
- **Technosols:** *Soils containing significant amounts of human artefacts or sealed by impermeable material*
- **Umbrisols:** *Young, acid soils with dark topsoil that is rich in organic matter*
- **Vertisols:** *Heavy clay soils that swell when wet and crack when dry*

Source: JOINT RESEARCH CENTRE, European Soil Data Centre (ESDAC)

Map 2. Variations in topsoil organic carbon content (%) across Europe.



Topsoil organic carbon content.

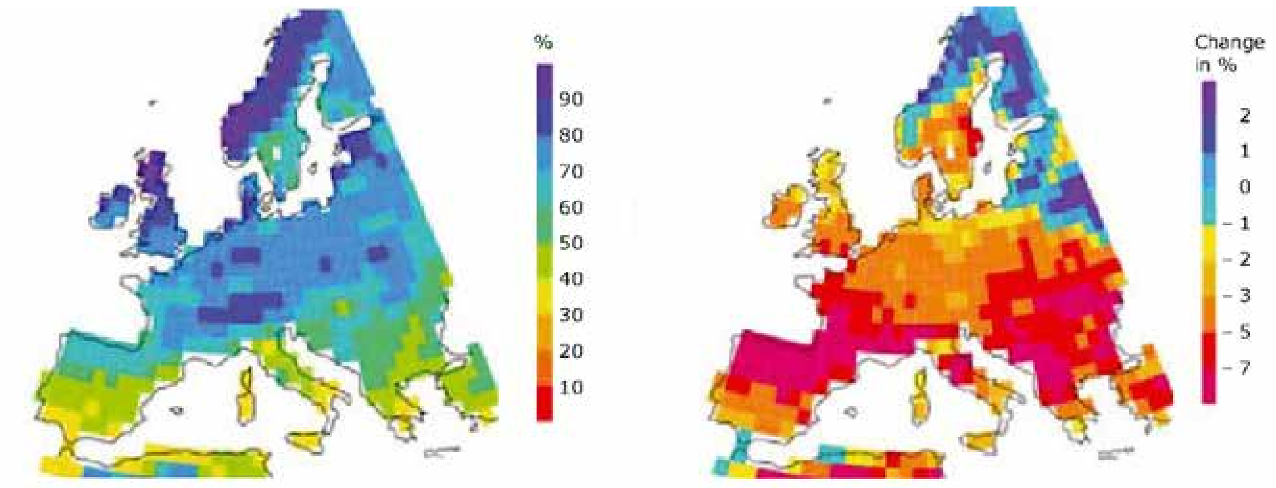
organic carbon (%)

- **0-1.0**
- **1.0-2.0**
- **2.0-6.0**
- **6.0-12.5**
- **12.5-25.0**
- **25.0-35.0**
- **>35.0**

- **No data**
- **Outside coverage**

Source: JOINT RESEARCH CENTRE

Map 3. Summer soil moisture conditions over Europe as for the period 1961–1990 (left) and projected changes for 2070–2080 (right)



Source: Simulated by the ECHAM5 global climate model

Almost 45% of mineral soils in Europe have low or very low content of organic substances, below 2%. Another 45% of European soils are characterised by the content of organic substance of 2-6%. Low levels are particularly prevalent in the countries of southern Europe. Approximately 74% of the area in this part of the continent is taken up by soils which contain less than 2% of organic carbon in the topsoil (0-30 cm). A low level of organic matter is not, however, restricted to the south of Europe. Areas with a low content of organic matter in soil can be found almost everywhere, including some parts of the northern countries such as United Kingdom, Norway, Belgium, Poland, and Germany. This is a result of mosaic-like nature of soils, as shown in map 1.

A reverse action is soil depletion, that is soil exploitation without the application of manure, together with poor crop rotation or monoculture. Such practises have an impoverishing effect on the soil. This was the practice in the past decades and still is in the current soil use and management. The activities which accompany the management have a huge effect on the most important properties of agricultural suitability of soil in the changing climate conditions. Currently, the most important properties which are directly related to the soil organic matter content, the level of regulation of physical and chemical parameters and soil biological life is the soil's ability to accumulate nutrients and water. These properties determine the soil site drought vulnerability.

In many regions, in particular in the south of Europe, we witness drying of watercourses, lowering of ground water levels, and, at the same time, torrential rains in excess of the normal levels. Decades of degradation of soils and natural environment have contributed to the increasing frequency of natural disasters which, directly or indirectly, affect farming. Therefore, it is fair to say that the time to restore natural soil condition is running out. All activities of regenerative farming aim to provide farmers with instructions to carry out farming in accordance with ideas of sustainable agriculture, without disturbing and putting a strain on nature. These activities are an exceptional chance to restore soil fertility and use soil potential in harmony with its natural assets. All this for the good of a farmer.

