Soil management

Katalin Sárdi
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Katalin Sárdi
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SOIL MANAGEMENT

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Table 1.
Chapter 1. Aims of soil tillage – traditions and new directions

1. Aims of soil tillage

Most classical authors held that the primary aim of cultivating soil was to meet crops requirements. In the late 19th century rendering the soil's fertile layer suitable for crop growing was considered to provide a good standing place for plants. The word suitable usually applied to the soil physical state, its favourably loose structure that was to be developed to the required depth.

However, it was recognised by some authors back in the late 1800s already, that creating soil condition assumed to be required by plants may even damage the soil, what with the frequent traffic involved in the process. In other words, taking a crop oriented approach will rather do harm than good.

In a regime of tillage focusing on conservation the need for protecting the soil is not subordinated to crops demands: these two are of equal importance, for creating a soil condition required by crops takes a lot less energy and causes much less mechanical damage in a soil whose good structure and condition has been carefully preserved. In the early years of the new millennium the primary goal of tillage is to create and maintain favourable interaction between soil conservation and cropping.

The goals reflect the expectations to be met by tillage in a given era. Periods in the development of tillage may be distinguished on the basis of the above aspects and other relevant characteristics.

2. Effects of conventional tillage on soil condition

The origins of conventional tillage date back to the development of the asymmetric plough share with a mouldboard inverting the soil (15th century) and the era of multi-ploughing tillage. Its spreading was encouraged primarily by the improvement of the plough structure and the reliability guaranteed by ploughing for producing a certain yield rate. Conventional systems retained the practices both of ploughing and of multiple tillage passes as had been practised in the multi-ploughing system. For quite a long period of time farmers attitude to ploughing was not affected by the development of implements suitable for ploughless tillage (disk, cultivator, subsoiler, rotavator). Although the plough was no longer used in some tillage operations within the cultivation system (stubble stripping, stubble treatment), yet the plough remained an indispensable implement for primary tillage.

The separation of conventional tillage from other trends and orientations started when experiments and field crop production equally prove that it is possible to create soil conditions required by crops without ploughing and by a smaller number of tillage operations. A clearly marked separation – in terms of the main relevant features – has only been observed during the past 30 years.

3. Features of conventional tillage

Conventional tillage affects the entire soil surface and in the regime of soil preparation conventional plough is used in carrying out the deepest (primary tillage) intervention. Soil condition that is considered to be favourable for crop growth is created through more than a reasonable number of tillage passes, involving massive time, energy and cost input. Adaptation to the soil condition occurs by chance, technical interventions of modest effectiveness are typically repeated (BIRKÁS, 1995).

The above definition is indicative of a European approach. North-American scientists consider working the entire surface through multiple tillage passes to be conventional.

One inevitable question relating to the increasingly marked criticism of conventional tillage in recent years is why despite the detrimental impacts it has been considered to be the basis for crop production for centuries. The main factors may have included the input of energy that is typical of conventional tillage, the clearly visible changes in the soil (inverting) as well as sentiments attached to the plough and to wheat. The weed control effect of multi-traffics tillage should also be taken into account.
The initial imperfections of ploughless implements and the expected risks entailed by their use also contributed to the persistent popularity of conventional tillage. Fortunately, there were some critical periods of time when inadequate precipitation, poor quality or increased costs drew attention to new solutions (adaptable tillage, anti-plough movement).

Despite its great time, energy and labour requirement conventional tillage continued to be a more attractive solution for many farmers – because it took less learning, it involved the use of customary simple implements and techniques – than taking the risks that could be entailed by methods to be newly acquired.

Multiple tillage operations are traditionally considered to provide a more reliable foundation for a good harvest since poorer quality of tillage may be corrected by the next intervention. Regular disturbance of the soil was recognised to control weeds, some pests and pathogens. Inverting stubble residues resulted in the clean surface required for sowing. Accordingly, multiple tillage passes were considered to be reasonably required for a good harvest, instead of something farmers were forced to do by necessity. This approach was weakened somewhat by growing fuel prices.

The stable position of conventional tillage was first undermined by soaring fuel prices and then by the recognition of losses caused by damage to soil and environment. The criticism that appeared first in the seventies has developed into actual measures to date (ECAF, 1999).

The features of conventional tillage:

- Multiple-traffic (6-10 or more tillage operations) comprising separate tillage interventions (where implements were not or only rarely used in combinations).

- Substantial time input, a typical feature resulting from multiple tillage trips and additional tillage interventions to remedy previous tillage defects. The excessive time requirement is a risk factor and it may jeopardise the performance of even the crucial tillage operations under unfavourable weather conditions.

- Great energy requirement, likely to be entailed by working on soils in conditions that are or have become unfavourable.

- The depth of tillage is more often adapted to the crop requirements and to the available implements than to the soil moisture content or the soil condition.

- Deep tillage – deep ploughing – is applied with the aim of enhancing the yield but the operations required for maintaining the impacts of deep cultivation often fail to be carried out.

- Stubble residues are regarded to be a factor hindering tillage therefore they are either inverted into the soil (good solution) or burned (a disputable solution). In this way they are not used for covering and protecting the soil surface and for reducing moisture loss during the period outside the growing season.

- Emphasising crop requirements efforts are made to create clean seedbed without crop residues, characterised by small crumbles of soil (which, indeed, looks good).

- A transition to reduced tillage without adequate soil condition improvement is rather a risky undertaking on soils that have been subject to conventional tillage.

4. The impacts of conventional tillage on soil and environment

An objective view of conventional tillage may be formed on the basis of its impacts on soil condition (Figure 1.1).
Critical aspects of conventional tillage:

- A compact impermissible layer develops right below the ploughing depth – the same depth year after year – and this compact layer grows thicker both upwards and downwards, unless remedial tillage operations are also carried out. As a consequence of the greater resistance of the compact layer the depth of ploughing gradually decreases.

- The middle of the ploughed soil layer may grow increasingly compacted as a result of disking in the way of surface forming. By reducing the depth of the root zone results in increasing sensitivity of crops to drought (for it is not possible to work the soil through again before sowing).

- Rainwater accumulating in larger quantities above the compact layer results in damage by water (silting, leaching, deteriorating site condition).

- As a result of the large number of tillage traffics involved in secondary tillage and seedbed preparation after ploughing the tilled layer may be re-compacted even before sowing.

- As a consequence of compaction and re-compaction water, air and heat transport in the soil are reduced, decomposition of crop residues and the process whereby nutrients become available slows down.

- As a consequence of no adaptation to soil moisture the primary tillage operation (that is ploughing) results in a cloddy or heavily cloddy soil surface. To render the soil suitable for sowing, clods are broken down through a number of tillage passes, while inevitably pulverising the soil.

- Pulverised soil is exposed to water and wind erosion, it goes silting when heavily wet, crusting when it dries out.

- As a consequence of the repeated mechanical impacts the process of biological mellowing is broken or it fails to take place and this prevents improving the quality of the next tillage intervention.
• The organic matter balance (*Figure 2.2, Table 2.4*) of over-disturbed soil, its quality, workability and bearing capacity deteriorates and after cultivation settling and compaction will accelerate.

• The rates of CO2 emission from disturbed soils left in a cloddy state are substantially higher than those cultivated with a view to conservation. *Figure 2.3* presents soil C-CO2 release from the tilled soils into the atmosphere. During the day after tillage was applied, flux were as high as 88 kg ha\(^{-1}\) day\(^{-1}\) in the ploughed soil and 31 kg in ploughed and pressed variant. However, less flux can be measured when soils are prepared with soil and carbon conservation methods (SP, K).

• A soil that has lost much of its organic matter content, structure and culture state has a *narrow range of soil moisture contents in which it is suitable for tillage*, i.e. there is reduced possibility of adaptation.

Tillage-induced *damaging impacts that deteriorate the quality of the soil and the environment* – compaction, re-compaction, pulverisation, crusting, high rates of CO2 flux, depletion of nutrients and weakening bearing capacity – *are undesirable side-effects of conventional tillage* with very few agronomical benefits to balance them.

### 5. Questions:

1. What is the aim of soil tillage?

2. What does the term conventional tillage mean and what are the major features of conventional tillage?

3. Compare the impacts of conventional system and conservation system on soil condition!
Chapter 2. Soil condition assessment, good and bad soil condition

Soil condition is usually assessed in terms of aspects of workability suitability for crop production, and the soil’s impacts on the environment. A soil is regarded to be in favourable condition when it is workable within a wide range of different moisture content levels, if it provides a reliable basis for crop production and its physical, chemical and biological features have no negative impacts on the environment. The condition of a soil is unfavourable when one or more of its physical properties (e.g. dusty, airtight or watertight or simply too compact structure), chemical characteristics (e.g. acidification) or biological features (e.g. biological inactivity) qualify as environmental damage and successful crop production requires costly interventions.

The description of soil condition. The condition of a soil can be exactly described with reference to its physical parameters. Its compactness, bulk density, pore volume, penetration resistance and moisture content are measurable parameters. The 'degree of compactness' of a favourably loosened soil is measured at 87-88 % of its maximum bulk density, corresponding (in the case of several, though not all, soil types) to an approx. 48 % total porosity, to an approx. 1.30 g cm−3 bulk density and 1.5-2.5 MPa penetration resistance. According to HAKANSSON et al. the degree of compaction of settled ploughed soil is 78 %, while cereals require of 87 % degree of compactness. Soil is in an unfavourable condition if its degree of compactness equals at least 95 %, its total pore volume drops below 40 % and its bulk density equals at least 1.60-1.70 g cm−3 and its penetration resistance (in humid soil) exceeds 2.75-3.0 MPa.

HAKANSSON (1990) elaborated the degree of compaction and this value has often been used in concerning soil tillage research:

\[ D = 100 \frac{BD}{BD_{\text{max}}} \]

where \( D \) = degree of compactness (%), \( BD \) = actual bulk density (g cm−3), \( BD_{\text{max}} \) = maximal bulk density (g cm−3), which can be stated at 200 kPa static load. For example, the degree of compaction in ploughed soil being in a settled condition is 78%.

DUMITRU (2000) also cited formula of the compaction degree developed by STANGA (1978) which is used for official soil survey method in Romania:

\[ CD = \frac{(PT_m - PT)}{PT_m} \times 100 \]

where \( CD \) is degree of compactness (%), \( PT_m \) is minimal required total porosity (%), and \( PT \) is actual total porosity (%). The minimal required total porosity results from: \( PT_m = 44,9 + 0,163 C \), where \( C \) is clay content (%). From this, compaction degree classes are as follows:

\( CD < -18 \) very loose
-18 < \( CD \) < 11 loose
-10 < \( CD \) < 0 non-compacted
0 < \( CD \) < 10 slightly compacted
10 < \( CD \) < 18 moderately compacted
\( CD > 18 \) severely compacted

BENNIE and Van ANTVERPEN (1988) stated another formula, used similar basic data:

\[ DC = \frac{(BD - BD_{\text{min}})}{(BD_{\text{max}} - BD_{\text{min}})} \]

where \( DC \) = degree of compaction (%), \( BD \) = actual bulk density (g cm−3), \( BD_{\text{min}} \) = minimal bulk density (g cm−3), \( BD_{\text{max}} \) = maximal bulk density (g cm−3).
Packing density (by Van RANST, et al., 1995) effectively integrates the bulk density, structure, organic matter content of mineral fraction, and clay content, to provide single measure of soil compactness. That is defined as

$$PD = Db + 0.009 C$$

where: $PD$ = packing density in t m$^{-3}$; $Db$ = actual bulk density in t m$^{-3}$; $C$ is clay content (%). Three classes of packing density are recognised: Low: < 1.40 t m$^{-3}$, medium 1.40-1.75 t m$^{-3}$, and high > 1.75 t m$^{-3}$. Soils with high packing density (> 1.75 t m$^{-3}$) are generally not very susceptible to further compaction whereas those with medium and low PD (1.40 t m$^{-3}$) are vulnerable at critical moisture content and loads. In situations where the actual bulk density is known, packing density can be determined through the incorporation of clay%. It is a useful parameter for spatial interpretations that require a measure of the compacted state of soils.

Soil quality and soil condition. The quality of a soil is characterised by the relationship between its physical state, biological condition and fertility. Any material change in any of these will affect the others and this may result in upsetting the ‘harmony’ among these elements. If the soil is too compact not only will its biological state decline but its water transport characteristics, the process of decomposition making nutrients available, as well as the availability of nutrients will also be restricted and finally even its very suitability for crop production will be undermined. Extreme physical and biochemical soil conditions qualify as environmental damage deteriorating the quality of life through reducing the standards of production as well.

Crop production requires cultivation creating, conserving and/or retaining good physical and biological soil condition. Reliable crop production may be provided for by improving and conserving the quality of the soil. Proper tillage contributes to creating and preserving harmony between the environment and the production systems by protecting the quality of the soil. The endeavours relating to the quality of soil – conservation and improvement – are identical with those relating to sustainable (reasonable and value conserving) farming. Good soil quality is an indispensable pre-requisite for cultured agricultural landscape.

Classical authors characterised the quality of soil by reference to its cultured state. Soil in its cultured state is free of weeds, it has a favourable structure, it is trafficable and has favourable air, heat and moisture transport characteristics, biological activity and nutrient supply. From another side such state is referred to as matured or mellowed soil, with its physical features (structure, moisture, air, temperature), chemical properties (nutrients, pH value) and biological characteristics (aerobic microbes, earthworm activity) constituting a harmonised system. Soil can be best cultivated in its matured state, when the least damage is caused and the smallest energy input is required.

The harmful interventions (e.g. cloddy summer ploughing) or defects (traffic, pulverisation) break the process of aggregation leading to declining biological life in the soil. By contrast, structure conserving tillage reducing the loss of moisture qualifies as an environment sound operation.

Studies of interactions between plants and the state of the soil have shown that neither excessively loose, nor excessively compact soil state is favourable for crop production (Table 2.1). Crops' soil condition requirements must be neither over- nor underestimated.

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<td>favourable biological processes, permanent revival</td>
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<td>Aggregation</td>
<td>reduced sensitivity to settling and compacting, adequate bearing capacity</td>
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<td>Workability</td>
<td>lower energy consumption to fulfil soil condition demands</td>
<td>reduced load, well-used landscape</td>
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<tr>
<td>Fertility</td>
<td>reduced sensitivity to climate, improved yield stability</td>
<td>reduced load, slight contamination</td>
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Table 2.1 Soil quality factors and their impacts
Soil condition assessment, good and bad soil condition

Soil condition may be *favourable, adequate or unsuitable* from the aspect of the requirements of crop production. Plants requirements concerning soil condition are related to the looseness of a given soil layer (seedbed or root zone). Crops requiring deeper tillage favour soil loosened to a greater depth (0-30 or 0-40 cm). If the soil is compact in this layer it needs to be cultivated more deeply. The advantages offered by improved soil condition will benefit both crops and the environment.

Soils have been exposed to impacts improving and to impacts deteriorating their state ever since they have been under cultivation. Most defects caused by tillage can be remedied by tillage. The value of proper cultivation is enhanced by the possibility of turning poor soil condition into good soil condition.

1. **Soil tillage deficiencies – Causes, consequences, and alleviation**

1.1. Defect – difference from specifications and/or requirements

In the course of tillage – in a single season or over a longer period of time – a variety of minor or major *soil condition defects* may appear, sometimes owing to lack of adequate expertise, sometimes as a consequence of a wrong decision due to insurmountable external factors, lack of good machinery or unfavourable weather conditions. A defect is a factor (or multiple factors) deteriorating the quality and outcome of tillage, or it may result from failure to carry out all of the planned activities. *From the aspect of quality assurance tillage is a process and it should be analysed through a process oriented approach.* In this case the *output of the process* is the soil condition resulting from cultivation.

The quality of tillage – as a process (e.g. loosening, ploughing, seedbed preparation) and as a *chain of processes* (that is the system of tillage) – can be planned and it can be specified in advance. The regulations, the specified procedures (the tillage procedures, the relevant circumstances, depth, quality, time and cost input), the control procedures, tests and analyses, the preventing and improving activities help achieving the aim of tillage and preventing defects affecting the whole of cropping and the environment.

The consequences of defects include damage and losses in the tillage process. Some defects (*e.g. cloddy seedbed*) can be remedied by an additional intervention but most of them may only be eliminated in the next season. Serious damage can be alleviated by improving tillage and production techniques and by reducing the intensity of traffic on the field concerned. Cultivation causes damage if it directly or indirectly endangers the environment.

Community and national environmental requirements are applied to encourage farmers to prevent defects caused in the tillage and cropping processes. *Quality assurance* may create a systemic framework, qualification and controlling criteria for such endeavours. The methods of quality assurance can also be applied in tillage despite the fact that the processes involved in tillage are also affected by factors beyond the farmer’s control (*e.g. weather conditions, parameters of the site itself*).

*Environmentally sound quality assurance* requirements of tillage are comprised of seven main phases:

1. Creating the fundamental requisites for cropping *while minimising soil damage and the costs of the procedure*.
2. *Elaborating different versions of land use systems* adapted to site and economic conditions; Assessment of potential environmental impacts in advance.
3. *Selecting from among the different versions the system that is the most suitable for the given conditions and circumstances* and then *choosing* the required processes for every crop and field (decision making); Assessing the possible quality risks.
4. *Setting quality regulations and checking schedules* for the cultivation processes, assessing their quality capabilities and environmental impacts.
5. *Identifying any defects* in the tillage processes and application of remedial procedures.
6. *Analysis of the result* of tillage and the *costs of quality* (with regard to individual fields and for the holding as a whole).
7. **Documentation** of tillage and quality information and **taking actions** to improve processes.

Planning based on a quality assurance oriented approach makes it possible to prevent or recognise defects in the state of the soil in time and to reduce costs incurred as a consequence of defects, for

- the relevant tillage process provides the expected quality right away,
- one specific defect occurs only once and then it is not reproduced at all or its reoccurrence can be substantially delayed,
- defects, quality and quality capability can be quantified and then compared and evaluated,
- the risk of defects can be minimised,
- as can any damage or loss, and
- when a defect has occurred, it can be quickly recognised and eliminated in good time, instead of coming to light only at the end of the tillage procedures.

The preventing damage by defects results in preserving the quality of soil and environment, and in mitigating the risks of farming. The following is a discussion of some of the more frequently encountered tillage defects to help prevention.

### 1.2. Soil compaction

Under natural conditions compaction occurs primarily in soils of little organic and inorganic colloid contents. Soil compaction may also be caused by loss of water content, drying out, by precipitation or coverage by water over an extended period of time.

Suboptimal land use, weather conditions frequently hindering tillage and neglecting tasks that should be carried out to improve the soil condition will likely lead to compaction in susceptible soils. In unfavourable circumstances even moderately susceptible soils are threatened.

In the process of **compaction** air is forced out of the soil’s three-phase medium, while the soil’s volume is reduced. In the case of conventional tillage involving multiple tillage trips the ploughed layer is loosened and then compacted back every year.

Compaction is a **mechanical stress** destroying the soil structure, reducing or eliminating its permeability to water, heat and air, which may be caused

- by traffic on (primarily moist) soil,
- during tillage of moist soil by the weight of the machinery or the tillage implements’ smearing, puddling or pressing impact, or
- as a consequence of the tillage implements – e.g. plough share, disk – repeatedly pressing the soil, in the case of multiple tillage operations reaching more or less the same depth.