3 PHYSICAL AND CHEMICAL SOIL PROPERTIES AND TYPES OF CULTIVATION DETERMINED BY THEM

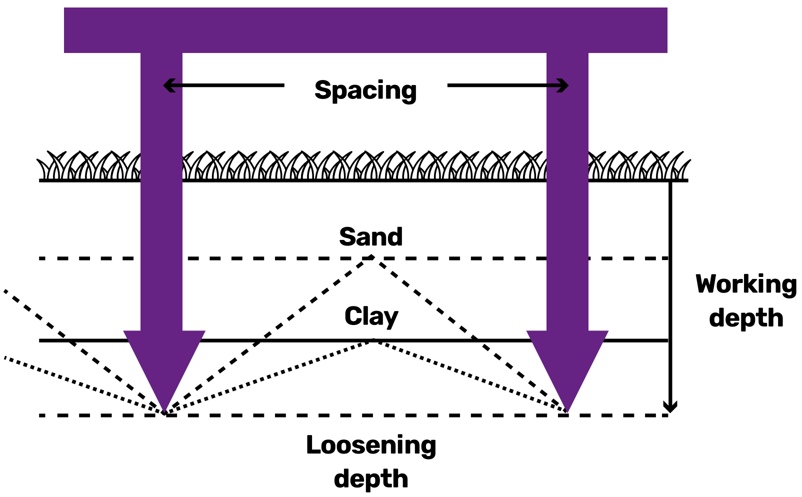
It is impossible to choose the right technology of soil cultivation without knowing its parameters and without assessing its current fertility, pH and general content of organic matter. The soil humus content, whether or not organic fertilisation is used on the field, whether there are crop residues on the soil surface after the harvest, whether a field with residues of aftercrops is to be cultivated, all these factors determine proper selection of machines shredding residues, mixing them with soil and loosening soil at the appropriate depth.

Depending on the type of soil, a different approach to selection of the reduced tillage technique is recommended, and so this applies to virtually all treatments. The tools, timing and working parameters will depend on the soil type, structure and moisture content.

The moisture content of the site is therefore crucial. Cultivation is based on the fundamental idea of regulating air-water relations through cultivation measures. The higher the moisture content of the soil, the more shallow the tilling should be. The drier the soil, the deeper the penetration with tillage tools should be.

One of the key parameters related to soil type which need to be considered at the beginning of tillage machine selection is the spacing of the machine working elements. This will be related to the working depth of the machine and the effectiveness of soil loosening achieved. On lighter, sandy soils, tillage should be carried out with a greater density of working elements, while on heavier soils, containing more clay fractions, the working elements can be spaced more sparsely.

Figure 1. Relation between the depth of soil loosening and the working depth on various soil types



This principle, using cultivator tines as an example, is presented in Figure 1, which shows how the working parts of the machine interact with the site in the soil profile. The heavier the soil, the deeper the impact site is located, and the lighter the soil, the more shallow the site. This means that as a result, a badly selected cultivator or subsoiler on a field with light soil will end up leaving uncultivated areas, so called virgin soil. Tillage carried out in this way will result in strip emergence and very unbalanced plant growth. This is due to unregulated air-water relations on the field surface. The result is uneven moisture content and an inadequately prepared zone for growth and development of plant roots. If the working elements, e.g. cultivator tines, are too densely spaced when cultivating medium soils, and even more so with the heavy soils, like alluvial or loessial soils, the effectiveness and efficiency of work will be considerably reduced, thus increasing the energy expenditure for the work. Therefore, special attention should be paid to matching machine parameters to the factors limiting the correct execution of cultivation treatments.

Factors positively affecting cultivation conditions:

- optimal moisture content in soil
- high humus content
- no excessive compaction
- regulated soil fertility and pH
- activity of soil organisms
- rich crop rotation – cultivating species with a deep root system
- using soil cover in order to accumulate nutrients and water

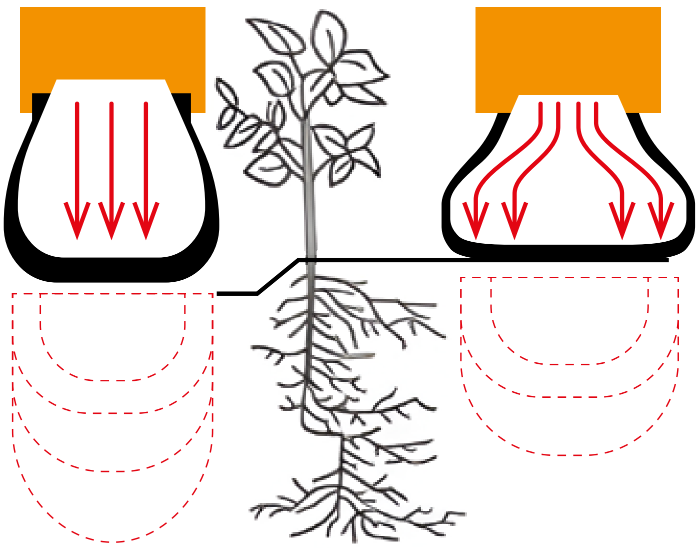
Factors with a negative impact on cultivation:

- excessive moisture content or overdrying of soil
- no organic matter in soil
- high soil compaction
- soils with unregulated pH and fertility
- no or limited biological life
- monoculture and cultivating the same species in succession in so-called short crop rotation, in particular with the use of machines degrading crumb structure of soil or reducing humus levels.

In order to improve the cultivation conditions soil should be protected against degradation occurring as a side effect of field work.

During the vegetation period the soil is compacted by passing machinery on average from 2.5 to as many as 8 times, therefore reducing the number of passes contributes to the lowering of percentage of over-compacted field area. With intensive cultivation, it is assumed that uncompacted area represents only 10% of the field. Soil compaction is promoted by excessive moisture content during cultivation, but also all other work and passes that take place in the field during the year. In reduced tillage this percentage is disproportionately higher. It can be assumed that the ratio of over-compacted to uncompacted areas is just the opposite, i.e. only 10-20% of the field is over-compacted. This includes mainly the area of tramlines and field headlands where the machine assembly has to turn around to conduct further work along the field.

Figure 2. Distribution of vehicle weight on a unit of area



The Figure shows the distribution of vehicle weight which with high tyre pressure has a much deeper effect than with reduced pressure, where the area of contact between a tyre and surface is wider and the compacting is more shallow. Therefore, the greater the surface area of the tyre or track chain of a vehicle, the lower the unit mass acting on soil per 1 sq. cm. Additionally, the figure shows the effect on plant root deformation in the compacted area.

Systems supporting the distribution of weight during field work:

- Specialist tyres which allow work with pressure reduced to 0.8 BAR,
- Twin wheels (double wheels, preferably on both axes of the vehicle) which provide a better weight distribution and improve traction,
- Application of continuous track systems in vehicles; single or double continuous tracks or a hybrid system, i.e. the rear fitted with a continuous track and the front with tyre wheels,
- Automatic system of regulating tyre pressure.
- A pass of a transport vehicle on an excessively moist soil causes soil compacting at various depth depending on the axle load:
 - 4 t per axle causes compacting up to 30 cm deep
 - 6 t per axle – up to 40 cm
 - 10 t per axle – up to 50 cm
 - 15 t per axle – up to 60 cm and more

According to various studies, the natural reconstruction of topsoil takes from six to more than ten years. A prerequisite for reconstruction in natural conditions is the occurrence of soil freezing and thawing processes at least to the depth of compaction. Another important factor determining a faster recovery of soil to its original loosening properties is the content of organic components and minerals. The higher the humus content, the faster the soil recovers. The best soils in this respect have the ability to recover their natural compaction after several cycles of moistening and drying. These are structure-forming activities.

A machine assembly in a farm adapted for controlled traffic farming. The basic working width in this example is 9 m.
Photo credit: P. Jakubowski

**CTF, Controlled Traffic Farming – a system of managing traffic in a farm which involves a reduction in the number of agricultural machinery passes and performing a number of treatments in one pass. The aim is to reduce soil compacting of the field caused by an excessive number of repeated passes.*

Depending on the quality of the soil and its moisture content during tillage and other field treatments, the compacting may contribute to the formation of stagnant water pools, which degrade the field. A site with a stagnant water pool, where drainage often does not function properly and a drainless basin collecting water with every rainfall is formed, is an infertile or unproductive part of the field. Roots do not have space to grow and bend in the initial development phase and as a result they can die due to excess water in the root zone.

Another effect of excessive passes, in particular in unfavourable conditions, is the formation of ruts in the field. Controlled traffic farming is an interesting solution which eliminates this risk.

In order to prevent this and to regenerate the soil when it occurs, several solutions are recommended:

- Repairing the drainage system and testing the soil at the site of stagnant water pool (possible soil acidification),

- Sub-soiling of the defective site,

- Introduction of additional organic matter – sowing deep-rooting catch-crops having a structure-forming effect is recommended,

- Preparing a soil regeneration plan through measures changing the cultivation system to reduced tillage, adapted to the site,

- Changing the direction of tillage and sowing in the field or introduction of modern solution of controlled traffic farming.

4

TYPES OF TREATMENTS IN REDUCED TILLAGE

In the regenerative cultivation system, the range of planned treatments is based on the most important assumption, which is that as few treatments as possible should be carried out and only those necessary to achieve the production objective.

Strip till sowing.
Photo credit: K. Strzelczyk

Therefore, the following principle for agricultural treatments applies: "As few as possible, as many as necessary"

The regenerative system involves treatments which introduce organic fertilisers into the soil, such as manure, compost or slurry, for example. Additionally, in this system of farming it is common to introduce various types of intercrops or winter catch crops. The accompanying measures are of course mineral fertilisation and liming or introducing various types of minerals which are important for the proper balancing of soil fertility and regulating its pH. All practices as well as the application of fertilisers and other production measures require the use of specific equipment and, as a consequence, determine the choice of solutions that will prepare the field for sowing in the best way.

Types of agricultural measures in the regenerative system:

- **Post-harvest shallow tillage with catch crop sowing,**
- **Deep tillage with direct sowing of catch crops,**
- **Subsoiling with a roller,**
- **Mulching of catch crops or cutting with knife rollers,**
- **Cultivating with a disc harrow,**
- **Cultivating with a cultivator with a roller,**
- **Strip till with sowing and an option of fertiliser application.**

Each of the applied treatments has a specific purpose, a capacity for optimal effect in specific conditions and certain work parameters, adapted to the needs. The choice of adequate treatments and the choice of machinery appropriate for carrying them out and finally the proper setting of work parameters is related to the type of site. What needs to be taken into consideration in this respect is the type of soil, the amount of crop residues and their condition, and whether there is an additional need to apply other treatment in order to shred them. It is also important to select an appropriate type of cultivation treatment depending on the amount of organic matter on the field surface and also if organic fertiliser is applied.