Different types of farming-induced compaction may be distinguished according to activities leading to soil deformation – tillage of wet soil, the same depth of cultivation year after year, field traffic – and to position within the soil (damage caused by tillage or traffic).

#### Tillage-induced soil compaction

**Tillage pan compaction.** Various tillage implements (disk, plough, rigid tine, wing share cultivator, spade harrow), produce a compact tillage pan – while loosen the top layer – between the cultivated and the undisturbed layer. As a consequence of repeating similar tillage operations and of failing to loosen a deeper layer of the soil, up to 2-3 excessively compacted layers may develop within a soil profile.

**Plough pan** develops underneath the plough share between the ploughed soil layer and the one underneath it, as a combined effect of the smearing of wet soil and the pressure under the tractor tyres in the furrow. Depending on the regular ploughing depth this may appear anywhere within the 20-36 cm layer. Subject to the number of
repeated tillage operations and to the condition of the soil at the time of tillage the plough pan may be a 2-10 cm or – in neglected soils – an even thicker layer. Soil compacted in this way has usually the greatest resistance in the given profile.

*Disk pan compaction* develops in moist and wet soil and is caused by the weight and the slip of disks, in layers below 6-18 cm depending on the regular disking depth. This term has been in use in Hungarian technical literature since 1987 (Birkás).

*Heavy disk pan compaction* is a result of wrong practice or tillage reduced out of necessity. Its more frequent occurrence indicates declining tillage culture.

**Compacted impermeable layer(s) should expected to be present where:**

- stagnant *rainwater* is present on the soil surface (and the soil is covered by moss after the puddles have dried out),
- in the compact layer the *soil* becomes *platy*,
- the *roots of plants* grow horizontally,
- on days of intense heat crops show signs of wilting much sooner than on soils in good condition,
- *crop residues* are preserved in the compacted layer or they go mouldy and they do not decompose,
- tillage takes a much larger energy input than on soils of the same type and of similar moisture content,
- the *quality of tillage* is poorer, the soil being more cloddy, more dominantly large cloddy or contains primarily large clods with smeared surface, regardless of its moisture content.

Soil compaction is an *environmental damage* that renders the soil less workable, increases the cost and energy intensity of tillage along with the risks of cropping. A compacted soil has a poor water absorbing capacity, hydraulic conductivity and water storage capacity. The closer the compacted layer is to the surface, the smaller amount of water can be absorbed and stored in the soil. The loosen layer above the *tillage pan* becomes quickly saturated during a rainy period and then, having silted up, it prevents water from infiltrating deeper layers. Water that does not soak into the soil is lost to farming. Compaction aggravates drought damage in a dry season by preventing moisture rising to the root zone from deeper layers.

**Alleviation of tillage-induced compaction:**

- A disk pan layer can be worked through with a cultivator or a plough.
- Plough pan compaction or compaction in deeper layers – below 35 cm – can be remedied in dry soils by mid-deep loosening. The physical state of layers below 40 cm can – depending on whether the soil natural compaction has or has not been aggravated by tillage defects – be improved by mid-deep loosening or deep loosening, if necessary.

**Traffic-induced soil compaction**

Most cropping operations are carried out with the aid of farm vehicles or, in some cases, using horse-drawn implements. The deforming impact of *field traffic* depends on the intensity of the factor affecting the soil, the pressure per unit area and the duration of the impact, the wheel slip, the size of the contact area between soil and tyre and the soil’s relevant characteristics. The extent of compaction in the topsoil is determined primarily by the wheel pressure of the implement.

Subsoil may also be compact owing to its natural features: in such cases the soil physical condition is not affected significantly by operations causing compaction. *Subsoil compacting caused by machines of high axle load imposes a permanent danger on soils fertility*. Machines’ compacting effect may – in wet soils – extend to 30 cm under a four-tonne axle load, while under a ten-tonne axle load it may extend to 50 cm or even deeper. In the top soil the duration of compacting is relative as a consequence of regular tillage to varying depths, in the subsoil it is permanent and difficult to remedy. Volume deformation takes less time in a dry soil, while in a wet soil it is a slower process. Clay soils can be compressed more than sandy soils but it does not mean less severe consequences of compacting in sandy soils.
Traffic-induced damage is visible on the surface. The depth of the damage is influenced by both the frequency of traffic on the soil and its timing (the season, the soil moisture content). Particularly endangered are the edges of fields along roads and where agricultural field vehicles turn around, where in addition to the machine turning around the drilling machine or the sprayer is filled up or where transport vehicles stand awaiting the combine harvester’s signal. During a rainy harvest season traffic-induced damage occurs in larger areas and they are not easy to remedy. Damage is not alleviated even during the tillage of such soils, for the use of the customary implements (plough, disk) is inevitably accompanied by smearing and puddling.

Serious traffic-induced damage is caused by conventional tillage involving multi-traffic tillage operations and when machines of small working width are used (the area affected by traffic may be as large as 1.5 hectares per hectare). Damage is aggravated by the different working widths of the machines used, since different routes will be trodden during the various phases of the tillage schedule and some parts of a field come under damaging loads more than once.

Prevention and alleviation of traffic-induced damage:

• The most important preventive task is to ensure avoidance of traffic on wet soil, restricting machinery running and regulation of traffic within fields.

• The available technical solutions include using running gears that cause little damage to the soil (on tractors and tillage implements as well as on transport vehicles), reducing specific soil pressure (applying flotation tyres, dual wheels, tracked running gears). These options are discussed in chapter 3.

• Deeper compaction can be remedied by mid-deep loosening.

1.3. Some practical aspects of factors affecting soil compaction

As a consequence of direct and indirect damage types soil compaction is a risk factor in regard to both crop production and to environment protection. Six important factors should be taken into account in assessing this risk: two natural factors (soil, precipitation) and four farming factors (land use, tillage, mechanisation and irrigation). Depending on their impacts on compaction these factors are be assigned to 3 categories each (Table 1.4) In view of these factors it is possible to assess the risk, on the basis of which the necessary preventive and remedial actions can be determined.

a) Natural factors (these may be influenced to some extent, e.g. susceptible soil bearing capacity can be improved by regular organic matter input, in the case of ample precipitation surface water stagnation may be avoided by keeping the soil adequately loose).

Soil is susceptible to compaction to varying degrees, depending on physical soil type, structure and moisture content. Soil bearing capacity also varies. Soils are categorised according to their natural characteristics, their resistance to compacting forces and the duration of the effects of tillage as follows:

• Susceptible (settleability and compactability is strong when the soil is humid or wet, the impacts of loosening do not last long, they rarely exceed one growing season).

• Moderately susceptible (settleability and compactability is moderate when the soil is humid or wet, the impacts of loosening last a medium length of time: usually 1-3 growing seasons).

• No or low susceptibility (settleability and compactability is low regardless of the moisture content and the impacts of loosening last for some 2-4 growing seasons).

Precipitation. Soil is compacted during the cropping and the tillage seasons both, depending on its moisture content and on field traffic. Soaked soil is compacted easily and to a greater depth.

During a period of average precipitation there is a lower risk of compacting and even that can be prevented. In drier seasons there is a lower risk of compacting. Rainfall during the harvesting and the tillage period should be regarded as follows:

• Abundant (rainfall exceeds the multiyear average by at least 50 %: in this case there is a high risk of soil compaction appearing or aggravating).
• **Average** (rainfall is close to the multiyear average: in this case there is an average risk of compaction appearing in the soil).

• **Little** (rainfall is below the multiyear average by at least 50%: in this case there is little risk of soil compaction).

**b) Farming factors** (e.g. the crop sequence includes crops of positive biological impacts, types of running gears causing little soil damage are used).

*Land use comprises* the sequence of crops produced in a given field as well as the applied cropping methods. Land use is *favourable* if in the course of the production of crops that are adapted to the site and the economic environment the soil is not exposed to additional damaging impacts over a longer period of time. Land use is *not favourable* if the production technology, or any of its elements, deteriorate or aggravate the condition of soil or environment.

Categories of land use practices according to the overall impact on the soil:

• **Harmful** (if the production technology has, on the whole, an adverse impact on the soil, there is a high risk of compaction and no remedial operations are carried out to improve the soil condition).

• **Neutral** (the production technology and the crops produced have, on the whole, neither a negative, nor a positive impact on the soil).

• **Soil conserving** (the applied production technology has a preserving and improving impact on the soil in a long run and the cropping regime includes plants improving and loosening the soil structure).

**Tillage.** The end result of tillage is affected by soil moisture, mechanisation and the operation of machinery. Tillage may enhance or mitigate the risk of compaction.

Categories of tillage regimes according to impacts on soil:

• **Harmful** (the soil structure is heavily deformed through, for instance, compaction, clodding and pulverising, tillage pan appears or grows worse).

• **Neutral** (the soil structure is not markedly deformed, tillage pan compaction may appear but it is easy to remedy).

• **Soil conserving** (no structural damage or tillage pan appears, the soil condition is improving or its good condition is preserved).

*Mechanisation.* The goals of tillage may only be achieved with the aid of machinery in perfect working order, of parameters well adapted to the soil characteristics. The most important factors include the weight of tractors and the implements, the construction of the implements and their suitability for the purposes concerned. In view of their structure and the impacts of their tillage elements on the soil, the use of machines entails higher or lower risks in various soil moisture ranges. The impacts of mechanisation may fall in the following categories:

• **Harmful** (the machines are heavy, their construction is not as required for the given circumstances and in addition to heavy compaction they cause clodding or pulverisation).

• **Neutral** (the weight and construction of the machines is adequate: they do not improve the original soil condition but they do not deteriorate it either).

• **Soil conserving** (the use of the machines contributes to improving the soil condition and to maintaining the favourable state of the soil).

Through increasing the soil moisture content *irrigation* alters the soil permeability and workability. The relevant factors here include the quantity of water delivered to a field, the intensity of irrigation, the length of the time between two irrigation periods and any rainfall after irrigation. Irrigation is not a generally applied element of production technologies therefore it is a factor to be taken into account in assessing the risk of compaction. Micro-irrigation, subsoil irrigation or ameliorating irrigation may have little impact on the trafficability (including compactability) of the soil.

According to its impacts on the soil irrigation may be categorised as follows:
Soil condition assessment, good and bad soil condition

- **Harmful** (due to the quantity of water delivered or to the time that has elapsed since the previous irrigation there is a high risk of appearance or aggravation of compaction).

- **Adequate** (as a consequence of the quantity of water delivered or of the time that has elapsed since the previous irrigation there is an average level of risk of appearance of compaction).

- **Soil conserving** (there is no significant risk of appearance or aggravation of compaction).

*In soils susceptible to compaction* the likelihood of damage is lower in dry years, medium years of average rainfall and it is higher in years of abundant precipitation. When the natural factors are not favourable, risks may be reduced only by improving the practices of land use, tillage and the standards of mechanisation. Improvements in agro-technical factors also entail reduced risks of irrigation.

*In soils of moderate susceptibility to compaction* there is a higher risk of compaction in years of more abundant precipitation. The risk of damage, however, may be reduced by up to 50% by making sure that the farming factors are of at least average standards. The risk of compaction is lower in drier years, but irrigation raises the level of risk to that of years of abundant precipitation. The risk of compaction is lowest in dry years on fields characterised by high standard adaptable land use.

*In soils that are not, or only slightly, susceptible to compaction* the risk of damage is highest in wet years, and in case of non appropriate tillage. Lower susceptibility is good but it does not eliminate the detrimental impacts of poor tillage and machine use practices. In a year of higher precipitation adaptable land use and machine as well as tillage sparing the soil structure use are just as important as in susceptible soils.

In summary:

- From among natural factors a susceptible soil and abundant precipitation increase the risk of compaction both in themselves and in combination.

- Risks relating to soil and precipitation are aggravated by wrong practices in land and machine use as well as in tillage and irrigation.

- Improved farming factors may effectively mitigate the risks linked to soil and the impacts of precipitation.

Related to adaptability, useful data were published by FULAJTAR and HOUSKOVÁ (2000) who summarized important physical characteristics for identification of soil compaction in Czech Republic relation (*Table 1.5*).

**Clod and dust formation on soils**

“... I wish to highlight one golden rule: spare no efforts to avoid producing large clods!” József GYÁRFÁS, 1922

The causes of clodding include the following:

Dry soil + Compacted soil + Unsuitable implement = Clodding

Soil generally dries out during a period with little, or no, precipitation but the process is more pronounced if the soil is uncovered and if it is disturbed without pressing. In the summer the following circumstances lead to clodding:

- Harvest removes shading, the stubble stubs delay but they do not prevent rising temperatures and loss of water.

- Undisturbed and uncovered soil conducts heat well, its temperature rises and so it dries out to a considerable depth.

- The layer affected by stubble stripping (e.g. 10 cm) left without pressing has a fairly homogeneous structure therefore it warms up almost evenly. It provides some heat insulation for the underlying undisturbed layer, but it can hardly withhold any of the moisture rising from the underlying layer, thus water is lost through the surface. Surface left without pressing results in increased loss of water.
Simultaneously with the evaporation of its moisture content soil gradually loses its aggregated structure and its flexibility. Good quality tillage is not possible on such dried and hardened soil and the result is heavy clodding.

Soil that has lost its moisture content is even less workable when compacted, consequently clodding can be reduced only when the soil has soaked over and dried out and it takes a lot of energy. Loss of soil moisture is intensified by deeper disturbance therefore summer ploughing must not be left without surface levelling and pressing. From the aspect of clodding: implements that results in a soil state that necessitates surface levelling after tillage of dried and compacted soil are not suitable for use under such conditions.

The texture of the soil should also be taken into account. Higher resistance further reduces the workability of compacted and dry soil. Proper stubble tillage in the summer – on any soil – contributes to reducing clodding by reducing moisture loss. Though a heavy soil texture cannot be improved by tillage, its compaction and drying out can be prevented.

Dust formation is a consequence of degradation processes and a long period of mechanical impacts (breaking up clods). Without a suitable implement the effort aiming at breaking up large clods is reduced to ‘clod shining’ (where the disk plate, slipping on the clod surface, slices off small bits, leaving a shiny surface behind). The slices so produced then fall apart into dust. During rainfall the dust blocks soil pores, thereby reducing the effectiveness of deeper tillage. Repeated clodding and breaking of aggregates by tillage over a longer period of time – plus lack of organic matter input – lead to degrading soil structure and decreasing bearing capacity.

The process and consequences of pulverising:

<table>
<thead>
<tr>
<th>Mechanical impacts</th>
<th>Soaking over</th>
<th>Drying out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clodding</td>
<td>Pulverisation</td>
<td>Silting</td>
</tr>
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</table>

Increasing potential water and wind erosion

Crusting is a sign of the presence of water-resistant aggregates and of deteriorating structure. It obstructs the aeration of the soil and hinders its biological processes, therefore the soil needs loosening during germination and in the early and later stages of growth. Additional interventions, however, lead to additional deterioration in the soil structure.

Pulverised soil is washed off by water (erosion) and it is carried away by the wind (deflation). Pulverisation of heavy soils in recent years has been reflected by damage caused by winds in early spring and in early summer.

Examples of silting and crusting are presented in Figure 1.6. Well-structured soil may be brought to the surface by ploughing, though this is not very likely in most places. Even the so-called ‘frost-crumbs’ forming on the surface of soils ploughed in the autumn should be regarded more as dust than as proper crumbs.

Practices for preventing clodding and dust forming:

- Soils should be kept in a cultured state, compaction should be prevented, or, once it has appeared, the compacted layer should be broken up by loosening.
- Soil should not be left without pressing after tillage in the summer.
- Crushed crop residues spread on the soil surface provide some protection for the soil against drying out, for a while.
- Stubble stripping should be kept shallow, crop residue-coverage (mulching) should be utilised for reducing loss of soil moisture.
- Depth of tillage should be increased gradually during a dry period (shallow stripping – somewhat deeper cultivation – tillage of the required depth).
Applying farmyard manure, green manure or crop residues into the soil usually improves the organic matter balance, biological activity, and workability, thereby reducing the risk of clodding. Seedless weeds and volunteer crops should be taken into account as having half the value of green manure.

**Soil moisture loss**

“...mellowing is most usually obstructed by lack of water, consequently, the essence of organic tillage lies – in most cases – in collecting water as appropriate and in preventing evaporation.” Ernő KEMENESY, 1964

In dry years and in years of average precipitation tillage should be aimed at rendering soil suitable for crop production, improving the soil water capacity and at reducing the loss of soil moisture. The soil water transport processes are affected by its clay content, physical condition, tillage and the production technology.

**Soil and soil condition** enhances the loss of moisture, if:

- it hinders the infiltration of water into the soil (i.e. it is excessively compacted),
- the soil is not covered (clean surface),
- it is over-worked, over-loosened and its evaporating surface is too large (e.g. summer ploughing).

*Cultivation results in increased moisture loss (Table 1.6)* if:

- it is carried out before or during hot days (stripping, ploughing, loosening etc. without pressing),
- it involves multi-traffic,
- tillage is too deep and it has a large surface for evaporation (e.g. in the case of spring or summer ploughing).

*Production technology* results in increased loss of moisture, if:

- crops of long growing periods are produced in the same field year after year,
- has become overly weed-infested and weed control (e.g. cutting, burning in order to provide soil coverage in this additional way as well) is neglected.

**Soil moisture loss may be reduced by:**

- eliminating compaction hindering the water infiltration into the soil,
- covering the surface (by residues, mulch), and it is given a water retaining form,
- conservation-focused tillage during dry periods (loosening, crumbling, pressing),
- producing crops of different growing periods in the sequence,
- keeping reasonable crop densities,
- controlling weed-infestation on the fields and on ruderal areas.

**Organic matter loss**

“Relentless cultivation will not improve the soil, indeed, its fertility will be lost ultimately and even applying manure will not be enough for restoring it.” János NAGYVÁTHY, 1821

Some authors estimate that cropping has resulted in the loss of some 50 % of the organic carbon contents of soils. *Multi-traffics intensive* (aerating) *tillage contributed to the loss of carbon* through breaking down the soil’s humified organic matter contents by stimulating aerobic microbial respiration processes.

Organic matter contents may be affected by land use – including disturbance entailed by cultivation – as follows:

- *increase* (ample organic matter supply, minimised disturbance of the soil),
• *keeping balance* (supply and loss in equal quantities over an extended period of time, with modest soil disturbance with a view to conservation),

• *loss* (multi-traffics cultivation involving intensive aeration over an extended period of time; the organic matter input does not make up for the loss).

The processes of organic matter transformation in the soil are affected by the looseness of the soil, its surface features, surface coverage and surface size, the quantity of humus, the quantity of organic matter input and the way it is worked into the soil (inverted in deeper layer, mixed in top layer). Few people know that summer ploughing or stubble stripping without pressing, leaving a large and clean surface behind, also contributes to the loss of carbon content of the soil.

Stubble residues are converted through microbial and chemical decomposing and building processes. Large-molecule compounds are split into smaller components – ultimately: carbon-dioxide and water – by micro-organisms as described below:

• *Biochemical phase:* plant tissues die, starch is turned into sugars, proteins are broken down into peptides and amino-acids, lignin releases quinones and phenols.

• *Mechanical crumbling:* this is carried out by the macro-and mesofauna (earthworms).

• *Decomposing:* micro-flora and -fauna provide for complete decomposition or conversion, using the organic compounds as a source of energy.