Post-harvest measures

The aim of post-harvest measures is to protect the soil against unproductive water loss and facilitating the germination of shed seeds or weeds present in the field after the harvest of forecrop. For this disc harrows, spring-tooth harrows or cultivators fitted with chisels of various width, duck-feet or a combination of the two are used. The desired depth of this type of tillage is very shallow: 1-3 cm. The work aims to evenly spread post-harvest residues, glumes and hay or leaves and stems residues as early as possible. The assumption is also to achieve the effect of light mixing of post-harvest residues and superficial cutting off of soil capillaries taking away moist from the soil directly after the harvest. Delicate covering or very shallow mixing of seeds of various species present on the field gives them a chance to germinate quickly and grow at the same time which makes it possible to remove them in subsequent treatments.

At the same time as shallow tillage, stubble intercropping can be carried out using a mounted spreader. During a pass with such an assembly, several treatments are carried out in one go, resulting in saving time, fuel, equipment, and human labour.

Post-harvest measure with a disc harrow after pea harvest.
Photo credit: K. Strzelczyk

Deep tillage with direct sowing of catch crops

In reduced tillage cultivation the primary aim is to conserve soil and operate in such a way as to regenerate the soil, enrich it with organic matter and maximise the use of the site between the main crops using cover crops. Deep tillage aims to introduce air into the deeper soil layer. Basically, this measure may play, in addition to the cultivation related to mixing crop residues, a similar role as a subsoiler, but at a slightly smaller depth. Machines for deep tillage have tines spaced more closely than a subsoiler, that is approx. 20-25 cm apart. Optimal work is carried out at the depth of 25 cm, but on more compact soils even up to 30 cm deep. The machines for such an operation usually have a higher power requirement, approx. 40-70 hp per running metre of a machine, but the effectiveness is then significantly higher than carrying out the treatments in conventional cultivation systems.

Additionally, the choice of chisels, their shape and width, the size of duck-feet, in particular their width, and additional fitting of soil mulching tines are the basic parameters of the working elements of machines. Their choice depends on the crop residues, organic fertilisation or other matter to be mixed with the soil. Sites after cereal crop, corn harvested for grain, but also sunflower, with a large amount of straw remaining on the field will require prior use of a mulcher. The advantage and the purpose of such a solution is additional shredding of plant stalks, destroying potential habitats for plant pests and speeding up the process of mineralisation of these residues after mixing them with soil.

Deep tillage and sowing catch crops in one pass.
Photo credit: K. Strzelczyk

Deep tillage is often technically supported by a tyre shaft or other type roller, e.g. a U-shaped cultivator roller, built from a C-channel section, or a clod crusher. In general, during the work of an aggregate rollers compact the top soil layer and possibly crush clods formed during cultivation. The function of the treatment is to regulate the air relations in soil by eliminating excessive aeration of seedbed and, at the same time, to prepare the site for sowing and enable the upper water movement from a deeper soil layer.

It is worthwhile to use soil mulching tines fitted on a cultivator for organic fertilisation on stubble after harvest. Thanks to them organic matter, fertilisers and crop residues are better mixed with soil and, as a result, decompose faster. During deep tillage it is useful to sow catch crops using mounted catch crop seeder or other type of seeder, for example a seeder with a disc sowing system.

Duck-feet can be used for a planned cutting of the root zone of catch crops during destroying their biomass before the winter resting period. The purpose of this treatment is to interrupt the vegetation, provoke the end of vegetation and speed up the decomposition of catch crops sowed after the harvest. They should decompose as much as possible during winter when the mulch plays a role of an anti-erosion cover and in the spring it will facilitate pre-sowing cultivation or direct sowing, e.g. using strip-till.

Treatments carried out during deep tillage:

- **Mulching (shredding crop residues),**
- **Proper deep tillage,**
- **Rolling,**
- **Postharvest sowing.**

Subsoiling with a roller

A subsoiler works with plough-beams spaced less densely, approx. 30-40 cm apart, but there are also subsoilers which have beams spaced 25-27 cm apart, which can then perform deep tillage. Such a solution in the regenerative system is recommended on sites following harvest of crops such as sugar beet or potatoes. In the cultivation of root crops the timing of harvest often falls in late autumn when the weather is more rainy. Heavy transportation equipment, mainly combine harvesters, may then cause compacting of soil, in particular topsoil. Subsoiling combined with a roller, e.g. a spike roller, recreates the crumb structure, first by aerating the whole profile in the work area, that is up to 35 cm deep. Then the spike roller rolling with the weight of the machine through the clods formed as a result of crushing compacted soil, crushes it and compacts the topsoil. In one pass crop residues and natural fertilisers can be mixed with the soil and catch crops can be sown, e.g. using a catch crop broadcast spreader.

The work of a subsoiler has the highest energy requirement, as on heaviest soils it may even be even 150 hp per 1 running metre of a machine.

Depending on the type of the machine and the manufacturer, the preparation of the structure to loads, various safety and pressing force systems are used. The necessary pressing force will be in accordance with the type of soil, with higher pressure on heavier sites and lower pressure on lighter sites.

A field cultivated with a subsoiler with more densely spaced tines is ready directly for sowing in the autumn and after mulching catch crops and cultivation for spring plants the field is ready after winter for spring sowing. Before the cultivation it is also possible to apply basic fertilisers, phosphorus and potassium in accordance with the demand of specific crops.

Cultivation using a subsoiler with a spike roller.
Photo credit: P. Jakubowski

Catch crop mulching or cutting with knife rollers

Catch crops sown in the regenerative system have various periods of their purposeful maintaining. Depending on the timing of sowing, species composition and the weather affecting the speed of development and growth of catch crops, also called intercrops, the need to mulch them may arise at different times. The aim is to grow and maintain the plants between the main crops so that they play a role of a cover for the longest possible part of the year. On the other hand, in order to control potential proliferation of plants sown in the catch crop, the work to prevent the generative parts of plants from fully developing must start at the right time. Flowering should be the last stage of their development and in the final stage they have to be cut. There are several types of mulching treatments.

Treatments performed during deep cultivation:

- **Mulching with an axe mulcher or flail mower,** that is cutting and shredding parts of plants,
- **Mulching with a knife roller fitted with roller knives** hitting the soil under the impact of weight, cutting the plants, mixing them with soil (the effect of roller loading can be increased by pouring them half-way with water),
- **Mulching with a chain system** using the effect of mechanical damage of plants, their partial cutting and shredding.

A mulcher during the autumn catch crop shredding before cultivation.
Photo credit: P. Jakubowski

Knife rollers during catch crop cutting.
Photo credit: P. Jakubowski

Cultivation with a disc harrow

One of the most popular cultivation systems in regenerative farming is cultivation with disc harrows. Various technological solutions used in these machines, such as frame structure, diameter of discs, possibility of adjustment of disc angle and additional equipment will determine their various uses.

A disc harrow with discs of smaller diameter, with discs 450 mm in diameter or Poetinger Terradisc with discs 580 mm in diameter, can be used in a shallow range, that is in mixing crop residues at a depth of 3 to 5 cm. A disc harrow is a fast alternative to cultivators for mixing organic fertiliser with soil. A high efficiency of such machines and the need to mix fertilisers within 12 hours of their application mean that sometimes they are a necessary complement in technology between spreading the fertilisers and deep tillage.

A disc harrow for deeper cultivation has discs with a diameter of 600-650 mm. Machines of this type are used to shred crop residue, e.g. corn or sun-flower when there is no mulcher available in the farm. It can also be used if, for example, there is a need to mix quickly manure applied in higher doses of 30-40 tonnes/ha.

Cultivating with a disc harrow after the harvest of sunflower.
Photo credit: P. Jakubowski

Cultivator with a roller

The treatment with a cultivator is the first treatment to have replaced tillage in transition from the conventional to reduced tillage system. In reduced tillage system in a regenerative approach a cultivator is a perfect complement for machines both for deep and shallow tillage. It plays a role of a treatment which flexibly adapts to various scenarios of crop rotation, on various sites and with various levels of organic fertilising. Various systems of chisels are used here, e.g. 4, 6 or 8 cm wide.

The lighter the soil, the wider the used chisels should be. The heavier the soils, the narrower chisels should be used, additionally using the support of pressing force of varied strength. Fitting of tines is related to their individual pressing force enforced by passive mechanical elements or, in some types by hydraulic actuators. The pressure should increase with increasing soils heaviness.

Cultivators are also fitted with various types of rollers. Some machines of this type are additionally fitted with the so called spring-tooth harrow, which during the cultivation aims to scatter and spread evenly crop residues, increasing the quality of performed work. The range of depth of cultivator work is from 5-8 cm to as much as 28-30 cm in case of narrow chisels. The possibility of sowing catch crops in one pass increases the versatility of machine use.

Tyre shafts selected for cultivator equipment should also be chosen depending on the soil type and should be the larger in diameter, the lighter the soil. On sandy sites the shaft should have a diameter above 80-90 cm, and on heavier sites shafts can be lower, with a diameter of wheels of 50-70 cm. In case of cultivation on sandy soils with a low shaft, the loosened soil may form so called “soil wave” which will be pushed by the shaft in front during cultivation. A larger shaft on such soils ensures easier rolling and running on freshly tilled soil, without the risk of the “wave” forming.

A cultivator during cultivation after organic fertilisation in a cereal stubble.
Photo credit: K. Strzelczyk

Strip-till

Strip-till originated and was popularised in the 1980s in the United States. It is important to note the need which made American farmers search for a system of cultivation and sowing so much different from the conventional methods. The origin of the strip-till is the climate change which has been taking place after years of industrial development and degradation of the natural environment. The combination of these factors resulted in soil erosion, both wind erosion caused by hurricanes and tornadoes and water erosion caused by thunderstorms with huge rainfall. Instability in agriculture caused by these catastrophic changes resulted in the need to search for solutions which would protect the soil and crops from unfavourable conditions and at the same time ensure stability of yield and income from production. A solution which began to be implemented as a way of soil protection against the effects of the phenomena resulting from the climate change was initially direct sowing. Unfortunately, in the first years of introducing direct sowing the yield fell. Such a regression in yield contributed to further search for sowing methods that would involve as little as possible mechanical soil loosening and this is how the new solution started to be implemented, penetrating only narrow strips of soil where tillage would be deeper and in this way created better conditions for sowing and plant growth. It also made possible the introduction of fertilisers into the root zone. Strip-till, with all the advantages offered by preparation of soil in the sowing zone, and then root growth, ensures actual stability of yield and desired crop safety.