• The output of an adequately aerated soil contains the following: CO2, H2O, NO3-, NH4+, H2PO4-, SO42-, Ca2+, Mg2+, and free micro-nutrients.

• In soils of inadequate aeration the output includes: CH4, NH4+, amines, organic acids, toxic gases (hydrogen-sulphide, ethylene).

*The impacts of relevant circumstances on the decomposition of organic matter:*

• microbes are most effective at temperatures between 25 ºC and 40 ºC (too high and too low temperature hinders their activity),

• decomposition requires a humid or wet soil,

• pH 6-8 is the favourable range,

• organic matter in the soil is in constant change (*decomposition, mineralization*): aeration stimulates decomposition, inadequate air supply helps accumulation (soil surface after stubble stripping without pressing is just as unfavourable as is excessive compaction of the soil surface),

• aeration and thereby the balance between decomposing and mineralizing of organic matter can be controlled by adaptable tillage (*Figure 1.8*),

• under favourable circumstances the easily decomposing parts of straw are broken down about 4-6 weeks, the rest is broken down in 8-10 weeks,

• some two thirds of the organic carbon released into the soil fluxes into the atmosphere in the form of CO2, and about a third of it remains in the soil in the form of humus matter and or taken up by micro-organisms.

*Structure- and organic matter-conserving cultivation* improves soil quality and its workability through reasonably controlling humus decomposing processes and by *reducing carbon loss.*

*Dead furrows and open furrows*

"...the ploughman should frequently check the field not only by taking a look, which may mislead him as earth crumbles on hidden compacted shelves, but also (...) by poking some measuring stick through ploughed soil (...) and when the stick hits a harder pan it shows that the fallow has not been broken. (...) For if you cultivate land in patches you will not be able to make do with it throughout the year and that land will not be good for sowing ... " COLUMELLA, 1st Century A.D.
A dead furrow is a patch of soil not sliced off by the plough share and it is created at the connection where the new pass is wider than the plough’s working width. It can also appear in the headlands of the field where the plough is not pulled out along a given straight line and then the headland is ploughed in a patch that is not as wide as it should be. Hidden dead furrows – covered by furrow rifts are created in fields much more frequently than open – or clearly visible – dead furrows. The top of a hidden dead furrow is cut-off by the surface forming implement – if the soil is adequately humid – but in a dry soil the surface forming implement slides across them. The seedbed preparing combinator slows down when it reaches such strips of land, indeed, even the cultivator tools may go deformed.

Places where weeds grow densely in patches or where crops that require good soil conditions fall behind the rate of growth of the same crop in other places. An exacting crop shows no signs of hidden compacted pans during germination and in the early phase of growth, but later on, when their roots reach the pans, they clearly show the tillage defect.

A dead furrow is a ploughing defect, which could be avoided by precisely matching passes and quarter lands and by ploughing headlands in an adequate depth.

Open furrows and ridges are created during conventional ploughing at the edges or in the middle of the quarter lands. If the quarter lands are always set and ploughed in the same place, ridges appear at the places where the process of filling or gathering takes place, which cannot be levelled out even by surface forming operations. At the same time, between lands marked open furrow strips (casts) appear, equal in length to that of the field itself. Rainwater accumulating in the open furrows during rainy autumns and winters is indicative of years of negligent tillage practices.

Prevention: alternation of starting furrow line of the ploughing in lands or, if possible, using reversible plough.

2. Questions:

• What kind of factors influence the quality of tillage?

• What kind of changing factors influence the quality of tillage?

• What are the forms of water holding capacity?

• How does the organic material content influence the workability of soils?

• What is the correlation between the soil moisture content and its workability?
Chapter 3. Expedient methods for assessing soil condition

A great variety of defects are bound to be created by tillage governed by routine or by tillage operations carried out just when there is time for it or as dictated by necessity.

- There is vehicle traffic on the soil carrying out tillage operations even when it is excessively wet and no such operations should be carried out.
- The soil is ploughed even when it is too dry and the cloddy soil is let dry out even more.
- Furrows are opened along the same lines as in the previous years and the soil surface is given an increasingly dominant profile of furrows and ridges.
- The soil is disked in the same place and depth year after year and if drought or water-logging destroys a third or half of the yield, the weather is always there to blame.

Knowledge of the soil condition is vital for a farmer. Based on knowledge drawn from assessing the soil condition farmer can decide whether a certain tillage technique may or may not be applied and he can determine the preferable depth and mode of intervention to improve soil condition. The soil preserves defects caused by poor tillage practices but it also reveals the farmer’s care and expertise.

Neglected soil:

- is characterised by clodding or pulverising even if its moisture content is favourable at the time of tillage, rains cause silting in such soils and goes capping when it dries out,
- it is compacted and contains little air, it can absorb and store little or no water at all,
- its heat transport processes cannot be controlled and in the summer crops barely surviving in such soil are damaged by heat stress as well,
- its nutrient content has diminished and the nutrients are hardly available for crops,
- its organic matter balance is poor as a consequence of wrong interventions,
- crop residues either fail to decompose or they decompose too quickly,
- it is weed-infested and the disturbed layer contains large quantities of weed seeds,
- useful microbes and earthworms do not survive in it,
- it aggravates the impacts of extreme weather conditions (drought, water-logging) and thereby
- it increases losses in the production process.

Properly cultivated soil:

- has an aggregated structure, it is highly workable and has a good carrying capacity,
- is suitable for absorbing, transporting and storing water once it lands on its surface,
- its aeration and temperature changes can be controlled as required by the objective of production,
- is fertile, it has an ample supply of nutrients that are readily available for plants,
- materials mixed into it and crop residues decompose in a balanced way,
- it is free of weeds, the cultivated layer is not infested with weed seeds,
Expedient methods for assessing soil condition

- it is a good habitat for useful microbes and earthworms,
- it mitigates the impacts of extreme weather conditions (draught, stagnant water) and thereby
- it is a reliable basis for crop production.

When should soil condition be carried out for the best results?

- Soil condition should be assessed at least once a year, during the second or third week after shallow stubble stripping. The finding of the assessment helps to determine the depth and mode of tillage.
- Additional tests and analyses should be carried out on newly purchased or leased land after seedbed preparation, before sowing, to check the quality of tillage operations carried out by that stage.
- During the growing season, if the plants are poorly developed and are wilting heavily on heat days, random checks should be carried out. It is worth checking the positioning of the roots.
- The sites where samples are to be taken should be marked on the field map.

**Soil layer probe**

An assessment may indicate the existence of loosened or compacted layers in the soil but it is not suitable for precise mechanical resistance measurements. It helps identifying the spots where there is a need for a spade test or profile examination.

The tasks to be carried out:

Proceeding diagonally across a field a purpose-made stick sound notched at 5 cm intervals, 150 cm in length, is stuck into the soil at spots 10-20 steps apart – where imperfections are found, smaller distances. The soil is really loosen as far as sound penetrates into the soil easily (a forced push – through the pan layer – results overestimation of the loosen layer depth). Then catch the sound at the soil surface, draw that and read the depth. The findings are marked in the schematic map of the field.

**Findings:**

- **Good soil condition** is where the probe can be stuck easily into the soil to a depth of 40 cm in any point in the field.
- **Medium soil condition** is where the probe reaches a depth of 26-30 cm.
- **Poor soil condition** is where the probe penetrated the soil at any spot in the field to a maximum depth of 10-20 cm.
Expedient methods for assessing soil condition

Figure 3.1 A stick-sound to score the depth of the loosen layer

**Spade probe**

Spade test reveals the structure and humidity of the soil and any compact layer (disk pan) to a depth of 25-28 cm (*Figure 3.1*). The spade probe makes it possible to form an opinion of the condition of the soil, showing whether it has a uniform compactness or looseness to the depth concerned, it reveals its moisture content and – accordingly – whether it is suitable for tillage.

In critical cases the depth of the spade test should be extended to two or three times the depth of a spade. A normal-shaped spade requires to soil probe.

**Course of a spade probe**

1. Simply push the spade into the surface soil around three sides of a rectangle and then on the final stick remove the spit of soil.
2. Keep the soil on the spade, laying it on the ground for examination.
3. Measure the depth of the compacted layer (if it occurred), and the thickness of the pan.
4. Examine the soil looking at the structure, humidity, roots, earthworms, old stubble residues.

**Assessment by spade probe (in top 30 cm layer)**

- **Soil condition is good**, if the whole depth of the sample has an adequate structure (comprising 0.25 - 10 mm crumbs), it contains earthworms and earthworm burrows and it does not contain compacted layers.
- **Soil condition is medium**, if under a stronger pressure the sample disintegrates into fractions of various sizes (3-5-10-20 mm), it contains no heavily compacted layer and it contains earthworm burrows.
- **Soil condition is unfavourable**, if it contains a hard-pressed compacted layer, no earthworm burrows and it cannot be broken down without a knife.
- **Soil condition is unfavourable**, if the top 10-15 cm layer has a very dusty structure.

**Soil profile assessment**
The spots where sample pits are to be dug are designated in areas within a field that show signs of unfavourable soil condition (water-logging, poorly developed plants). Sample pits must be dug in parts of the same field where the soil appears to be in good condition, for a basis of comparison. The pit should be 50-60 cm deep and wide enough for stepping in and carry out the required tasks. The walls of the pit must be cut so as to have a clear and even surface and then with a pointed knife it must be slit ‘nice and easy’ from top to bottom. A profile examination makes it possible to see where there are looser or ‘thick, silted, hard layers’ from top down (a measuring tape is required and sketches/photos should be taken of the various layers).

**Soil condition assessment according to M. Birkás et al.**

**Tasks of a simple soil condition assessment:**

1. Designate the spots for taking samples.

2. Dig a pit of vertical walls across the usual tillage pass direction (to a depth some 2-4 inches deeper than the tillage depth). The width of the pit should be equal to its depth.

3. Identify (measure) the depth and thickness of each layer that can be clearly distinguished and then produce a sketch and photos.

4. On the side of the pit that is perpendicular to the direction of tillage passes peel off the layers as they follow one another from top down – using a strong blunt knife – and jot down your findings (empirical assessment).

5. The empirical assessment of the various layers reveals following:
   - position and thickness of compact layers,
   - soil humidity – by touch – in, underneath and above the compact layer(s) (if the top segment of the compact layer contains more water, there must have been a longer period of stagnant water coverage on the surface).
   - the position of roots, the degree of their development and their growth direction (roots grow horizontally above a compact layer),
   - the position and quality of crop residues (embedded in the compact layer they do not start decomposing, they are clearly identifiable, even if mouldy).
   - are there earthworms and earthworm burrows, and if there are, the depth to which they occur in the soil (many burrows – to a certain depth – is indicative of favourable physical, biological and chemical state).

**Supplementing empirical assessment by sampling:**

1. On the same – undisturbed – side of the pit, proceeding from top down, undisturbed four soil samples are taken with the aid of the cartridge – that is the standard instrument for physical soil condition checks – from each of the distinct layers in the relevant profile (this will make it possible to precisely identify the soil moisture content and its loose/compact state).

2. This examination can be supplemented or substituted by penetrometric soil resistance tests which do not require such pits.

The ‘pit test’ is a labour intensive exercise but it is suitable for convincing those who are somewhat averse to instrumental checks.

**Penetration resistance measurement**

The condition of a soil can be established on-site, by measuring mechanical resistance. Static penetrometers of a 60 degree cone angle are the most commonly used instruments for this purpose today. In addition to mechanical resistance (expressed in MPa, for instance) some combined instruments also measure soil moisture content in mass percentage of volume percentage. Different models of these instruments are suitable for measuring soil parameters to different depths. Types of Field Scout TDR instruments are applicable to quick measuring of the water content of soil.

**Assessment of soil workability** (according to M. Birkás)
Expedient methods for assessing soil condition

Tasks to be carried out when the surface has dried out and the layer to be cultivated is wet:

• Take a handful of soil at the bottom of the intended depth of tillage (e.g. if the planned tillage depth is 18 cm, take the sample from the layer between about 18 and 25 cm).

• Press the soil in your hand. If you can knead by hand and your hand is smeared with mud (Figure 3.1a), your soil is too wet and there is a risk of compaction. Disking and ploughing should not be carried out at this point. A spring tine cultivator should leave less damage in such soil. If tillage is required nonetheless and the farmer has no implements that can minimise soil damage, ploughing will result in tasks to be carried out in the next season (for the layer puddled underneath the ploughing depth will have to be loosened).

• If the sample taken from soil underneath the planned tillage depth feels humid if pressed by hand (Figure 3.2b) but it crumbles if pressed between one’s fingers, the soil is suitable for ploughing/disking though there is a risk of tillage pan formation even in this case. Spring tine cultivators are more suitable for soils in this condition.

Tasks to be carried out when the top 30-40 cm of the soil is dry:

• In this case the sample taken from any layer of the soil feels dry in one’s palm (Figure 3.2c). If the soil is crumbly, any tillage implement can be used for cultivation.

• If the soil is so compact that it is difficult even to take a sample, ploughing is not the technique to be chosen: disk, a subsoiler (ripper) or cultivator should be used rather than a plough and the surface should be pressed right after tillage to minimise further moisture loss.

Figure 3.2 A simple palm-probe for soil suitability to tillage: wet (a), humid (b), dry (c)

Checking the effectiveness of loosening

In the case of loosening attention should be paid to
• the moisture content of the soil: the soil should be dry but not overly dry,

• the operation should take place after stubble stripping, when the mellowing process has already started.

• a handful sample should be taken from the disturbed layer on the 3rd or 4th week after stubble stripping. If the sample is humid and crumbly, it is time to start the loosening operations. *Crumbly structure is a favourable sign of suitability for loosening.*

• Stubble stripping carried out with due care ensures that the soil does not lose too much of its moisture content and its workability improves as a result of the biological processes taking place in the wake of stubble stripping – loosening will be easier and it will take less energy.

*In assessing the effective depth of loosening it is not enough just to see how the sides and cutting edges of the loosening tines are polished or to take measurements using a 'crowbar', for these may be misleading. Measuring depth from the top of the clods – instead of the stubble surface – may result in errors of 10-15 cm. The depth of loosening and the effectiveness of ripping through compacted layers are easy to establish: e.g. in profile pits of adequate width, dug perpendicularly to the direction of the loosening pass:

• If the soil has become friable in the entire profile to the planned depth, loosening is effective.

• If depth and crumbliness equals 65-70 % of the planned extent, loosening is moderately effective.

• If actual depth and crumbliness falls below 50 %, loosening is ineffective.

*The effectiveness of loosening may also be checked by the spade probe:*

• in the wake of the loosening tines, across the pass direction to a width of 20 cm on both sides and to a depth of two spade spits (38-45 cm). Measure the width and depth of the friable soil profile and compare it to the plan.

The effectiveness of loosening can be *checked* with the aid of an instrument using a penetrometer (*pressure gauge*): push the probe into the soil at 15-20 spots proceeding diagonally across the field and record the measurements. This procedure provides correct results in a humid soil. The conclusion:

• *highly effective* loosening, if the readings fall within < 2-2.5 MPa soil resistance range to the planned depth,

• *moderately effective* loosening, if the targeted <2-2.5 MPa soil resistance readings are found down to 75 % of the planned depth (e.g. target: 45 cm, actual: 34 cm), with readings of 3 MPa or more in deeper layers,

• *ineffective* loosening, if the optimum <2-2.5 MPa soil resistance readings are found only down to 50 % of the planned depth (e.g. target: 50 cm, actual: 25 cm).

*Loosening to let the soil dry*

*Soils that are frequently immersed in water-logging may require loosening to facilitate drainage. If the loosening tines are set widely apart, cleaving may not occur. In such cases only the depth should be measured, using a pointed measuring stick graduated in 5 cm units.*

The conclusion:

• *loosening is effective*, if 90-100 % of the planned depth has been achieved (e.g. target: 50 cm, actual: 45-50 cm),

• *loosening is moderately effective*, 75 % of the planned depth has been achieved (e.g. target: 50 cm, actual: 38 cm),

• *loosening is ineffective*, less than 50 % of the planned depth has been achieved (e.g. target: 50 cm, actual: 20-25 cm).

*Description of biological soil condition in terms of earthworm activity*

Earthworms and their burrows can be *identified with the aid of a simple method.*
Expedient methods for assessing soil condition

One method for this examination is placing soil taken out in the course of a spade test on a plastic sheet or a sheet of newspaper and then counting the earthworms after crumbling the soil by hand. Some 5-10 such samples should be examined in a given field. The conclusion:

- **If digging is easy** and 3-4 earthworms are found in the soil along with a number of burrows and casts, the soil structure and humidity is favourable, its biological condition is good and there is likely to be food (stubble residue) available for the earthworms.

- **If digging is not easy** for the soil is settled and compacted and no earthworms or burrows are found in it, the soil is highly likely to be in an unfavourable biological condition.

**The other method:** a wooden or metal frame of 50 x 50 cm is pushed into cultivated soil. The disturbed soil is placed on a plastic or newspaper sheet with the aid of a small shovel, counting the earthworms. Multiplying the number of earthworms by four provides the number of earthworms per square metre to the depth checked.

*Earthworm burrows* can be identified in the sides of the profile or in sample taken with a spade – but these can be found only in a soil in good condition.

The above tests and examinations may help the farmer to learn more and more about the soil and about defects that are bound to occur. *Learning more and more about the condition of the tilled layer of the soil will help a farmer become increasingly assured about the results of his efforts. Knowing errors and defects helps one avoid making them again. Soil in good condition, well known by the farmer, is the farmer’s virtue.*

1. **Questions:**

- How can you define a tillage defect?
- How can you feature a good soil condition?
- What testing methods can be used to assess soil condition?
- How can you recognise the presence of a compact layer?
Chapter 4. Phases in a conventional tillage system

In this chapter the five main phases of the classic, conventional tillage system are described, highlighting practices that make it possible to prevent defects and environment damage and to reduce the energy input. The seedbed preparation comprises the following phases: stubble tillage, primary tillage, secondary tillage, seedbed preparation and surface forming after planting.

1. Stubble tillage

Stubble tillage comprises the operations aimed at maintaining and improving the soil water transport regime and its workability after harvest. Stubble treatment serves a variety of purposes: the residues of most crop types need to be chopped; it is important that crop residues are cut into as small pieces as possible, hard stalks (maize, sunflower) must be crushed and the chopped residues must be evenly spread. If straw or stalks are to be utilised as fodder or for industrial purposes, collecting and transportation must be provided for.

Stubble tillage after a crop harvested early during the year comprises two processes: stubble stripping and the subsequent treatment of the soil.

Stubble stripping is shallow (6-10 cm) tillage in fields with residues of crops harvested in early or mid-summer; its surface needs not only levelling but also pressing. Stripping may take place after or in one go with chopping crop residues.

The likely benefits of proper stubble stripping:

- **Reduced soil moisture loss.** Stripped and somewhat compacted soil – with part of the crop residues mixed in it and with the rest on the surface – loses 16-40 % less water during the dry summer season than undisturbed or bare stubble and 55-75 % less than cloddy and too deeply ploughed soil without surface pressing.

- **Controlling the soil heat transport regime.** The stripped layer warms up more during daytime than does soil surface that has not been stripped, however, it reduces temperature rise in layers underneath. Functioning as an insulating layer it also reduces water loss. During night hours the deeper layers remain warmer. Water moving upwards turns into steam and, moistening at the bottom of the stripped layer, it gradually moisturises the soil. Only a fraction of this moisture evaporates from the top insulating layer during daytime (Figure 4.1).