Strip till and beet sowing.
Photo credit: K. Strzelczyk

Features of strip-till:

- Loosening of soil at the appropriate depth without the need for tilling all of the field,
- Possibility of precise placing of fertilisers in the appropriate zone
- Preventing wind and water erosion,
- Maintaining better bearing capacity of soil,
- Eliminating crust formation,
- Reducing and controlling weed infestation,
- Reducing water loss, increased water holding capacity and reduced evaporation,
- Saving fuel and time and the possibility of earlier sowing in the period of adverse weather,
- Development of biological life in soil,
- Increasing soil fertility,
- Better accumulation of nutrients and reduction of nutrient loss in the period of rest or intensive rainfall.

The advantages listed above are actual benefits compared to traditional tillage technology as well as direct sowing. After more than 40 years since the start of tests in the USA, the strip-till system has become widespread in the world and is used together with a variety of solutions supporting better adaptation to various types of soils and sites in terms of forecrop, including differences in after-harvest residue. The main effect achieved thanks to the introduction and application of strip-till is ensuring optimal conditions for sowing and emergence of plants. At the same time, the conditions are most suitable for root formation and growth, as well as the uptake of nutrients.

Reduced tillage strip-till cultivation may be carried out with various degree of soil loosening, depending on the type of soil, type of crop and the history of the field. Shallower tillage for shallow-rooted crops may be carried out to a depth of 15 cm, while deeper tillage of up to 35 cm is recommended for crops with a deeper, taproot system. Deep tillage should also be carried out if the field needs to be broken up and the compacted subsoil layer destroyed. The hard layer of soil is formed at the level below the so-called topsoil, usually at the depth of about 25-35 cm in the soil profile, for various reasons. One of them in the conventional, tillage cultivation system, is the effect of compacting the soil as a result of annually repeated ploughing at the same level and the formation of a hardpan, or dense layer of soil. Similar effect can also arise with the use of other cultivation tools, e.g. a disc harrow, used at the same depth in every cultivation season. However, the compact subsoil in the field is also sometimes caused by heavy rainfall or irrigation. In such conditions fine floating soil particles move between soils crumbs into the lower layer, below the cultivated zone and are usually deposited there forming a layer of compacted, hard crust.

A huge advantage of strip-till is the possibility of sowing without disturbing the whole width of the field. Depending on the production technology of specific crops in various row spacing, working sections work at the widths adapted for them.

Widths of rows in strip-till:

- 15 cm – for cereals, rapeseed and catch crops
- 30-45 cm – for rapeseed, papilionaceous plants and catch crops
- 45-75 cm – for sugar beet, corn, sunflower

The flexibility of strip-till technology relates also to the application of fertilisers during work. Fertiliser can be applied at depths from 0 to 25 cm, within the whole range of tillage depths. Depending on the machine manufacturer and the need to apply various nutrients, it is possible to apply fertiliser at different depths in one pass, e.g. nitrogen at 10 cm and phosphorus at 20 cm. Level adjustment can be fluid within working ranges on a given field and additionally there is a possibility of changeable dosage.

5 MACHINES BY VARIOUS CULTIVATION SYSTEMS

5.1 Wide-row tillage and sowing system

In this system the width of rows is from 45 to 75 cm and machines are dedicated mainly to preparation of the site and sowing such crops as beet, rapeseed, corn and sunflower. Recommended tillage for these crops is at the depth of 25-35 cm, and additionally is usually combined with localised fertilisation. Wide-row spacing is also adapted for combine harvesters harvesting specific crops.

Wide-row system machines are available from a wide range of manufacturers.

Typical elements of design and operation:

- Rhomboid section mounted on the machine frame, inclining within the range during soil resistance and lowering under the pressure from tines while they dip into the soil,
- Section tines loosening the soil,
- Double discs raking up soil to form a furrow and in it rows with exposed surface for sowing,
- Square bar rollers preparing seedbed,
- Disc coulters and star clearers removing crop residue and cleaning the rows before sowing,
- System of in-soil placement of mineral fertilisers or, in some models, liquid organic fertilisers behind tines,
- Aggregate single-seed drill for 45-75 cm row spacing.