<table>
<thead>
<tr>
<th>Soil layer</th>
<th>Stubble-mulch tillage</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 cm tilled</td>
<td>heat, water, air penetration into soil</td>
<td>minimal water loss</td>
</tr>
<tr>
<td></td>
<td>(1st insulating layer)</td>
<td>Biological processes, mellowing</td>
</tr>
<tr>
<td>undisturbed</td>
<td>moderated heating</td>
<td>(1st insulating layer)</td>
</tr>
<tr>
<td></td>
<td>vapour-state water</td>
<td>humid, well-workable state, moderated clod formation</td>
</tr>
</tbody>
</table>

*Figure 4.1 Water-, air- and heat management in a soil after stubble stripping*

- **Stimulating biological activity in the soil.** Aerobic micro-organisms are a lot more active in well-aerated, loose and moist soil whose surface has been pressed. The result of the biological processes is decomposition of crop residues, biological mellowing and improving workability.

- **Crop protection effect** through facilitating the germination of volunteer crops and weeds (control and weed-killing in the course of treatment operation) reducing the availability of the requisites and deteriorating the
conditions for the life of pathogens and pests at the same time. The best tillage for weed control is where good and fast volunteer crop and weed germination is stimulated by providing favourable conditions.

- **Leaving a mulch cover**, mixing part of the crushed crop residues in the soil and leaving some 35-45% of it on the surface. In the regularly applied tillage systems mixing is started by stubble stripping and then it is continued by the treatment of the stripped stubble and finished by primary tillage.

**Points to ponder.** Direct agronomical benefits along with indirect benefits in terms of energy saving should be expected of adequately completed tillage operations. Soil that has lost its cover after harvest should be stripped as long as it retains its so-called mellowed state. A mellowed state caused by shading is not of biological origin therefore it is not a persistent feature. It exists for 2-3 days on the hottest days if the soil is evenly covered by crushed crop residues. A proper coverage of the surface should also be retained even after stubble stripping. Covering and pressing the loosened and crumbled soil provides the insulating layer that will reduce moisture loss and control the heat transport in deeper layers. Increasingly active biological life in properly covered soil whose gradually growing moisture content is supplied from deeper layers helps decomposing stubble residues. These favourable processes do not take place in compacted soil that has been subject to intensive traffic and that has dried out, that is, on the whole, neglected.

In the case of an excessively wet soil the possibility of skipping the stubble stripping operations or that of carrying out primary tillage right after the soil has adequately dried out should be contemplated. In this case, however, the favourable biological changes that are characteristic of soil after shallow stripping do not take place. Stubble stripping may be dropped from the tillage regime in order to protect the soil (on slopes, on loose soils) or in years of excessive precipitation but weeds should be prevented from producing seeds even in such cases (by mowing or by burning as a means of weed control).

**Trends in the changes of soil structure** point to the importance of proper stubble tillage. Stubble stripping creates favourable conditions for weed germination, thereby reducing the number of viable weed seeds in the soil layer concerned.

An indirect purpose of stubble stripping is to prevent and/or mitigate harmful impacts (overheating, drying out, capping, anaerobic processes, weed-infestation, gradation of pests) in the top soil and in the layers underneath.

Techniques meeting the requirements listed above in the given circumstances are suitable for stubble tillage.

The second phase of stubble tillage is referred to as the treatment of stripped stubble which may be necessitated by a quick and vigorous emergence of dense volunteer crop and/or weed populations. The best time for weed killing is the beginning of flowering for weeds can quickly produce ripe seeds. Stubble treatment is usually a mechanical intervention – a bit deeper than stripping – but it may also be a chemical treatment using some scorching agent. Soil-conservation related arguments can be listed for and against both methods (e.g. the residues of chemically killed weeds are a useful means of soil cover).

Treatment has a favourable impact on preserving the soil’s good physical condition and in maintaining its mellowing process (besides a weed and pest control function).

**2. Primary tillage**

Primary tillage is the deepest process in the tillage system, aimed to create a physical state within the soil’s regularly cultivated layer to meet crops requirements and to protect the soil.

Attention should be paid to the following:

- Quality expectations: e.g. cloddiness, workability, looseness, inverting or mixing stubble residues in the soil.
- The site features: determining depth of tillage and implements to be used.
- The stubble residues from the previous crop (mass of stalks and roots) and weed infestation; whether or not there is a need for ploughing.
- Soil protection tasks: the best method should be chosen for the given circumstances or any inevitable damage should be minimised.
- The wide range of the available machinery or implements.
The methods and tools of primary tillage. Primary tillage may be shallow, mid-deep and deep, while in terms of implements:

- ploughing,
- ploughless methods as
  - shallow loosening with the aid of disk, cultivator or rotavator,
  - deeper loosening with the aid of subsoiler or deep ripper implements.
- combined method: in one tillage operation, using plough combined with subsoiler shank, or loosening and ploughing separately.

Frequently encountered defects in primary tillage

Wrongly chosen interventions creating unfavourable conditions – or making them even worse – entailing excessive energy input should be regarded as ‘wrong practice’. Such cases may include excesses or shortcomings in terms of depth and quality of primary tillage.

- **Primary tillage is too deep** if it exceeds the depth required by the condition of the soil, the mode of production or the need for environmental protection, if its depth is not warranted by agronomical considerations or if it entails a waste of energy. The depth and mode of primary tillage can be adapted to the condition of the soil at the time of the intervention. Failure to provide for such adaptation may result in excess energy input without improving the soil condition, just like any primary tillage when it is not necessary.

- **Too shallow primary tillage** on compacted top soil is a highly risky intervention from the aspect both of cropping (lower yields) and of environmental protection (water-logging on compacted layer, the whole of the shallow tilled layer being drifted down the slope). In this case the energy saving that may be achieved in comparison to deeper soil condition improving tillage will result in more loss and damage than the benefits of saving on fuel costs. Shallow tillage should also be carefully considered on pest- or weed-infested fields.

- **Disregarding soil parameters affecting the quality of primary tillage.** In addition to the soil natural parameters (clay content, plasticity, stratification, humus content etc.) the quality of tillage is also affected by moisture content and compaction. If compaction has appeared in the top 10-20 cm layer and the implement gently loosens the soil (*cultivator*) or if work carried out with the aid of the implement is not heavily affected by the compaction of the top soil (*disk*), the two factors have identical impacts on quality.

  - The compactness of deeper layers has a stronger impact on clodding caused by loosening than had soil moisture. The higher clay content (heavier soils) has the greater impact on soil compaction.
  - The quality of deep ploughing is also affected more by compaction than by soil moisture. The unfavourable impacts of compaction are greater in heavier soils.
  - The quality of tillage using *cultivator* is affected more strongly by soil moisture content and the compaction of the top soil. In the case of *disks* – resulting in a stronger disturbance of the cultivated layer – the quality of the operation was similarly affected by the compact layers.
  - The quality of *loosening* is affected by soil moisture in light and in heavy soils. The compaction of the top layer was the second most important factor in light and medium heavy soils. In heavy soils compaction of deeper layers was found to be more unfavourable.
  - Soil moisture does have an important impact on the quality of loosening but this technique is judged more in terms of the loosening effect than in terms of clodding.
  - Compaction of the top soil layer is the primary factor determining the cloddiness of the soil after ploughing. At the higher content of the clay the impact of soil moisture is also stronger.
  - Assessments have confirmed the assumption soil’s current condition (moisture, compaction, the depth of compact layers) determines the best possible quality of the soil after primary tillage. Adaptation is an essential prerequisite for optimising quality. The possible quality of the soil after primary tillage and the required
Phases in a conventional tillage system

energy input can be planned more precisely and any damage to soil structure can be best avoided by taking soil condition into account.

3. Surface preparation after primary tillage

Surface preparation is carried out in order to further improve the condition of the soil after primary tillage in view of crop requirements and with a view to soil conservation. Sub-optimal (too loose or too cloddy) soil condition resulting from primary tillage should be improved as required for equalising soil moisture content differences, for stimulating the decomposition of materials mixed into the soil and to encourage biological processes.

In some cases surface preparing involves flattening and crumbling, in other cases – e.g. in the summer, to reduce moisture loss – it also includes pressing of the surface. Surface preparation may be carried out:

- **in the same pass with primary tillage**, with the aid of loosening, crumbling, flattening and/or pressing implements mounted on the primary tillage implement (clod crumbling roll spring tine and leveller combination).

- **in separate tillage operations**, using simple implements (e.g. disk, leveller, ring roll, tooth harrow), powered implements resulting in intensive crumbling and mixing (e.g. rotavator, rotary harrow, reciprocating harrow), soil driven (rotary element, spading harrow) combinations, deep and top pressing rolls as well as structure conserving spring tine leveller implements (cross-board).

Frequently defects and shortcomings in preparing the soil after primary tillage

- **Repeating operations** not suited to the current condition of the soil. Additional processes carried out in the way of wrong practice or as dictated by necessity or for lack of appropriate implements inevitably entail degrading structure, unnecessary traffic, re-compacting and – consequently – waste of energy.

- The reason for multiple surface preparing operations before crops sown in late summer or in the autumn is *loss of moisture* caused between stubble stripping and primary tillage (particularly during the dry season) and in some cases the lack of suitable implements. The former defect, however, can be avoided even if there is an insufficient range of implements available for the farmer.

- In the regular tillage regime for crops sown in the spring the quality of the preparing of primary tillage carried out in the autumn tends to be the weakest link since it does not enable a reasonable reduction of summer tillage operations, nor does it make it possible to prevent damaging the soil structure.

- The *widely used disks* tend to re-compact the soil in the course of preparation, as a consequence of which it takes much longer for the autumn and winter precipitation to penetrate the soil and much of the water is lost to crops. Farmers avoid this by not preparing the surface after the autumn ploughing (still using the conventional plough in most cases), but then they have to carry out the levelling operation in the early spring.

- Levelling in the spring – with the aid of conventional implements – results traffic-induced soil structure damage (through the inevitable kneading of soil) entailing an increased number of seed-bed preparation tillage passes. The benefit of this approach appears in a reduced moisture losing surface.

The following should be considered in regard to surface preparation:

- The quality of primary tillage must not be undermined. Excessive traffic, pulverisation, soil drying, clodding and smearing should be avoided for these defects lead to increasing number tillage trips for seedbed preparation and growing tillage costs.

- If the farm has only seed drills that are sensitive to stubble residues, such residues should not be brought up to the surface.

- *Clods should be broken down through a process crumbling instead of pulverising*, i.e. the requirements of soil conservation should also be met.

- Efforts should be made to eliminate germinating weeds mechanically.

- Soil condition in which fewer tillage passes are required for seedbed preparation should be created.
4. Seedbed preparation

Seedbed preparation is the operation whereby soil condition resulting from primary tillage and levelling is adjusted to the requirements of sowing. The structure of a good seedbed is made up of a high proportion of small crumbles (with little dust fraction), it is settled (but not compacted), the soil is humid and is free of weeds. The depth of the seedbed depends on the requirements of the crop to be produced (alfalfa, wheat, maize etc.), the size (thousand seed weight) and the time of the seeds germination and early growth.

The following needs to be considered for creating high quality seedbed:

• It should help seeds or other propagating materials germinate and emerge quickly and it should boost the impact of chemicals and starter fertilisers.

• Its preparation should entail minimised soil disturbance, pulverisation and traffic.

• An additional tillage operation may improve the top soil quality but it may also compact deeper levels.

A good seedbed is characterised by the following:

• it enables an even sowing depth,

• the seedbed base on which the seeds are laid, is adequately – not excessively – pressed,

• the soil above the seed is comprised mainly of small crumbles but not of dust,

• the soil is pressed back above the seeding line,

• it is coarse (providing protection) but not excessively cloddy between seeding lines,

• humid and weed-free,

• the layer below the seedbed base is also adequately loosened and it does not impede root growth (Figure 4.2).

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Dusty, removable, susceptible to cracking</th>
<th>Soil layer cm</th>
<th>Friable, stable, protects deeper layers</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>High climate sensitivity; limits germination and growth</td>
<td>loosen and dusty</td>
<td>0 / 6</td>
<td>pressed</td>
<td>Low climate sensitivity, improves germination and growth; Improves</td>
</tr>
<tr>
<td>Limits water transport</td>
<td>over-compacted</td>
<td>10 / 20</td>
<td>settled</td>
<td>water infiltration and water storage</td>
</tr>
<tr>
<td>Loss for crop production</td>
<td>loosen</td>
<td>20 / 30</td>
<td>loosen to required depth</td>
<td>Favourable water transport to root zone</td>
</tr>
<tr>
<td>Limits water transport to root zone</td>
<td>subsoil compaction</td>
<td>50 / 60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.2 Differences between seedbed variants

Energy requirement of seedbed preparation depends on the wrong adaptation of soil moisture conditions, the deeper than necessary tillage depth and the unnecessarily repeated tillage operations. The first two shortcomings are regarded to be wrong practice while third one may result from low quality primary tillage.

The implements applied in seedbed preparation (combinator, compactor) are combinations of elements carrying out the functions of loosening, crumbling, levelling and compacting in one go e.g. leveller, cultivator and cage roller combination or spading harrow plus cage roller, rotary element, leveller and cage roller combination.
Phases in a conventional tillage system

Seedbed defects are indicative of poor utilisation of growing resource inputs and of growing losses, thus for instance:

- the soil has dried out and contains a high dust fraction in the sowing layer (frequently encountered in late summer or autumn sowing),
- the top 10-15 cm layer is adequately loose but it is heavily compacted underneath (where levelling of the autumn primary tillage is carried out in the spring on wet soil),
- the seedbed base is more compact than it should be and the layer over the seeds has varying moisture contents and crumbliness (its consequence: ‘uneven’ germination),
- the seedbed base depth varies and so does its compaction (as a result of uneven primary tillage in the autumn or of shortcomings in the process of seedbed preparation),
- the soil is in good condition down to the depth of the seedbed but the intended root zone layer is compacted,
- the seedbed and the layer below have been compacted by traffic, the soil is not sufficiently aerated and its temperature is low (typically seen in the ruts created by wheels of machines and implements, in the spring).

Rapid germination and early growth is facilitated by soil conditions characterised by the best possible water, air and heat transport. A method – including implements – must be chosen whereby the requisites for good germination/emergence can be created by minimised intervention, without soil structure damage and at the least costs. If the required technology is available, the way and the costs of creating soil conditions meeting crop requirements and the need for soil conservation are determined by the farmer’s decisions, which, in turn, depend on his expertise.

5. Surface formation after sowing

Surface forming in the wake of sowing is aimed at covering the seeds, pressing loosened soil to contact the seeds and to form the surface of the seedbed.

Criteria:

- Soil moisture, temperature and air transport can be controlled by compacting and by surface forming.
- Surface that is resistant to water and wind erosion (mitigating their impacts) and that is, at the same time, suitable for post-drilling chemical treatments.
- On soils prone to capping profiled surface should be formed.
- The required traffic should be minimised.

Surface forming can be carried out in one go with seed drilling with the drilling machine’s row compacting elements or with the aid of surface forming implement attached to the seed-drill. After drilling it can be carried out in a separate tillage run, using a tooth harrow for seed covering or a roll.

In the case of broadcasting the seeds are spread on the levelled surface by hand or using a machine, thereafter the seeds are worked into the soil and the surface is pressed in one or two tillage passes.

Planting is placing vegetative propagating materials or seedlings into the soil. By cutting the soil open, the small plants, tubers etc. are placed in the soil, compacting and forming the surface at the same time. The final surface is not necessarily formed during the planting process: it is often shaped in the course of the crop treatment.

Basic fertilisation and starter fertilisation should be aligned to or should be planned simultaneously with the tillage operations between stubble stripping and seed drilling, along with the process of soil disinfection and the application of pre-and post-emergent chemicals during or after sowing.

6. Questions:

- What are the major phases of a conventional tillage system?
Phases in a *conventional* tillage system

• Summarize the major aims of stubble tillage!

• What are the most important effects of primary tillage?

• What should we focus at seedbed preparation on?
Chapter 5. Tillage – energy requirement and soil damage

Efforts have been made to reduce the energy requirement since the early 20th century, but it has been turned into an urgent necessity by soaring fuel prices. The golden age of the relevant technical and agronomical research activities was between 1975 and 1985, across the world. In line with the latest challenges research activities today are being pursued in a broad range of areas and have been enriched by additional dimensions, such as soil and environment preservation and sustainable production. The need for reducing or preventing soil damage was already dealt with in publications and the work of several classical authors. It became an urgent global task in the sixties when environmental damage on a global scale (including soil compaction, degradation of soil structure, erosion, deflation etc.) pointed to the need for solutions to mitigate damage.

The recognition of the fact that the majority of the factors turning tillage an increasingly energy-intensive activity are identical with those causing increased soil damage – where the only differences to be found in the scale of damage or shortcomings and in the modes of and costs of remedying interventions – calls for coordinated efforts aimed at prevention and those aimed at improving economic efficiency. The relevant factors are discussed from technical and operational aspects as well as in view of aspects of production site and tillage. Factors that can be managed by farmers more with the aid of careful farming practices and sound expertise will be discussed in more detail than those that can only be dealt with by increased spending.

1. Technical and operational factors

1.1. The tractor

A tractor, as an agricultural machine providing the necessary traction power, can be operated economically within an optimum speed range. This is when minimised fuel consumption enables the utilisation of maximum power output. Using a given tractor for tillage operations where its capacity cannot be fully exploited results in wasting fuel, just like where the agricultural implement demands too much traction power. In regard to energy requirement particular attention should be paid to the type of the tractor concerned, its engine capacity, its state of wear as well as its specific fuel consumption. A heavily used engine that tends to break down quite frequently should not be expected to run economically.

The capacity of a tractor

The tractor is the type of machine used most extensively in agricultural operations – particularly in the mechanisation of tillage – with universal tractors being the most widely used type. Tractors running on wheels or on other running gear types are categorised by the ISO standards according to nominal engine capacity, in four main groups (Table 5.1).

<table>
<thead>
<tr>
<th>Motor capacity</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50 kW</td>
<td>Light universal</td>
</tr>
<tr>
<td>50-80 kW</td>
<td>Medium universal</td>
</tr>
<tr>
<td>80-130 kW</td>
<td>Heavy universal</td>
</tr>
<tr>
<td>&gt; 130 kW</td>
<td>Super heavy universal</td>
</tr>
</tbody>
</table>

Table 5.1 Tractor categories according to ISO

The power generated by a tractor’s engine can be utilised in two ways. On the one hand it provides tractive capacity through its running gear while on the other hand it provides cardan transmission capacity through the power take-off shaft to drive farming implements. Higher capacity tractors are heavier-built machines. The primary goal of tractor development efforts is to enable the highest possible rates of utilisation of the built-in engine capacity.
The weight of a tractor

An agricultural tractor’s engine power is transformed into traction power through its running gear. The greater the load on the running gear (which depends primarily on the machine’s weight), the greater is its traction power. A heavier tractor can put out greater traction power as a consequence of the greater load on the wheels.

A greater weight results in extra energy consumption if the running gear is not quite adequate or if the working speed is not optimised. A categorisation of tractors in terms of capacity weight and some features of a few well known models are presented in Table 5.2 and 5.3.

<table>
<thead>
<tr>
<th>Tractor capacity weight (kg/kW)*</th>
<th>Tractor weight category</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-39</td>
<td>light</td>
</tr>
<tr>
<td>40-49</td>
<td>medium heavy</td>
</tr>
<tr>
<td>50-59</td>
<td>heavy</td>
</tr>
<tr>
<td>60-69</td>
<td>super heavy</td>
</tr>
<tr>
<td>&lt; 70</td>
<td>extra heavy</td>
</tr>
</tbody>
</table>

Table 5.2 Tractor categories in terms of capacity weight

Table 5.3 Capacity weight data of some tractor types

Energy efficiency may be improved by using up-to-date tractors of low fuel consumption and of relatively small weight or equipped with some soil preserving running gear, that are suitable for the required tillage operations.

The running gear of a tractor

The inevitable adverse impact of the running gear on the soil appears in the form of structure degradation and compaction as a consequence of the axle load and wheel slip. The issue of compaction causing deformation even in the subsoil layers may be summed up as follows:

- The pressure on the soil is determined by the load per wheel or axle.
- Traffic-induced soil damage extends deepest in wet soils. In a slightly moist loam soil structure deformation may extend, under machines of 6 tonne axle load, with regular tyres, to about 40 cm while under machines of axle loads of 9 tonnes or more, deformation may reach 75 cm or more.
- Traffic-induced subsoil compaction is more durable and is more difficult to remedy than tillage pan caused by wrong tillage practices.
- The extent of damage is also characterised by the size of the area affected by traffic. One simple method to assess this is comparing the area under wheel tracks to the total area (or a unit – e.g. a hectare – of land). Measurements show that – in the case of the production of small seed crops and maize and soybeans – if a rear wheel driven tractor is used, the total area affected by traffic may equal up to twice the total area.

Soil compaction during the operation of machinery is affected primarily by the following factors:
• the total weight of the machine or units,
• dynamic impacts (working speed, slip, swings),
• the running gear’s bearing surface,
• the running gear’s ground pressure,
• the soil structure and moisture content,
• the duration of the impact of load on the soil (passing on the same track multiple times).

**Options for reducing traffic-induced soil damage**

*Controlled tillage traffics.* This category includes any crop production system where the zones of crops are distinguished and permanently separated from the tillage tracks or routes. The cropping zone is not exposed to traffic – only to natural impacts – and traffic in the field can be made independent of weather conditions. No crops are grown in the lanes dedicated to tillage traffic and as a consequence of the reduction of the area under crop this could even lead to reduced yields. In general, however, no such loss occurs for the traffic lane enables precisely timed and highly accurately executed interventions that have positive impacts on the produce (e.g. crop protection, foliar fertilisation), along with the benefit of the edge effect along the unsown lane.

The method based on tillage lanes is not yet widely used in the Pannonian region. The machines that are suitable for different tasks in the production technology have different working widths and complications may also result from trying to standardise the working widths of machines of different makes, models and ages.

The concept of controlled traffic was developed into a *cropping system* (called CTF- Controlled Traffic Farming) in Australia, and was applied – according to TULLBERG – on 2 million hectares in 2007). With the aid of permanent traffic lanes they avoid soil compaction, which is an inevitable development in rainy periods of during irrigation and is observed in entire fields. The technological interventions of the cropping regime are carried out at the best possible times and in the best possible ways, without causing damage, turning cropping into a profitable undertaking.

*Using high capacity tractors and tillage implements.* Increased working width and capacity makes tillage operations less time dependent. More options will become available for achieving planned goals of tillage under more favourable soil conditions and there will be fewer trafficked strips on the soil. Since high capacity machines are heavier, their compacting effect penetrates deeper into the soil. This may be avoided by applying smaller capacity and lighter machines during periods of more rainfall. This, however, assumes the availability of a broader variety of machines, which in turn assumes a sound financial background.

*The tractor is not driven on the field.* The greatest advantage of single and dual steam engine systems developed in the early phase of mechanisation was that the machine providing traction power did not enter the field – so it did not compact the soil – and the implement was towed along in the suitably shaped field with the aid of a stranded wire rope (*Figure 5.1*). HAKANSSON et al. (1988) noted that yields produced this way exceeded by about 26 % the yields produced under similar circumstances where tractors were used instead of the stationary engines.
1.2. Working speed

The limit of increasing *working speed* is determined by the parameters (size) of the given tillage implement as well as agro-technological circumstances and requirements. In the range of speeds between 7.5 and 14.5 km h\(^{-1}\), the rate of utilisation of the traction power of up-to-date, high capacity tractors may be as high as 85-90 %. The useful speed range of the tillage implement can be determined in view of the tillage requirements: e.g. 6-10 km h\(^{-1}\) for ploughing, 6-12 km h\(^{-1}\) for disking, 8-14 km h\(^{-1}\) in the case of seedbed preparation using combinator or seedbed preparation and drilling in one go. A given tillage machine unit can be used within a speed range in which the quality requirements are met without over-loading the tractor. The speed limit recommended for a farming implement should not be exceeded because in addition to deteriorating the quality of work the implement’s traction resistance will also increase. If the working speed is not suitable for the given soil and terrain conditions, both the quality of work and the rate of utilisation of the tractor’s traction power will decline.

1.3. Energetic harmonization between tractor and tillage tools

Maximising area capacity – and performance – and minimising expenditures are two fundamental pre-requisites for economical operation. A tractor of an adequate capacity needs to be used as required by the given tillage implement and as is necessary for attaining the desired working speed.

The width of a tillage implement is favourable if its capacity requirement permits the tractor to be operated at optimum speed. If the tillage implement’s traction power requirement is too low, the tractor capacity can be economically utilised only at unfavourably high speeds. Harmonising tractor capacity with the tillage implement’s capacity requirement and maintaining this under soil conditions varying within a given field is an important goal of operation.

Tractor and tillage implement are working in harmony – from the aspect of energy consumption and utilisation – if the tractor’s current traction power output falls in a high capacity utilisation range when working at the given speed. Such favourable relationship between tractor and farming implement in terms of energy consumption and utilisation can be maintained even under varying soil conditions without wasting fuel. The following options are available for achieving this:

- **Using farming implements of variable working width:** if a working width aligned to the type and condition of the soil is chosen the number of subsequent operations and the ratio of idle running will also be reduced. Such a solution is also applied in developing conventional and reversible ploughs (*Figure 3.14*) and in that of mid-deep loosening implements. By adapting the working width to the tractor both the working speed and fuel consumption can be optimised.

1.4. The weight of the tillage implement

The weight of a tillage implement is determined by requirements concerning strength, structure design and agronomy. Trailing and operating a heavier machine takes more energy (a higher capacity tractor) and increased
soil load. This is why bridging material quality shortcomings by building more robust implements that are not quite the best approach.

1.5. The working width of the farming implement

The width of a tillage implement is determined by quality and operational criteria. A large working width can be utilised economically only in larger fields. Disadvantages of a large working width are encountered during transport, when the implement is attached to the tractor and during operation (manoeuvrability). Increasing the working width is limited by the necessity of even quality of work across the tillage direction, by field size and manoeuvrability/ease of handling. Favourable soil conditions enable economical use of implements of greater working widths but where the soil is in a poor condition, only implements of smaller working widths can be used economically with a tractor of a given tractive capacity. Working width not suitable to soil and terrain conditions results in waste of energy through reducing the prescribed working quality (e.g. depth, thorough loosening).

Working width (in the case of ploughing) affects the productive time utilisation ratio of the ploughing machine unit – and consequently the utilisation of the tractor capacity – through its impact on the length of idle runs. Working width depends on the length of the route of turning and the working width of the machine unit, while the productive time ratio is also affected by field size.

1.6. The state and shape of the tilling elements

The state and shape of tilling elements on a given implement help or impede the accomplishment of the tillage goal (inverting, crumbling etc.). To improve the quality of work and to reduce energy requirement the tillage elements must be set as prescribed by the manufacturer and cutting edges must be kept in good working order.

Manufacturers’ and machine distributors’ specifications must be observed. A poorly set plough’s specific traction resistance exceeds the normal drag under the given circumstances by up to 30-40 cm. In the case of other tillage implements (e.g. loosening tines, cultivator shanks) the energy loss may vary between 5 and 35 %.

By using worn and blunt tillage elements 10-40 % of the energy input may be wasted depending on the width of the worn edge (e.g. plough share), the depth of tillage may be reduced and the soil may be compacted underneath the cultivated layer.

Costs may also be cut by using replaceable tillage elements, reducing friction and adhesion in the course of tillage, reducing the working surface (by slatted mouldboard) or the use of special surfaces (e.g. plastic mouldboard).

• A slatted mouldboard (Figure 5.2) offers agronomical benefits in ploughing wet soils as a consequence of reduced adhesion. On soils in Hungary the traction power requirement may be reduced by up to 20 % according to estimates based on practical experience, while the investment cost exceeds that of ploughs with mouldboards of conventional surface finish by 5-15 %.

Figure 5.2 Scheme of a slotted board (from LEMKEN)

• By studying ploughs with plastic mouldboards JÓRI and SOÓS (1985) found that in the case of a working speed between 6 and 10 km h⁻¹ the specific traction resistance of a plough with steel mouldboard is higher by 12.9-5.8 % on sandy soils and by 5.5-2.9 % on medium heavy soils, while its specific fuel consumption is higher by 11.0-9.9 % on sandy soils and by 7.0-6.1 % on medium heavy soils. The average useful life of a plastic mouldboard was found to equal some 100 hectares. No difference was found regarding the quality of
work in the wake of the two types of mouldboards. Thanks to the reduced adhesion enabled by the special surface ploughing is possible in clay soils with higher moisture contents.

**Developments improving the efficiency of mid-deep loosening:**

- **Reducing the weight of loosening tools** by using high strength materials (strength and durability used to be provided for by robust structures, owing to poor material quality).

- **Using replaceable tools** (loosening tine, cutting edge) offers the benefit of more durable loosening implements and more efficient work.

- **Reaching adequate working depth** – adapted to soil condition – with the aid of tractor and tillage implement that suitable for the tillage task.

- **Developing tools of variable parameters** to enable adaptation to soil condition, to reduce the load on the tractor and to make sure the required loosening depth is reached.

- **Minimised crumbling**, if that is not the primary goal of tillage. In the case of mid-deep loosening implements crumbling is carried out by an attached or mounted supplementary element (disk, roll).

- **Use of implements with active tools** operated by vibration.

- **Use of wing shares** if compact layer near the surface needs to be thoroughly loosened. The loosening implements with tines and with wing shares have different places and functions in tillage systems. The former one is also suitable for primary tillage before some crops and for improving the state of layers below 30 cm.

- **If the soil is kept in favourable condition** tillage is generally less energy-intensive. Applying certain agronomical techniques – such as loosening of soil in field after stubble stripping – is recommended on compact soils. Loosening a thick tillage pan, however, takes extra energy input. Energy is also saved when re-compacting is prevented in the secondary tillage of loosened soil.

**The effects of mid-deep loosening** – aiming at improving the physical state of the layer underneath the regular ploughing depth – last for about 1-3 growing seasons as a consequence of the depth (30-35 cm or even 35-40 cm) of the intervention. For this reason, the best possible effect should be with minimised energy input.

**Technical developments** to improve the quality of loosening and to reduce its energy-intensity:

**The shape of the beam.** In earlier and recently developed versions it may be perpendicular to the direction of tillage and it may be straight or V-shaped or may be set at an angle to the direction of tillage.

**The shape of the ripper shank** and the loosening tine. The aim is to achieve the easiest penetration into the soil and – with a suitable tine distribution – the best possible loosening, with reasonable traction power output.

**Reducing the weight of the ripper shank** to optimise the tractive capacity requirement, while maintaining the loosening effect and strength.

**Angular bladed rippers.** One of the best known versions is called HOWARD Paraplow, the one most appraised in technical periodicals abroad between 1982 and 1990. Four tillage implements with curved ripper shanks are mounted at a 45 degree slant one after another on its beam set at an angle to the tillage direction. One disk coulter of waved edge is mounted before each of the angular blades to facilitate the blades’ penetration in the soil.

The slanted tools break through the plough plan, lift and loosen the soil but – thanks to their position – they do not bring clods to the surface, so there is no need for any drastic surface crumbling operation after loosening. This was the advantage of the approach for which it was recommended for aerating the layers below the turf layer as well.

**‘Helioplow’ loosening tines.** Loosening tines with laterally curved ripper shanks, penetrating the soil at a slant were “the new thing” in 1991. According to manufacturers’ recommendations these implements helped farmers loosen the soil without mixing it, a clear benefit in soils with layers of unfavourable chemical features below the ploughed layer. Helioplow loosening implements were not considered to be likely to spread widely but in the recent 2-3 years they have reappeared in the market.
2. Questions:

• What is the cause of sub-soil deforming compaction?

• How can we mitigate or eliminate this degradation process?

• What kind of soil conserving running gears do you know?

• What influences the energy requirement of tillage?
Chapter 6. Adaptable, environmentally focused tillage

The various trends of tillage (conventional, reduced, soil conservation) and endeavours (e.g. energy saving, sustaining) have been distinguished according to two major factors, during the past 25-30 years in terms of definitions as well:

• it has been proven that crops demands concerning soil condition can be met without conventional tillage techniques, regardless of the number of tillage passes, at reduced costs,

• any form of conventional tillage leads – through much soil disturbance – to soil and environment damage, reducing the productivity of cropping.

Recognition of the above contributed to changes in the approach taken to farming. Deteriorating economic conditions may force a farmer to cut production costs, while the deteriorating state of the environment may make him apply preserving and preventive procedures, i.e. to adapt to prevailing circumstances.

Adaptation may be interpreted simply as adjustment of things to the given circumstances. Adaptation in tillage means adjustment to ecological (environmental) and economic (financial) conditions. In making farmers to introduce adaptable techniques foresight or recognition of facts is more favourable and more encouraging than actions taken under the pressure of losses already suffered. For this reason adaptable tillage is based on applying economical and conserving techniques in producing crops best suited to the given site and conditions as well as circumstances of farming in general, that do not lead to increased risks of production even over a longer run. (BIRKÁS, 1995). The two main pillars of adaptable tillage are energy saving and soil conserving.

1. Minimising tillage – in accordance with the soil condition

Since the first energy crisis (mid-1970s), the endeavours to reduce tillage have been motivated by a variety of factors. During the first ten years (1978-1988) this was a conscious effort where the endeavour to reduce tillage was supplemented by the aim of conserving the soil. During the next ten years reduced tillage under the pressure of economic constraints was practised on more than half of the total arable land in Hungary.

The failure to apply conserving or even soil condition improving implements and techniques led first to physical and biological degradation of the soils, later this process turned into increasing soil and environmental damage (compaction, water and wind erosion). Accordingly, in this region it is not possible to adopt techniques of energy saving and soil conserving tillage without improving the condition of the soil.

The risks of applying reduced tillage cannot be mitigated without adequate knowledge of the factors affecting such risks. The tasks involved in this include:

• In the case of a soil degraded by tillage defects the first step is improving its physical state.

• The improvement of the soil physical state can be enhanced by or supplemented with biological techniques.

• Techniques of mechanical, chemical and biological weed control need to be applied simultaneously on a weed-infested field.

• Regular tillage operations aiming at improving the soil condition need to be scheduled on soils that are highly or moderately prone to settling and compacting.

• Conventional disking should be restricted on soils that are prone to compacting or that have been pulverised. Soil preserving implements should be applied in stubble stripping after preceding crops harvested early in the year, in primary tillage before autumn-sown crops and in secondary tillage after ploughing.

• The application of ploughing should be aligned to the crop sequence and to crop protection operations.
• Ploughing and disk ing on excessively wet or dry soil should be refrained from to avoid producing defects that will be expensive to remedy later on.

• Healthy crop and other plant residues should be inverted or mixed in the soil to improve its organic material balance.

• To reduce the loss of soil moisture and to improve workability chopped crop residues should be left on the soil surface for a longer period of time after harvest and stubble stripping in the summer.

• Tillage and sowing techniques causing the smallest possible damage should be applied on wet soils.

• Defects caused in a wet soil (traffic induced soil damage, tillage pan smearing) must be remedied in the next year to prevent damage from aggravating later on.

• Compaction can – in dry soil – be alleviated by loosening.

• Favourable soil condition and good workability are easier to maintain by reducing moisture loss (with the aid of a mulch cover), by gentle crumbling and by applying techniques that minimise clodding and conserve good soil structure.

• To prevent soil state defects the farmer can rely on tillage implement and tool combinations that can carry out a variety of operations in one go. The higher price of combined machines is in line with their capabilities. Their operation takes higher skills than that of simpler, conventional implements.

• The harmony between the soil physical and biological state can be created and maintained through soil conservation tillage (Table 6.1).

Table 6.1 Factors improving soil quality condition (from BIRKÁS, 1999)

2. Soil condition improvement and maintenance

The need for avoiding tillage defects was already mentioned in ancient records, but it was not until the past decades that more attention began to be paid – on a global scale – to preventing and remedying soil damage. This change in attitudes began to appear in an age when certain processes (e.g. soil compaction) developed from rare phenomena into a certain form of environmental damage. The state of soils is rather far from the optimum in our region as well. There has been two periods so far (between 1922 and 1938 and between 1976 and 1988) when specific efforts were made in order to bring the deterioration of the condition of soils to a halt.

The state of the soil is actually reflected by its suitability for cropping and by its effects on the environment. The soil state is favourable if by way of its physical and biological parameters and features it qualifies as a medium suitable for crop production and at the same time it qualifies as a ‘cultured environment’. Tillage, if its impacts are preserving, maintaining or improving, is just as much the groundwork for successful tillage as it is for environmental protection. The state of the soil is unfavourable if any of its features (e.g. dusty structure,
impermeable to water or air, compacted), qualifies as environmental damage and crops cannot be produced successfully without expensive interventions.

2.1. Improving the soil state by tillage

Issues relating to loosening the soil

Unfavourable soil conditions can appear as a consequence of wrong tillage practices in any part of the soil layer of importance for cropping. Compaction in deeper layers can be alleviated through mid-deep or deep ripping but improved soil condition can then be kept up by applying other methods and techniques as well.

The soil improving effects of loosening have been known in this region since 1860 (CSERHÁTI, 1891). From a practical aspect of the issues of usefulness and necessity, however, there are a number of different, sometimes conflicting views. Some practical objections against loosening (ripping) include:

- failure to work the desired depth,
- large clods are produced by ripping,
- this technique is highly energy-intensive.

Loosening interventions produce clods and are highly energy-intensive

As a consequence of compaction the platy structure of pressed soil break up under the force of loosening along the lines of the smallest resistance and this process produces large clods (in fields where the compact layer is an extensive undivided sheet, as in the case of a tillage pan, the proportion of the areas where soil resistance is lower is very small). The more compact the soil and the drier its top layer is, the heavier clodding will result from loosening. Clodding is aggravated by the high clay content in the soil but this process is also frequently observed in settled sand soils of low humus contents. In view of the underlying causes, clodding – as a consequence of a loosening intervention – can be alleviated even in compacted soils with the aid of the appropriate agronomical techniques. Tillage techniques for reducing clodding in dry or moderately moist soils:

- **Loosening soil covered by crop residue after harvesting** eared cereals, without stubble stripping, should preferably take place on the day of the harvest, with the straw chopped and evenly spread on the surface. In this case advantage is taken of the soil short-lived higher workability resulting from what is referred to as mellowing by shading. Surface forming of the loosened soil can be carried out simultaneously with the shallow stubble stripping and the top must, by all means, be pressed. This technique should not be applied on wet or overly dry soil.