A seeder in reduced tillage with fertiliser spreading – for corn and sunflower.
Photo credit: P. Jakubowski

A seeder system with a fertiliser hopper behind the front three-point hitch of the tractor.
Photo credit: P. Jakubowski

A seeder system with a fertiliser hopper behind the front three-point hitch of the tractor.
Photo credit: P. Jakubowski

A seeder system with a fertiliser hopper behind the front three-point hitch of the tractor.
Photo credit: P. Jakubowski

The effects of sowing rapeseed using a MOM strip-till seed drill.
Photo credit: P. Jakubowski

Strip-till and sunflower sowing with an option of fertiliser application.
Photo credit: K. Strzelczyk

Strip-till aggregate – rapeseed sowing with fertiliser application on mulched grass.
Photo credit: P. Jakubowski

Strip-till aggregate – visible soil furrow in the place of deep tillage (25-28 cm) in a sowing strip.
Photo credit: P. Jakubowski

The effects of sowing rapeseed in reduced tillage.
Photo credit: P. Jakubowski

5.2 Narrow-row tillage and sowing systems in which the range of width of the aggregate is from 15 to 35 cm.

Machines of this type are applied in and particularly dedicated for cultivation of cereals, rapeseed and papilionaceous crops. Narrow-row cultivation of these crops ensures the most optimal spacing between seeds and, eventually, between plants. If crops grow in narrower rows, it is easier to control weed infestation.

Typical elements of design and operation:

- Tines for more shallow tillage mounted on the machine frame,
- Tyre shafts,
- Drill integrated with the machine as a standard, usually a two-row drill,
- Disc or duck-foot coulters spaced every 15 cm or every 30-35 cm,
- A system of in-soil fertiliser application.

Wheat sowing in reduced tillage with duck-foot chisel plough at the depth of 5-10 cm and two-row sowing.
Photo credit: P. Jakubowski

Wheat sowing in reduced tillage with duck-foot chisel plough at the depth of 5-10 cm and two-row sowing.
Photo credit: P. Jakubowski

Wheat sowing in reduced tillage with duck-foot chisel plough at the depth of 5-10 cm and two-row sowing.
Photo credit: P. Jakubowski

A strip cut by working tine of strip-till seed drill – rapeseed sowing.
Photo credit: P. Jakubowski

Versatile strip-till systems 5.3

The design of this type of machines is most complicated, however they have a wider range of applications. The costs of manufacturing and purchase of strip-till machines is very high, therefore it is economically justified to ensure their widest application.

Versatile machines are used in cultivation of cereals, rapeseed, beet, corn or sunflower. Thanks to the application of sections with adjustable row width from 15 cm to 30, 45 up to 75 cm, it is possible to couple and operate both with a single-seed drill and a row drill.

CURRENT TRENDS IN TECHNOLOGICAL DEVELOPMENT AND APPLICATION OF REDUCED TILLAGE 6

With the development of technology and the changing agricultural environment as well as a political initiative concerning legislation, the focus has shifted towards ensuring better soil health. Supporting this was the introduction of principles of integrated plant protection which provided better flexibility and possibility to responsibly combine agrochemicals and reduce their doses. This allowed for the development of protection technologies, but what is also important, sparked the search for innovation in other areas, including machine technology. Over the years reduced tillage was implemented in many places in combination with conventional system or used alternately. Cultivators for medium tillage, disc harrows and alternate cultivation with these machines have not always been optimal solutions, as often elements complementing cultivation technology were missing. Only the introduction of a comprehensive approach to reduced tillage technology with all its elements such as proper crop residue management, bringing in organic fertilisers or various placement of fertilisers in soil, as well as evolution of various types of solutions for soil loosening, sowing and care resulted in a real development of technology.

Strip-till with sowing – a solution with a finger press system.
Photo credit: K. Strzelczyk

Even spacing of seeds in a furrow in single-seed sowing in strip-till.
Photo credit: K. Strzelczyk

Strip-till with sunflower sowing – making furrows protecting seedlings against wind and frost.
Photo credit: K. Strzelczyk

Sunflower grown in a strip-till system.
Photo credit: P. Jakubowski

Strip-till technology, which originated in the 1980s in the USA, although initially applied only in corn cultivation, developed over the years and now it is applicable in almost all cultivated crops. Due to various climate and soil conditions in specific agricultural areas in various countries, reduced tillage and development of this system is not equally popular everywhere. The example of the United States is a clear proof that farmers actively seek new solutions, in particular when affected by a crisis. Since the start of the 21st century we have witnessed climate changes occurring at an ever increasing rate. More and more often we hear reports of or actually see dry water reservoirs or the largest rivers of the south of Europe, for example in France in 2022 or in Spain and Italy in 2023. Other regions, even in the same countries, suffer from catastrophic floods and farming is everywhere, right next to them. Bearing in mind that we have to adapt and somehow prepare for this climate change, it is necessary to start soil regeneration. Carrying out this operation is a restorative process, however for its effectiveness it is necessary to use all available methods and supporting measures. From appropriate crop rotation, rich with various types of crops, through proper, limited soil disturbance, dedicated for a specific place and time, through its fertilisation to proper protection of fields against the effects of erosion.

Modern trends in the development of machines for reduced tillage are multi-task aggregates which combine many functions necessary to achieve the correct work parameters.