- **Loosening the soil after crops harvested in the summer** – leaving residues relatively easy to chop – after well-timed shallow stripping followed by pressing. Loosening should in this case be carried out after the passage of 3-4 weeks following stubble stripping when the top layer has become friable and – together with the layer underneath – humid as a consequence biological mellowing processes. The surface of the loosened soil can, if there is no pressing element on the assembly, be finished with the aid of flat plate disks or cultivators. If surface forming is carried out in a separate go, it should be coordinated with other mechanical weed control interventions (soil surface treatment). Carrying out stubble stripping later than it should have been, leaving the surface without pressing after stubble stripping, reduces the likelihood of achieving adequately effective loosening.

- **Loosening the soil under field residues of crops harvested in the autumn**. In an ‘average’ season it is easier to avoid heavier clodding, since the soil between rows of wide row crops remains friable up to the time of harvest. After a dry growing season – when the crop can be harvested earlier than normally – shallow disking should be carried out first, with the aim of mixing and crumbling the top layer. The soil will become suitably humid underneath the mulch layer so created and it will be easier to loosen it than right after harvest. This method is less effective in wet soils.

The techniques that have been found to be suitable for reducing clodding are also suitable for cutting the energy intensity of loosening. The most important conclusion that can be drawn from the data in the table is the relationship observed between unfavourable soil conditions and the defects that can result from working such soils as well as the extra energy input, on the one hand, and between favourable soil conditions and the possible savings, on the other hand. Loosening soil that has been settled to an average degree does not take a particularly
large energy input (16.9 l ha⁻¹), but if there is a compact layer in the soil near the surface, energy intensity may increase by up to 10-40 %. Conclusions can also be drawn from this kind of relationship concerning types of disadvantages in terms of quality and the extra resource input requirements that have to be faced in the case of different soil conditions. Deep ploughing of a more compact soil also entails higher fuel consumption (up 10-25 %), but in regard to the smaller increment the difference between the working depths of the two techniques (ploughing: 28-32 cm, ripping: 40-45 cm) should also be taken into account.

The specific energy requirements of loosening vary between rather wide extremes, for this technique’s fuel input is affected by a larger number of different factors than that of other tillage methods. Such factors include, for instance, the depth at which a compact layer is to be found in the soil, the looseness of the surface layer, the resistance of the compact layer and that of other layers and, not least, by the moisture contents of the various soil layers (0-5, 5-10, 10-20, 20-30 cm etc.). *Unfavourable interactions between the above features result in very significant increases in the energy intensity of loosening.*

Where the soil conditions vary, the energy intensity of loosening increases by at least about 10-15 %, which is not more than the increase of fuel consumption in the case of other techniques under similar conditions. That is, if compaction in deeper soil layers has reached a harmful level but the tilling element penetration is not hindered by the top layer resistance, the compact layer energy intensity increasing effect is negligible. The higher extremes of increase in energy requirement (30-50 %) point to the necessity of preventing the aggravation of compaction.

When loosening is suspended, it is not possible to form a realistic view of the impact of soil compaction resulting the technique increased energy intensity. *Heavy compaction that has become a permanent feature may increase the energy intensity of loosening by up to 50-60 %.* Breaking up the compact layer will inevitably produce clods. Nonetheless, applying the technique on a more humid soil is not the way to reduce clodding and cut the intervention’s energy requirement. The loosening effect will be rather weak in a wet soil and the implement will simultaneously puddle and smear the soil, producing large sticky slices of soil. Accordingly, the views – based on practical experience – of *the high energy intensity of loosening are correct only to the extent to which they apply to highly compacted soils with a dry surface layer.*

Particular attention should be paid to the working width of the loosening implement. If it is not wider than the distance between the tyres of the tractor, the tractor will inevitably press the soil back in the next turn.

If the farmer knows where his efforts fail to achieve the intended degree of loosening, his attention will be drawn to tasks required for improving his soil condition. Loosening should be approached from the aspect of the need for improving the condition of the soil and not from that of arguing in favour of increased tillage depths. Farmers in some countries of advanced agriculture (USA, Canada) have started to adopt practices involving shallower, rather than deeper, tillage. The underlying motives include, on the one hand, economic factors, for reduced tillage involves minimising the number of tillage passes, indeed, applying no tillage at all in some cases. On the other hand, reducing the tillage depth is considered to be desirable primarily in *extensive land use systems* (with reduced resource input, smaller yield rates but large areas). Studies reflecting changes in the approaches and attitudes relating to tillage, however, show that the result is usually preserving and maintaining better soil conditions, rather than conserving poor soil conditions. For this very reason, abandoning conventional tillage techniques that are usually – though not always – detrimental to the soil (ECAF, 1999) may become possible in this region only in areas where good physical and biological soil conditions have been restored.

**Alleviating soil pulverisation, improving the soil structure**

Dust forming is caused by closely inter-related factors of physical and biological origin. By stimulating the activity of *aerobic* microbes frequent manipulation and aeration of the soil reduces the quantity of humus, a crucially important component of the soil from the aspect of its structure building and water resistance. In day-to-day practice the cycles of clodding and then the mechanical crumbling of the clods, increased loss of organic material and failure to supply the soil with organic materials together lead to the pulverisation of the soil.

Damage by wind in the spring and in early summer tends to affect even relatively compact soils, if their condition has been neglected for some time. Rains wash the frost-formed soil aggregates off larger clods and as they accumulate in gaps between clods they contribute to the compaction of the soil surface. The large clods left without a ‘protective coating’ dry out more quickly and they will be more difficult to break and crumble. In particularly rainy early springs frost-formed soil aggregates silt away, and, as they dry out, capping appears on the surface. According to DVORACSEK (1957) soils containing more than 30 % clay fractions and those containing a small proportion (below 35 %) water resistant crumbs (i.e. soils of degraded structures) are most
likely to develop capping. 

Pulverisation of the soil is an indication of the deterioration of the soil ‘cultured’ – friable and mellowed – state and of the conditions for cropping. This needs to be prevented for soil conservation, environmental protection as well as for cropping.

Dust forming can be alleviated and prevented by agronomical techniques. The most important tasks include:

- **Preventing compaction** and consequently heavy clodding and the need for mechanical crumbling;
- **Refraining from too much soil disturbance** and unnecessary aeration, combining tillage operations as much as possible;
- **Gentle crumbling of dry soils**, gradually increasing the working depth and pressing the loosened surface;
- **Keeping machinery** off the fields and refraining from tilling fields when the soil is wet;
- **Keeping the soil covered** by crop residues during periods out of the growing season (which is also a good technique for preventing moisture loss);
- **Recycling crop residues** into the soil (preferably after chopping to avoid having to carry out supplementary operations to mix them into the soil);
- **Integrating crops** having positive effects on the soil biological activity in the crop sequence, e.g. crops loosening the soil, legumes, papilionaceous or other catch crops, or crops to be utilised as green manure.

**Techniques recommended for heavily pulverised soils:**

- **Growing green manure crops** producing large green masses, and then, after mowing and chopping, mixing a third to a half of the chopped material in the soil leaving the rest on the surface, thereafter letting the soil rest for a month or two.
- **Repeated mowing** during the resting period, if necessary.
- After the end of the resting period **mixing the mulch residue gently into the soil** then growing preferably some winter cereal. Shallow crumbling, mixing and pressing are good solution, followed after the passage of 2-3 weeks by slightly deeper crumbling, mixing and surface pressing.
- **Some catch crop should be sown** in the field in the middle of summer while the cereal crop residues still on the surface. The crop residues can – having frozen over – protect the surface of the soil during the off-season period.
- Reduce tillage in the spring: primary tillage using cultivator, seedbed preparation and seeding in one pass, producing some densely sown crop (eared cereals, legumes, perennial papilionaceous plants).
- Thereafter, applying the above described preventive techniques, covering the surface adequately, and refraining from applying tillage resulting in clodding.

### 2.2. Periodical deep tillage

According to a definition worked out by Sándor SIPOS (1978) **periodical deep tillage comprises deeper tillage at regular intervals as necessary for a given type of soil in a given environment** and applying tillage systems of lower cost and time requirements, involving reduced numbers of tillage passes during the years in between. The more costly mode of cropping pays off through the increased yields, resulting from the tillage effects and through the lower costs during the periods between the seasons of deep tillage.

Right from its first application deep tillage lays the groundwork for more reliable cropping and – also very importantly – for protecting the soil. Views taken of the **necessity of deep tillage have in the recent past changed somewhat**. The state of the soil needs to be judged from the aspect of the conditions it provides – in the given (average, dry, wet) environmental circumstances – for the crops to be grown and whether the required conditions could be created in an economical and environmentally sound way or otherwise. **The role of deep tillage in improving or preserving the state of the soil and the environment has come to be just as important as, or sometimes more important than, increasing yields.**
Crops need for particular soil conditions is related primarily to the looseness of the various soil layers, which may be attained by or without deeper tillage. More exacting plants can be grown more reliably in soils loosened to greater depths. Other crops are not so heavily affected by compacted soil layers in years of average or abundant precipitation.

In dry years the majority of crops do not tolerate the combined effects of shortage of water and soil compaction. Accordingly, deepening the working depth should be accompanied by improving the soil state. The following is a discussion of the most important questions relating to deep tillage carried out with the aim of improving the soil condition. When is there a need for deep tillage with a focus on improving the soil condition?

- When the soil is heavily compacted below a depth of 25-30 cm resulting in increased risks of farming and environmental damage.
- When there are previously not encountered signs – such as stagnant water on the soil surface, diminishing tillage depth, heavy clodding, increased energy requirement, severe drought effect – indicative of compaction.
- When there is a need to restore and maintain the reliability of cropping.
- When there is a need to prevent environmental damage.

What deep tillage techniques should be applied? To ensure economical and effective tillage account must be taken of the soil moisture content.

- **Ploughing** is the technique of choice where the soil can be inverted to a greater depth (of 32-40 cm), it is humid and there really is a need for turning the top layer over (the higher costs of turning over a thicker soil layer should also be taken into account).
- It should be carried out with the aid of a plough combined with a loosening element (Figure 6.8), if the soil top layer is friable and easy to plough, the layer to be loosened is dry, i.e. it can be cracked.
- Some mid-deep loosening implement (down to 35-45 cm) can be used where the entire soil layer to be loosened is dry but not overly dry, at least the top layer is biologically active and is not heavily compacted.
- **Deep loosening** implement (down to a depth of 60-100 cm) may be used primarily for purposes of amelioration.

![Figure 6.1 Plough with subsoiler shank (left), and a crumbling roll to subsoiler (right)](image)

The penetration resistance of soil ploughed to the usual 20-22 cm depth before and after loosening is shown in Figure 6.2. Compaction – plough pan – has appeared in the layer between 22 and 32 cm, and the soil resistance is high (the almost 6 MPa is the resistance of harmfully compacted soil). Loosening was carried out in dry soil, loosened to some extent in its top 16 cm layer. The planned loosening depth was achieved to a considerable degree and the compacted layer was loosened well.
Adaptable, environmentally focused tillage

Figure 6.2 Efficiency of soil ripping in a clay loam soil (from BIRKÁS, 2000)

Legend: Clay content of soil: 54%, v/v Soil moisture content at soil ripping (0-50cm): 15.9%, w/w Depth of soil ripping: 50-55cm Harmful compaction at given soil moisture content: >3.0 MPa

When does deep tillage with the aim of improving the soil condition need to be carried out again?

• When the critical layer of the soil has become compacted again. When soil improving tillage is followed by a wet period and a lot of traffic induced soil damage, the effect of the intervention will not last very long, while in dryer years and where soil conserving land use is practised, those effects will last longer.

• In the case of soils that are prone to settle and compact the farmer should expect the effects of the intervention to last over a shorter period of time, while in the case of soils that are moderately or not at all prone to settle and compact the favourable effects of the intervention should be expected to last longer.

How can the effects of soil improving tillage be made to last longer?

• Not exposing wet soil to traffic or tillage.

• Avoiding clodding and pulverising the soil (to prevent re-compacting and structure damage).

• Applying tillage systems of reduced numbers of tillage passes.

• Integrating plants, whose roots loosen the soil, in the crop sequence (oil-seed rape, mustard, oil-seed radish, sunflower).

The following are crucial from the aspect of the economic efficiency of tillage focusing on improving the soil condition:

• The planned depth and quality (loosening the compact layer, minimised clodding) at the expense of the smallest possible energy input and preserving the favourable state for as long as possible.

The following advantages and benefits may be expected in the wake of deep tillage:

• Improvement of the soil physical and biological state, benefiting both farming and environmental protection.

• In the wake of tillage focusing on improving soil condition, which can be adjusted to the crop sequence, it becomes possible to grow crops demanding good soil conditions in lower soil layers (e.g. sugar beets, maize, sunflower, potatoes).

• In the wake of soil improving tillage applying shallow tillage before subsequent crops will entail lower risks.

• Damage and losses caused by weather extremes (drought, excess rainfall), will be reduced and so will cropping losses.
Adaptable, environmentally focused tillage

- The activity of weeds, pests and pathogens can be controlled. Secretions produced as a consequence of increased anaerobic microbial activity in soils of insufficient aeration disappear as a consequence of loosening. Healthy and vigorous plants that can successfully compete with pests and weeds can grow in a soil in favourable state.

**What tillage techniques and regimes can be planned during years following deep tillage?**

1. in soils prone to compact: deep tillage > shallow tillage system > mid-deep tillage system > shallow tillage system > deep tillage;

2. in soils moderately prone to compact: deep tillage > shallow tillage system > shallow tillage system (or zero tillage cropping) > mid-deep tillage system > deep tillage;

3. in soils not prone to compact: deep tillage > shallow tillage system (or zero tillage cropping) > mid-deep tillage system > shallow tillage system (or zero tillage cropping) > mid-deep tillage system > deep tillage.

The above schemes may be successfully applied in dry years (for in rainy years the effects of deep tillage is not so persistent). Not many farmers applying the technique of loosening know that breaking through gley layers should be avoided.

In Chapter 4.5 mention was made of the method called *loosening with the aim of drying*. The solution described there as one applied out of necessity requires an approach that is different from regular cycles of soil condition improvement and maintenance.

### 3. Environmentally focused tillage

Soil protection comprises preventing soil damage and improving as well as preserving the soil physical and biological condition to keep up the quality of the environment and to maintain the standards of farming. The state of soil resulting from tillage and farming in general over a shorter or a longer period of time must not be harmful to the environment.

Tillage qualifies as ‘favourable’ on the whole, if the applied system or technique is environmentally-sound and economically efficient. If the soil state before tillage greatly differs from what is required for cropping (*Figure 6.10*), eliminating the deficit itself takes a lot of time and energy, while damage may also be caused. If the expertise and capital required for improving the state of the soil is not available, the difference between the intended and the actual state of the soil keeps growing, along with the risks of cropping.

*Figure 6.3 Soil conservation in the soil tillage tasks*

Compacted, pulverised soil of degraded structure, which is often characterised by surface capping, is not suitable for alleviating damage caused by unfavourable weather conditions. Cropping on such soils becomes impossible over time and the situation is aggravated by environmental damage. Tillage defects and damage can be mitigated by tillage and, in the majority of cases, they can even be prevented. To achieve this objective a set of – environmentally focused – requirements integrating

**Environmental impacts of tillage in the case of different soil moisture levels**
Adaptable, environmentally focused tillage

Despite similarities, in practice there still are some differences between the set of environmentally focused requirements and the requirements of cropping. Large soil surface created by the plough inverting action, clods or even large clods with smeared surfaces are considered to be just as acceptable as carrying out multiple rounds of disking and the dust forming they entail. From an environmental aspect these processes are harmful, since they cause soil damage. Soil damage could be minimised by tightening agronomical requirements in line with environmental ones.

Environmental risk factors linked to tillage:

- soil compaction,
- clodding, pulverising or puddling and smearing,
- water and wind erosion,
- carbon-dioxide flux,
- loss of (OM) organic material,
- degrading earthworms habitat and environment.

Though they have different impacts on farming, the above factors are equally important from an environmental perspective. Taking environmental damage into account it is possible to objectively establish the environmental capability of every single tillage process, even before starting work.

Out of the six environmental risk factors the risk of compaction and that of dust forming is the lowest in a humid soil at average moisture content, though carbon-dioxide flux may grow and the organic material content may drop. Conventional ploughing entails the largest, tillage with cultivator entails the smallest number of risks. Inverting leads to increasing organic material loss and upsets the earthworm habitat. Combining the plough with a pressing element substantially reduces the environmental risk, while tillage with cultivator entails practically no risk at all.

In a humid soil the primary tillage techniques can be arranged in the following order by increasing environmental risk: tillage with cultivator = mid-deep loosening = ploughing with reversible plough and surface pressing = subsoiling < ploughing with subsoiler shank element < conventional disking < conventional ploughing. Conclusions may be drawn from the above concerning the degrees to which the various tillage processes are suitable for mitigating the environmental risks in soils of average moisture contents. Environmental damage is more likely to be avoided when tilling humid soils.

In dry soils clodding is added to the array of environmental risk factors. This is one of the most frequently encountered type of damage, however, the risk of compaction and that of erosion is a lot smaller under such circumstances. Conventional tillage without pressing and disking both tend to cause more environmental damage in a dry soil. Ploughing and disking combined with pressing are considered to have more favourable effects. Using the cultivator has favourable impacts in terms of soil conservation. In a dry soil the primary tillage techniques can be arranged in the following order by increasing environmental risk: tillage with cultivator = mid-deep loosening = ploughing with reversible plough and surface pressing = subsoiling = ploughing with subsoiler shank element = conventional disking < conventional ploughing. The risks to be faced in tilling dry soils point to the importance of adaptation.

In a wet soil the risk of dust forming is replaced by that of puddling and smearing, as the greatest risks of tillage. Ploughing and disking entail great environmental damage, while deep loosening (subsoiling) entails lower risks. Mid-deep loosening entails moderate environmental damage, without the benefits of loosening. Using the cultivator helps minimising damage. Clearly, there is a very restricted range of techniques that can be applied in tilling wet soils. In a wet soil the primary tillage techniques can be arranged in the following order by increasing environmental risk: tillage with cultivator = mid-deep loosening = subsoiling = ploughing with subsoiler shank element = conventional disking < conventional ploughing.

In a dry soil any of the techniques is suitable for preventing re-compacting and increased erosion or deflation. Carbon-dioxide emission and organic material loss will not increase either, for these techniques produce more or less evenly formed soil surfaces. Dust forming may be caused by using the tooth harrow or the rotary spade harrow. Using the rotary element, compactor or combinator has a very good environmental impact through gently crumbling the soil. In a dry soil the techniques can be arranged in the following order by increasing
environmental risk: use of compactor = use of combinator = use of rotary element < rotary spade harrowing < rotary harrowing < tooth harrowing.

In a wet soil the order of the techniques by increasing environmental risk: use of rotary element = use of compactor, combinator or rotary harrow < tooth harrowing < rotary spade harrowing. The risks of compaction, puddling and smearing are higher, particularly in the case of tooth harrowing or rotary spade harrowing. The use of rotary elements entails the lowest risks for it crumbles larger aggregates without compacting, puddling and smearing.

Reasonable use of compacting/surface forming techniques in humid soils does not lead to compaction and it does not upset earthworms habitats either. Some techniques result in pulverising, leading to potential deflation. Crossboard and rolling harrow both do a perfect job. The nice and smooth surface left behind by a ring roller or a levelling implement will turn into a source of problems later on (siling, capping). In a humid soil the techniques can be arranged in the following order by increasing risk: use of crossboard < use of rolling harrow = use of deep and surface compacting roll < use of ring roller < use of conventional leveller.

The smallest degree of dusting is caused in a dry soil by the cross board and the rolling harrow, while more dust is formed by conventional leveller and the ring roller. The techniques can be arranged in the following order by increasing risk: use of crossboard < use of rolling harrow = use of deep and surface compacting roll < use of ring roller < use of conventional leveller.

The techniques can be arranged in the following order by increasing environmental risk: use of crossboard < use of rolling harrow < use of deep and surface compactor roll < use of conventional leveller = ring rolling.

Assessment of the environmentally-focused requirements

Primary tillage with cultivator has a very good environmental impact regardless of the soil moisture content, while the impacts of mid-deep loosening are very good in dry soils and in soils of average moisture content, which is when they can be exploited without doing harm. By contrast, conventional ploughing (‘clodding ploughing’) and conventional diskng have unfavourable environmental impacts, their use results – depending on moisture content – in various degrees of damage.

From among secondary tillage and seedbed preparation techniques the use of the compactor, rotary element and combinator have favourable effects, tooth harrowing and rotary spade harrowing entailing less favourable effects. From among the compacting and surface forming implements crossboards, the rolling harrows and combined rollers have good, conventional levellers and ring rollers have less favourable environmental impacts.

The relevant environmental risks associated by every single tillage technique (procedure) can be assessed in advance. This can help preparing decisions to be made, along with implementing soil and environment conservation tillage. In view of the environmental impacts of tillage processes it is when tilling humid soil when a farmer has the widest range of alternative decision options entailing more or less the same levels of risks. The number of decision making options is minimised under extreme weather conditions.

The benefits of adopting the environmentally-focused approach to tillage are in the assessment of risks in advance and in the elaboration and application of alternatives with a view to minimising damage. As a consequence of minimising environmental damage the soil state will improve and favourable soil condition can be maintained.

4. Questions:

• What does the term environmentally focused tillage mean?

• What factors can improve soil quality conditions?

• How can we improve the soil state by tillage?

• How can we maintain soil structure?
Adaptable, environmentally focused tillage

• Describe the periodical deep tillage!
• How does the soil moisture level influence the impact of tillage?
Chapter 7. Rationalising tillage systems based on ploughing

1. Advantages and risks of ploughing

The mode, depth and quality of primary tillage are dominant factors of a tillage system because they not only affect the circumstances of seedbed preparation but they also determine the costs of all of the other interventions. Ploughing is the mode of primary tillage in a tillage system based on ploughing, whose most important action is turning the soil over. The agronomical benefits of ploughing come from inverting the soil, but concerns of importance are also related to inverting (Table 7.1).

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*Table 7.1 Advantages and considerations of conventional ploughing*

From an agronomical perspective ploughing entails risks where it aggravates erosion, if it produces a soil surface with clods or even with large smeared clods necessitating several rounds of secondary tillage (which will inevitably entail recompaacting the soil and turning soil into dust). Clodding, pulverising, the aggravation of water and wind erosion as well as compaction itself are ploughing’s environmental risk factors. Knowledge of further risks entailed by inverting – including increased carbon-dioxide flux, loss of organic material, disturbing earthworms habitats – enables not only taking an objective view of ploughing but it may also prompt the farmer to prevent greater damage. The value and the risks of ploughing vary by its timing. Ploughing is regularly carried out in the regional circumstances in the summer, in the autumn and in the spring (Figure 7.1). The conclusion that can be drawn from Figure 7.1 the benefits of ploughing carried out in different seasons should be exploited and the risks – since they are known and can be taken into account – should be alleviated.
Rationalising tillage systems based on ploughing

Ploughing defects

The quality of the result of ploughing is, in general, affected by certain parameters of the soil (clay content, heaviness of texture), moisture content and workability, which is determined by these parameters. The physical condition – compact or loose – also has a substantial impact. Factors of relevance from the aspect of operation include the plough implement design, setting and the mode of ploughing (using conventional or reversible plough). The following factors are taken into account in evaluating the result of ploughing.

Frequently encountered defects after ploughing, in the summer:

- **stubble stripping is not carried out or it is carried out late** as a consequence of which the soil dries out and it becomes much less ploughable.

- **stubble stripping** is not followed by pressing, the soil is left cloddy, with a large surface through which soil moisture is lost; disturbing the soil makes it dry out to a greater depth and becomes a lot harder to plough later on.

- **deep stubble stripping is carried out** (by disking) and the surface is left without pressing; though the tilled layer provides some isolation, the chance for high quality ploughing diminishes.

It is clear from the above that stubble treatment defects contribute more to poor ploughing quality than had been usually assumed. Defects encountered in the course of ploughing, during and at the end of summer, in dry weather are as follows.

**Ploughing in the summer, without levelling and pressing the surface.** Farmers applying this practice disregard the soil moisture loss and the risks to which crops sown in late summer or spring will be exposed. Indeed, the soil moisture reserves may drop to such a low level where even the very survival of crops will be at risk, if the next one is a dry season.

**Damaging the soil structure.** Owing to the substantial moisture loss caused by a wrongly chosen or a badly performed stubble stripping intervention ploughing results in a heavily cloddy surface, as a consequence of which surface forming or pressing has to be postponed until the first rain. The soil keeps losing water during...
until surface forming and pressing, and since it is cloddy, it goes unevenly soaked. An additional intervention inevitably entails additional costs and traffic induced soil damage.

*Loss of organic materials.* The excessive aeration and large surface of ploughed soil boosts aerobic microbial activity, whose end product – carbon-dioxide – is emitted in the atmosphere. Soil disturbance, moving the soil about, that is entailed by ploughing, i.e. tillage leaving large soil surface exposed to the air and resulting in increased aeration, has contributed – over centuries – to the degradation of organic materials and to the upsetting of the carbon balance.

*Unfavourable biological effects.* Between large clods torn up from the desiccated top layer of the soil, even useful biological activity (earthworms) gets suspended for quite a while.

The benefits of summer ploughing come from turning the top layer over while its disadvantages stem from the loss of soil moisture and from the difficulties of the subsequent tillage operations. Where ploughing in the summer is opted for, account must be taken of the possibility of disadvantages outweighing the benefits that may come from inverting.

**Defects in the course of ploughing, in the autumn (winter) or in a wet soil:**

- **Puddling the soil underneath the ploughed layer, producing large smeared clods on the surface.** The farmer may hope for the crumbling effects of the alternating processes of freezing and thawing out in the summer, but this should not be over-estimated. For frost has no loosening effect on soil pressed by the plough share and compacted by tractor tyres in the furrow. Any impact that is detrimental to the soil – including smearing and puddling – leaves its mark on the structure, making the soil more and more prone to pulverising and clodding.

- **Uneven ploughing depth** which is linked to variations in the soil features or to higher resistance of a compacted layer formed earlier. Ploughing the same depth as a routine, particularly when the soil has soaked over, leads to increasing risk of plough pan appearing or thickening in the soil. The increased resistance of compressed soil – if the traction power is suitable only for average soil conditions – makes it impossible to reach the required depth. It takes increased draught power, higher quality ploughs or some other technique (ripping) to break and work the compacted layer.

- **Unless improved ploughing techniques are adopted, an earlier created plough pan develops into a permanent feature at a depth between 25 and 30 cm.**

- **Unequally ploughed depth** and ridges created by ploughing in lands (that is by conventional mode) are not eliminated or they even grow more and more marked. Rainwater accumulates in puddles in a field that is growing increasingly ‘undulating’ and the quality and the feasibility of other production procedures decline.

The greatest benefit of ploughing in the autumn is that the soil is rendered suitable for taking in and storing autumn and winter precipitation. After poorly performed ploughing, however, this expectation is hardly met at all. Instead of seeping down into deeper layers rainwater landing on the surface accumulates above the compact plough pan layer and it runs off the field down the furrows. Additional losses occur when freezing is followed by thawing.

**Levelling the surface and seedbed preparation after poorly finished ploughing:**

- **Uneven surface features created by ploughing remain visible even when the crop has emerged.** If the degree of cloddiness and the soil moisture content varies within a field even the best efforts will not be enough to create an even quality of soil during the crumbling interventions or in seedbed preparation. An uneven seedbed results in defects in the crop emergence and in differences in the crop growth later on.

- **Soil that has soaked through to different depths in the winter will dry out unevenly in the spring.** In one part of the field the soil is not trafficable yet while in other parts it has dried out excessively. Consequently, the first interventions in the spring may just as easily result in compaction by traffic or in smearing as in dust forming.

- **Water transport between soil layers smeared by ploughing or by seedbed preparation become upset, which may entail particularly serious risks in a dry growing season.** For the soil susceptibility to drought is aggravated primarily by physical state defects obstructing the vertical movement of soil moisture, while insufficient precipitation is only the second most important cause of water shortage problems.
The quality of the seedbed is a sum of all of the outputs (and the quality of the outputs) of all of the tillage interventions from stubble treatment to seedbed preparation. Although it is not impossible to create a seedbed that looks good, even in a poorly ploughed field (though it takes a larger amount of more expensive work), it is hardly possible to produce a seedbed that meets the crop requirements.

Ploughing, if not properly, is characterised by the following, regardless of the site:

- it is hardly possible to lay down the required groundwork for cropping if ploughing is carried out on soil of unsuitable moisture content,
- inverting and surface forming are highly energy-intensive operations both separately and in combination, if they are carried out on desiccated soil (e.g. if no stubble stripping was carried out first),
- surface that has not been levelled or pressed results in increased loss of water after ploughing in the summer or in the spring,
- the structure is damaged if ploughing is carried out on too wet soil (through compaction and puddling) or on too dry soil (through clodding),
- in the case of ploughing in lands the soil in the headland area where the tractor turns is subject to increased traffic induced soil damage,
- plough pan compaction develops when wet soil is ploughed many times over several years. If the edge of the ploughshare is not sharp enough it is prone to smear the soil and in this case the mode of ploughing makes not much difference.

In summary, a poorly performed ploughing does much damage to the soil, instead of economic benefit. This, of course, does not apply to ploughing in general. Problems are caused by poorly timed or finished ploughing, not by the plough itself. Partly to mitigate damage caused by the climate change the plough is probably going to be used less frequently in this region in the future.

Good ploughing

Ploughing is good when the soil has been worked to the planned depth, inverting is perfect, the slices of soil cut off by the plough crumble adequately or well, depending on the soil current condition, the ploughing passes are not clearly separated, there are no patches of soil left intact (dead furrows) and the bottom of the furrows is not compacted. High quality ploughing can be achieved through proper operation of the machinery. It is difficult to get close to what qualifies as ‘good’ with the aid of the conventional plough (there being more idle running without actual ploughing, along with inevitable traffic-induced damage), while a reversible plough helps producing better output. The type of the plough itself and the mode of ploughing only offer the possibility but no guarantee for achieving high quality ploughed land. Good ploughing helps economical utilisation of the agronomical benefits offered by inverting the soil, including:

- reliable groundwork for cropping,
- turning over manure and soil improving materials, crop residues and weeds (that hinder seedbed preparation) and weed seeds into the desired depth in the soil,
- improving the effectiveness of crop protection,
- conserving or preserving the soil structure (this is most effective in humid soils).

The above benefits can be attained most easily if the soil is suitable for ploughing (i.e. when it is humid), and if reaching the planned ploughing depth and quality is not hindered by physical soil defects. The goal of rationalising ploughing-based tillage systems is to retain this technique that is so highly popular among farmers, to prevent typical defects and to alleviate cropping and environmental risks.

The following are mitigated or reduced in the wake of rationalising tillage systems based on ploughing:

- damage linked to the frequency of ploughing,
- damage linked to inverting the soil,
Rationalising tillage systems based on ploughing

- the risks linked to the timing of ploughing.
- the number of tillage operations between ploughing and seeding without loss of quality, and
- the total number of tillage passes.

Ploughing can even have an improving effect, if by inverting the pulverised top soil layer over a more friable layer can be brought to the surface (a spade test needs to be carried out beforehand). Ploughing may be necessitated for crop protection through deteriorating the chances of survival of pests, pathogens and weeds and through disturbing their activity. Nevertheless, instead of ploughing whether or not it is really necessary, this technique should be applied at carefully planned intervals.

The risk of inverting the soil can be mitigated by improving the quality of the inverting action and by eliminating unfavourable changes (e.g. large surface through which moisture is lost, loss of organic material). Turning the soil over should be resorted to when the state of the soil is favourable – when it is moist, its surface has not been compacted – and surface forming can be carried out with the aid of an implement combined with the plough. Instead of conventional ploughing it is more rational (saving on costs and preserving the soil) to carry out this task with the aid of reversible plough combined with surface forming element, when the soil is not damaged by traffic resulting from idle running (with ploughs raised) and a separate surface forming intervention. Even if the farmer insists on using the conventional plough it is possible to apply a surface forming tool (with a rotary element) preserving the soil structure. Table 7.3 shows the levels of environmental risks entailed by inverting, from which conclusions can be drawn with regard to the possible ways of preventing damage. Carbon-dioxide flux and organic material loss can be alleviated by reducing the large surface area and the volume of air pockets in the soil. In a humid soil the expected quality can be attained, while in a dry soil clods can be sliced up and the surface can be evened with the aid of suitable tillage implements.

Earthworms’ habitat is disrupted by inverting. A soil after proper surface forming, which has not lost much of its moisture content quickly becomes habitable for earthworms, while the process takes more time in a soil damaged by clodding and overly loosened in the summer. Earthworms disappear from soils that have been smeared and then dried out. Ploughing with a reversible plough combined with a surface forming implement in the same pass entails a smaller environmental risk whatever the soil moisture content, than does conventional ploughing without surface forming. Conventional ploughing does the better job on larger fields. Using some surface forming element does no damage in this case either: its use should depend on the current soil moisture content.

The risk relating to the timing of ploughing can be reduced by enhancing agronomical benefits, such as effective inverting, avoiding the production of clods to be broken down later on etc. Risks differ from season to season (autumn, spring, summer, see: Table 7.1). High quality ploughed soil can be produced in any of the seasons if the soil falls in the range of favourable moisture content levels but moisture loss is more difficult to control in the summer and in the spring. Whichever season ploughing is carried out in, it must not deteriorate the soil physical and biological condition. Risks are increased by compacting and smearing the soil in the case of ploughing in the autumn, by compacting and moisture loss in case of ploughing in the spring and by extreme moisture loss in the case of ploughing in the summer. Accordingly, there is a need for mitigating the risks entailed by inverting the top soil from the aspect of agronomy (preventing defects) and from that of the environment (preventing damage). Combining the plough with some surface forming element – if ploughing is carried out within the moisture range in which the soil type concerned is suitable for ploughing – should provide the best results, irrespective of the time of the year in which ploughing is carried out.

Quality may be improved and the number of tillage processes to be carried out between ploughing and seeding may be reduced only following high quality ploughing that does not necessitate an increased number of supplementary interventions for agronomical purposes.

In the conventional tillage system based on ploughing the farmer has to face the possibility of deteriorating quality and growing risks throughout the period between the completion of harvesting and sowing the next crop. The greatest risks lie in loss of soil moisture (increasing the damage caused by the climate), traffic induced soil damage (conventional ploughing) and secondary tillage in separate passes. Accumulation of agronomical defects (moisture loss, inadequate crumbling of clods, increased dust forming and recompacting by traffic) points to the potential of expanding environmental damage. Rationalising the tillage system based on ploughing – with ploughing carried out in the soil optimum moisture range for this kind of intervention – offers a chance for preventing damage and cutting costs.
Rationalising tillage systems based on ploughing

The quality of the operations before ploughing (stubble stripping), and of inverting affect the total number of tillage passes. The solution lies in reducing the soil moisture loss, for instance through carrying out stubble stripping with the aid of cultivator combined with crumbling and pressing elements, ploughing with reversible plough combined by a surface forming element, seedbed preparation using some implement that does not turn the soil into dust.

2. Rationalising tillage systems based on ploughing

The following is a discussion of the techniques that can be used for reducing the number of tillage passes and for cutting costs as well as for improving quality and environmental impacts. A tillage system based on ploughing meets expectations if the agronomical task on hand can be carried out by inverting the soil at the expense of any major environmental damage. Conventional ploughing has unfavourable effects even on humid soil from the aspect of conservation and those effects are aggravated by surface forming in a separate go as well as by the preceding stubble stripping by disking, if it is carried out without subsequent surface forming. This sort of tillage system could be improved by using another implement for stubble stripping (cultivator combined with crumbling and pressing elements) and by mounting a surface forming (rotary) element that can do a gentle job on the soil as well as by applying some more up-to-date technique for surface forming and seedbed preparation.

Soil condition that is not suitable for ploughing is a risk factor aggravated by stubble stripping’s moisture loss increasing impact and the secondary tillage passes following conventional ploughing. The proposed system comprises procedures having an overall soil conserving impact. Stubble stripping with cultivator before ploughing reduces the soil moisture loss, helps mellowing and improves workability. Combining ploughing with surface forming and the subsequent interventions have favourable impacts not only on the quality of the tillage system and its costs but also on the soil itself.

Ploughing is often carried out in late autumn (winter) on set fields in the tillage system of producing spring-sown crops. Ploughing wet soil carries risks as a consequence of soil compaction by tractor and tillage implement as well as of puddling and smearing by the tillage tools. Damage caused to wet soil in the autumn in a conventional system is not alleviated in the course of the winter and despite the improved circumstances for tillage additional defects may be caused in the spring. The use of conventional levelling implements increases risks for it often results in inadequate levelling and even smearing, puddling, pulverising and clodding may occur simultaneously. In such circumstances it is not possible to create a seedbed in a single tillage pass. The recommended solution enables alleviating damage caused to a wet soil and it helps avoid causing additional damage in the spring.

Surface forming after ploughing in the autumn. The discussion of this question does not apply to land where soil is best left in furrows and ridges (on slopes, in areas exposed to erosion or deflation, where the soil is prone to silting). Another thing to be avoided is puddling and smearing of the soil, where ploughing in the late autumn resulted in large smeared clods. One of the weak links of the conventional tillage systems is the quality of the soil after ploughing in the autumn, for it often hinders any reasonable reduction of the tillage passes in the spring and because it indirectly contributes to damaging the soil structure. Some farmers have been right in recognising that it is not advisable to use any secondary tillage implement that compacts the soil (besides performing its function) before winter sets in. For in this case it takes a lot more time for autumn and winter precipitation to seep into the soil afterwards and more of it will be wasted. Nonetheless, the solution is not leaving the field without secondary tillage after – usually conventional – ploughing even when and where there is no reason for doing so. In this way even levelling has to be carried out in the spring, which is difficult to carry out in a way that yields a good result. The benefits of levelling include reduced surface through which water is lost, while the different forms of damage that may be caused by levelling include damage by traffic on the ploughed layer that has undergone a process of mellowing by frost, smearing the soil with an unsuitable implement and, not least, an increased number of tillage passes required for seedbed preparation.