Typical elements of machines for reduced tillage, modularly aggregated in machines:

- Spring-tooth harrow (evenly distributing crop residue, glumes etc.),

- Disc harrow,

- Discs or knives mulching crop residue or catch crop residue,

- Loosening tines (working depth in the range 5-35 cm),

- Disc or star-shaped elements clearing the sowing surface (strips) and creating furrows,

- Rollers compacting soil superficially or crushing and compacting soil in deep tillage,

- Rollers distributing post-harvest residues and clearing the soil before the sowing section in strip-till,

- Spreaders of organic or mineral fertiliser with changeable dosage connected to fertility maps and crop and biomass maps for a given field,

- Spreader of slug/snail granules,

- After-sowing re-compacting rollers, supporting upward water movement and speeding up germination,

- Sowing sections or complete drills for single-seed or row sowing – mounted using hydraulic coupling with an option of variable sowing based on a map of field yielding potential,

- Fitting with sat-nav aerials for precise parallel driving, also using an RTK correction signal for optimal use of resources and increased work effectiveness.

Apart from the additional equipment, machines differ by the size of frame, wheelset, the number of working cultivating sections or e.g. the number of tines or discs. Different equipment directly affects the weight of the machine, and what follows, the requirement for power necessary to achieve appropriate work parameters of the assembly on various soil sites. An aggregate for deep tillage, with a working width of 4 m, for deep loosening (30-35 cm) on light soil requires 350 horsepower. In order to maintain similar work parameters, the depth and speed of tillage (approx. 7-8 km/h) on heavy, crusting-prone soils, for example alluvial soils, the same machine requires 550-600 horsepower.

Currently the development is focused on the widest possible use of technology in terms of flexible use of machines and, on the other hand, on the use of machines in the most precise way involving all available solutions of precision farming. There is a visible focus on soil loosening at a precisely specified depth, placement of fertilisers adjusted for the needs, and sowing seeds at the requested depth with an appropriate density and spacing. In the whole production technology one should also remember about weed control which due to increasing restrictions in availability of active pesticide ingredients in a way enforces the search for alternative solutions. One of them is of course reduced tillage which carried out in a sustainable way and well thought-out in terms of species, also in the selection of catch crops, reduces weed infestation. Another element is the possibility of intercropping the main crop, for example with spring crops, e.g. serradella or peas in winter rapeseed. Plant competition does not allow for the growth of weeds and at the same time accumulates nutrients taken from the soil – which in case of rapeseed may also have a beneficial effect in the autumn reducing overgrowth. Practical observation indicates that in this case it is possible to reduce the use of growth regulators in the autumn. After the early frost, in temperatures below 0° C, spring species die forming a cover for the rows, shading the surface of the soil. In the winter residues of dead plants undergo mineralisation and return nutrients to the main crop, in this case rapeseed. The third way to fight weeds in reduced tillage system is the use of mechanical weeding machines.

The range of available solutions equipped with precise cameras instantly identifying weeds is increasingly wider, therefore their work efficiency and effectiveness are getting higher and higher.

Mechanical weeding in a beet field.
Photo credit: K. Strzelczyk

7

CONCLUSION

The industrial development of the world has made a deep impact on the agriculture. Alongside these changes, incredible technological advances have taken place. The effectiveness of machines increased, yields have risen, as a result of both increasingly better cultivation technology, but also plant genetics and plant nutrition by artificial fertilisers.

In this revolution, human activity has unfortunately caused a great deal of damage. This relates mainly to soil degradation, water pollution, destruction of certain ecosystems or their strain. Today there is still a chance to reverse this negative impact and all farmers have an opportunity to take measures which draw from the use of natural resources, but without their degradation, and even with benefit for the environment and, ultimately, the climate. All these actions can be carried out by implementing the widest possible regenerative practice in farms. Enriching the soils with organic matter which as a consequence rebuilds microbiological life in the fields, which ultimately feed people. Therefore, everything we can do to this end, we ultimately do for ourselves.

A positive effect for the environment resulting from the introduction of reduced tillage is reduced fuel consumption. With the reduced fuel consumption the emission of carbon dioxide to the atmosphere is reduced. According to the scientists, reduced tillage burns approximately 20 litres less fuel per hectare and each litre burned emits 2.7 kg carbon dioxide.

Remodelling of agriculture in terms of preservation and improvement of soil quality, defined as a living structure, would significantly reduce the demand for artificial fertilisers and pesticides, would also limit the amount of fertilisers washed to the rivers and the crops would require less watering.

According to the scientists, intensive sustainable arming would be based on three main principles:

- Direct application of fertilisers into the soil
- Crop rotation
- No-tillage

These practices make it possible to restore organic matter, improve soil structure and its ability of water and nutrient retention, at the same time preventing its erosion. It is advisable to use biotechnology in order to "wean" the crops off the artificial, harmful production methods which we created for them and restore the ability of crops to enter into symbiosis with soil microorganisms. Such a symbiosis allows the crops to source organic nutrients from the soil making the crops more resistant to pests and disease.

Regenerative reduced tillage cultivation is therefore one of the very important elements of the whole field production technology and farmer's involvement in the production process. The way in which a farmer undertakes certain production has an impact both on incurred costs and the proper use of resources of nutrients from soil and water. The actions of a farmer today affect mainly the quality of soil that will be left for the next crop, the costs of its recovery, and eventually what is left for the next generations. To sum up, adapting tools and measures to the recovery of the environment of production which in case of a farmer's "factory" is soil, is the key to the economic, health and quality success throughout the production, and ultimately our environment.

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