Secondary tillage until reaching the quality of a seedbed (levelling plus compacting and pressing) is just as extreme a solution as is carrying out no secondary tillage at all in the autumn (where it is possible to carry out) with the aim of letting a more uneven surface retain the snow more effectively. A farmer who really cares about the quality of his soils cannot rely on the unpredictable amount of snow because he should design and carry out every single step of tillage – from well-timed stubble stripping to seeding – with a view to facilitating the infiltration of water and to reducing moisture loss. Water is most effectively taken in by a soil whose top 40 cm layer is adequately loose, while loss of water can be reduced by rationalising soil disturbance.
The agronomical benefits of *surface forming carried out in one pass with ploughing include crumbling and surface levelling simultaneously with inverting*, reduced moisture loss and traffic induced soil damage. The economic benefit of this approach is that although a combined assembly of machines requires increased tractive power and takes more fuel than ploughing without the supplementary tools but the fuel consumption in this way is lower than it is when the processes are carried out in separate tillage passes. Applying this method is hindered by soil moisture if it is outside the optimum range for both ploughing and surface forming. *From among the possible solutions in terms of machinery the version involving the mounting of the secondary elements on the plough – e.g. rotary element on conventional plough, ridge crumbling and levelling element on reversible plough – is the best solution from the aspect of both quality and handling.* The supplementary element is raised out of the soil and then lowered back into the soil together with the plough at the headland turns so it does not catch clumps of field residues in the unploughed parts of the field, it needs no cleaning at these points and this leads to increased percentage of time actually spent tilling. In addition to the secondary tillage elements developed for use in soils in different conditions some ingenious in-house solutions are also encountered every now and then. *Surface forming elements coupled to the plough* tend to be simple tools, including ring roller, tooth harrow or some leveller. Coupling may be loose (e.g. with chains) or rigid (a metal rod) which may even lead to undesirable results. The secondary element may – as it starts swaying behind the plough – get stuck with stalk residues or it can dig itself into the soil. In either case, traction power requirement and fuel consumption increases.

Less frequent, more reasonably planned and more careful application of ploughing is also facilitated by technical and technological advancement. A plough may qualify in the future as fully equipped if it is supplemented with secondary tillage elements adapted to different soil moisture content levels and with loosening elements working the plough pan layer as well. In this way the value of not only the implement but that of its work may increase.

Surface forming in separate tillage passes shortly after ploughing or after the passage of some more time is still the most frequently applied approach today among the possible tillage operations after inverting the soil. Timing is dominated by the time of seeding, the soil moisture content or by the need for its protection. If little time is available the *one that is the most effective on a soil of the given moisture content* has to be chosen from among the available surface forming implements. *In a dry and cloddy soil* combinations of implements carrying out the task in several tillage processes are more effective because they do a better job in breaking up clods while producing less dust. *In a soil that is wet but still workable* lighter combinations including spring tines or finger harrows should be used.

*Secondary tillage operations before spring-sown crops* after ploughing in the autumn are distributed in time. In the wake of ploughing in the autumn the soil surface should be evened but not compacted so that it retains its water intake capacity. Another benefit of this approach is even moisture distribution. A field so prepared will dry evenly in the spring it becomes trafficable, with reduced variations in the quality of the seedbed within the field.

*Soils of good structure* can be worked to an extent in the autumn that a suitable seedbed can be prepared in one pass for crops sown in the early spring. For water protection surface forming is not recommended on slopes and in fields where the soil does not have an adequate structure.

*Ploughing in the spring* is usually forced by necessity and it is normally accompanied by disadvantageous consequences (air pockets, loss of moisture, no mellowing). The number and severity of defects can be reduced by making sure that ploughing is carried out when its moisture content is suitable for ploughing or if ploughing is kept shallow (18-22 cm) and is followed by surface forming in the same tillage pass. If sowing is followed by surface forming after a longer delay, the surface is to be pressed after ploughing.

*The surface of the soil after ploughing in the summer has to be levelled and at the same time pressed*, to conserve its moisture content. Crumbling furrow slices also helps eliminating air pockets from the soil.

Ploughing should be scheduled in a period when the conditions are expected to be suitable for ploughing and surface forming. The quality of ploughing of a soil which is in a ploughable condition, with the aid of an up-to-date plough equipped with some secondary tillage element, will meet the most exacting expectations. *The benefits of ploughing* may be enhanced by simultaneously improving the condition of lower soil layers. The best tool for this is a combination of *reversible plough equipped subsoiler shank*. The value of the use of such a tool can be enhanced by reducing the frequency of ploughing and by improving the state of the root zone that is crucial from the aspect of production. The *two tillage elements have different optimum soil moisture ranges*
Rationalising tillage systems based on ploughing

Therefore the best quality can be attained when the layer to be improved is dryer, while the layer to be inverted is humid i.e. when the furrow slices are friable when they are turned over.

The benefits of ploughing in the autumn come from taking in and storing autumn and winter precipitation and in reducing the number of tillage passes required in the spring. Ploughing for spring-sown crops can be carried out in fields after stubble stripping and stubble treatment from late August, until the first frost sets in. Soils may be ploughed earlier on steeper slopes, in deeper-lying fields and in forest soils, meadow soils and alkaline soils that are more difficult to till when wet. Autumn (winter) ploughing is good when it has loosened the soil to the necessary depth, worked through the compact disk pan layer and has turned whatever could result in disturbances in growing the next crop under a layer of soil. Ploughing is good if its costs had been minimised and has not caused defects whose elimination would entail additional costs.

The possible disadvantages of ploughing in the spring may include creating soil state of varying moisture content and crumbliness. The risks can be reduced by keeping the ploughed layer thin and if ploughing is promptly followed by surface forming with the aid of a coupled crumbling-levelling tool or rotary element. Air pockets can be eliminated with the aid of furrow slicing roll. It should be noted again that just like primary tillage in the autumn, the same in the spring can also be carried out without ploughing. If the farmer insists on ploughing, he should do so in the spring only if the following conditions are met:

- on saline soils without adequate soil structure where ploughing carried out in winter would have to be repeated in the spring as a consequence of the cultivated layer’s settling,

- on endangered sandy and organic soils,

- in floodplains and low lying areas that may be submerged in early spring,

- out of necessity, when ploughing is prevented by early autumn frost.

Textbooks recommend this to be applied in fields where the autumn-sown crop has been killed by the winter, yet tillage with cultivator entails reduced risks in such circumstances. Quite some time ago ploughing was also carried out in fields where maize stalks were fed to grazing beef cattle in the winter. Though this mode of utilisation is no longer widely practised, traffic induced soil damage has not been alleviated.

Ploughing for crop protection. For a long time weed killing used to be the single most important purposes of tillage. The introduction of chemical weed control prompted many to think that there is no longer need for tillage since the most important task can be carried out with the aid of chemicals. Those people did not, of course, take account of variations in soil condition and with the ever-increasing susceptibility and vulnerability of soils since cropping has been started. The tasks of ploughing for crop protection – in concert with soil protection – include:

- To prevent unfavourable soil conditions eroding crops resistance to pathogens, weeds, impacts of weather extremes etc.

- To maintain a high level of workability partly in order to enable performing interventions required for ensuring reliable cropping in time and without incurring larger than expected costs.

- To prevent deteriorating soil condition in order to achieve good quality of inverting for crop protection (ensuring high level of ploughability of the soil, to alleviate heavy dependence on available moisture content).

- Exploiting opportunities (conserving the soil state, cutting down moisture loss) for mitigating exposure in view of the inevitable risks of ploughing, such as plough-pan formation, the need for secondary tillage.

- To conserve the soil organic matter content, maintaining structure forming, bearing capability and workability in the year of ploughing and in years between them.

- To ensure that the condition of the soil after ploughing and surface forming meet the requirements for effective action of chemicals.

In summary, rationalising tillage system based on ploughing helps retain a technique that is so popular among farmers, prevent typical errors and defects, and mitigate risks of agronomical and environmental risks. Turning the top soil over from time to time fits in well with cropping systems. High quality ploughing does not degrade soil structure and does not cause harmful loss of moisture and carbon. Good ploughing requires knowledge of
the soil, good timing and good implements. Cutting out traffic induced soil damage and extra costs resulting from the machines’ idle running and from having to level furrows adds to the benefits of ploughing. Inverting at a time and under soil conditions suitable for ploughing yields higher quality at the expense of reduced energy input, and the number of secondary tillage passes is also reduced. Making the right decision is also important from the aspect of soil protection for damage and defects can be avoided only if at the time of ploughing the soil has the optimum moisture content for ploughing.

How to make a good decision concerning ploughing? In the same way, as about any other technique: based on careful consideration, prudently, with a view to the soil itself.

3. Questions:

• What are the advantages and considerations of conventional ploughing?

• What ploughing defects can you mention?

• What are the characteristics of good ploughing?

• What are the possible ways of rationalizing the tillage systems based on ploughing?
Chapter 8. Tillage systems based on mid-deep loosening

Loosening, in the general sense of the term, means separating aggregated, settled, compacted dry soil into fractions of aggregates of various sizes. The techniques of mid-deep or deep loosening are suitable for eliminating compactness underneath the regularly tilled (most commonly: ploughed) layer. The former technique is usually applied as a regular tillage method the latter qualifies more as a technique for soil improvement (amelioration). The state of the soil is improved by mid-deep loosening to a depth of 35-50 cm, while deep loosening implements work the soil to a depth of 50-100 cm. Soil compaction is usually indicated by the following signs in a field:

- rainwater remains stagnating on the soil surface, leaving a mossy film when it has evaporated,
- in a spade test compact soil shows a series of platy structure,
- tilling the soil when dry results in a heavily cloddy surface,
- tilling the soil is even harder and more energy-intensive than normally,
- conserved or mouldy crop residues that have not been decomposed, are to be found in or underneath the compact layer(s),
- germination and emerging is a sluggish process in a compact soil, plants remain stunted, their resistance is diminished,
- plant roots grow horizontally above the compact layer.

The compact layer that has been formed as a consequence of some tillage defect hinders the infiltration of extra water in a rainy period into the soil and its storage there. Instead of getting utilised at a later stage, the extra water runs off the field or evaporates. Crops cannot tolerate extra water and shortage of air for very long and in patches covered by water they die off. A compact tillage pan prevents water stored in deeper layers from rising to the root zone. If there is no rain, moisture cannot rise to the shallow surface layer that is left as a habitat for plants even from below and this results in aggravated drought damage. The solution is offered by remedial interventions in the form of loosening the compacted soil layers (Figure 8.1).

<table>
<thead>
<tr>
<th>Soil compaction in tilled layer</th>
<th>Soil condition improving tillage</th>
<th>Beneficial impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regularly tilled layer (0-15, 0-25 cm)</td>
<td>Loosening of compacted layer(s)</td>
<td>Less sensitivity to climatic extremes</td>
</tr>
<tr>
<td>compacted layer (without air and water transport)</td>
<td>re-establish aeration, heat and water transport between top- and subsoil</td>
<td>maintain a good soil physical and biological condition</td>
</tr>
<tr>
<td></td>
<td>anaerobe processes, organic matter decomposition</td>
<td>aeration, water storage</td>
</tr>
</tbody>
</table>

Figure 8.1 Occurrence and alleviation of subsoil compaction

The benefits of applying the technique of mid-deep loosening and things to be taken into consideration
Tillage systems based on mid-deep loosening

The advantages and benefits offered by mid-deep loosening lie in alleviating compaction and thereby mitigating environmental and cropping risks. The economic benefit of loosening the soil lies in improving the reliability of cropping (after eliminating compaction) and maintaining high level reliability (by regularly applying the intervention). Reliable cropping with reduced (tolerable) losses in the case of weather extremes is possible in fields where the soil is free of tillage pan compaction, it has good bearing capacity and a good structure and it is not short of nutrients. Reliability of cropping is enhanced in general if the application of methods preserving the soil biological condition and its structure turns into a daily task on every farm, as an indispensable constituent of cropping practices. The advantages of mid-deep loosening and the things to be taken into considerations should be assessed in the light of soil condition improvement (Table 8.1). The majority of risks are linked to the completion of the task of loosening.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Alleviation of compacted state (a ploughless process)</td>
<td>1. Unsuitable on wet soil (less efficiency)</td>
</tr>
<tr>
<td>2. Maintaining and improving a favourable biological activity in soil</td>
<td>2. A periodical adoption is required on soil are sensitive to compaction</td>
</tr>
<tr>
<td>3. It can be adopted periodically</td>
<td>3. A ploughless operation (crumbling or mixing by combined elements)</td>
</tr>
<tr>
<td>4. Applicable on dry soil</td>
<td>4. Heavy clod formation on dry and compacted soil</td>
</tr>
<tr>
<td>5. Adaptable to improving of drainage after water logging harm</td>
<td>5. Higher energy requirement on dry and compacted soil</td>
</tr>
<tr>
<td>6. Less moisture loss after loosening</td>
<td>6. It does not control weed (however it limits life activity of some rizomatous perennial weeds)</td>
</tr>
<tr>
<td>7. Less energy requirement related to ploughing (at same depth)</td>
<td>7. Effectiveness depends on quality of work</td>
</tr>
<tr>
<td>8. Improving crop production stability</td>
<td>8. Adequate secondary processes are required to surface preparation (prevention of recompaction)</td>
</tr>
<tr>
<td>9. Less environmental risk – less climate harm</td>
<td></td>
</tr>
<tr>
<td>10. A profitable process related to soil state improvement</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.1 Advantages and considerations of mid-deep loosening

Crucial factors relating to the effectiveness of soil loosening:

- **The soil moisture content.** Effective loosening should be expected when the soil moisture content equals about 40-45 % of field moisture capacity – i.e. when the soil is dry.

- **Loosening wet soils** that are frequently saturated or immersed in water is aimed at lowering the moisture content level, it is adequately effective but the improvement is short-lived (if it is carried out in the autumn it relieves the area from waterlogging in the winter and in early spring).

- **The depth of loosening.** The farmer should know the depth at which there is a compacted impermeable soil layer undermining the reliability of cropping.

- **Reaching the planned depth of loosening.** This is affected by the soil clay content, moisture content, compactness, the thickness of the compact layer, the spacing of the loosening tines and the required tractive capacity. Planning should be based on the given circumstances and the degree of attaining the planned depth should be precisely checked. Over-estimating the achieved depth of loosening will lead to wrong decisions.

- **The expected energy requirement of loosening.** This depends on the soil clay and moisture content, compactness and the depth of loosening. Loosening soil that has mellowed after stubble stripping is less energy intensive. Under the same soil conditions the fuel requirement of loosening to a depth of 35-40 cm practically equals that of ploughing a 28-32 cm layer.

- **Improving the effectiveness of loosening.** In a field after stubble stripping, when the process of mellowing has already started, the planned depth of loosening is more likely to be reached while the energy requirement of breaking the compact layer and of loosening to the required depth will diminish and the soil will become less cloddy.
Tillage systems based on mid-deep loosening

• The persistence of the improved conditions after loosening depends on the depth and quality of loosening and on the extent to which the soil is prone to settle. If the soil is not compacted back by traffic, the effects of mid-deep loosening reaching 35-40 cm may last for up to three growing seasons. Favourable conditions created by loosening in soil layers below 30 cm can be exploited by plants if the top layer is not recompressed.

• Growing crops that can utilise the loosened state of deeper soil layers. Mid-deep loosening is a primary tillage technique, a good method for loosening compacted layers deeper than 30 cm. Since protecting the soil is more important, any kind of crops may be grown in a field of loosened soil (it is more advisable to grow deep rooting plants).

Attention must be paid to the following, in order to ensure that loosening results in the desired effects:

• The planned depth can be more easily reached in a wet soil but in this case the loosening effect is weaker and the expected duration of the improved state is shorter. Tractor tyre slip and machine weight aggravate existing soil damage.

• In loosening soil that has already been ploughed, the ploughed layer is exposed to more than the expected traffic induced soil damage and the desired depth is not reached.

• In a field where no stubble stripping has been carried out, where the soil has dried out to crops’ wilting point, up to 15-30 % more energy is used (wasted) than normally, without reaching the planned depth of loosening. Breaking up a soil this way leads to unfavourable views of both the implement and the technique.

• The surface of loosened soil must be promptly pressed on days of intense heat to prevent moisture loss. Failing to carry out surface forming – e.g. until pressing – may entail a risk of recompingcting. Disking is good on dry soil it is adequate on humid soil and is harmful on wet soil.

• Proper crumbling of the surface layer of the loosened soil contributes to making the improved state more long-lasting. A secondary tillage element that can break down clods created by breaking through the compact layers without deteriorating the soil friable state is more useful. If no surface forming element is attached to the loosening implement, a cultivator, crossboard combined with clod slicing roller or flat plate disk is suitable for crumbling in a separate tillage pass.

Tillage system based on mid-deep loosening

During the period of cheap energy mid-deep loosening used to be applied in both plough-based and ploughless tillage systems. Differences between the two systems are still notable today (Figure 8.2). In version 1 – consisting of up to 7-8 tillage passes – inverting the soil was considered also to be important in addition to improving the soil state. From an agronomical aspect loosening in the wake of stubble stripping is a good solution. Ploughing soil that has been soaked through after loosening is not recommended on account of the high risk of recompingcting. As a consequence of the large number of tillage passes and of inverting which often results in defects, such a system does not yield the desired results. In version 2 there is no ploughing, loosening takes place between two disking interventions and the total number of tillage passes is not higher than 5-6. If a second disking takes place after loosening, there is a risk of recompingcting but not as high as in the case of version 1, thus version 2 is more efficient.

In the following there is a comparison of the expected impacts of two tillage systems based on loosening, on wet soils. Version 1 is a practical example, and version 2 is a modified one, where the supplementary procedures have a soil preserving effect (Figure 8.3). Version 1 comprises 6 tillage passes, which is an acceptable number from a conventional perspective. The ‘0’ rating of mid-deep loosening indicates that this is not a technique for a wet soil. Compaction is not alleviated, indeed, additional damage is caused by surface forming and consequently there is a high risk of recompingcting. In the case of version 2 the soil structure suffers little damage, but loosening is not achieved in this case either. As we have noted already, loosening in a wet soil may only be applied with the aim of reducing moisture content, and even so the effects are short-lived.
Tillage systems based on mid-deep loosening

<table>
<thead>
<tr>
<th>1st version</th>
<th>2nd version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble tillage by disk (+)</td>
<td>Stubble tillage by disk (+)</td>
</tr>
<tr>
<td>SOIL LOOSENING (-)</td>
<td>SOIL LOOSENING (-)</td>
</tr>
<tr>
<td>Preparation by disk (+)</td>
<td>Preparation by disk + crusher roll (+)</td>
</tr>
<tr>
<td>Ploughing in lands (+)</td>
<td></td>
</tr>
<tr>
<td>Preparation by disk + crusher roll (+)</td>
<td></td>
</tr>
<tr>
<td>Seedbed preparation by combinator 1/2x (-)</td>
<td>Seedbed preparation by combinator 1/2x (-)</td>
</tr>
<tr>
<td>Sowing (conventional)</td>
<td>Sowing (conventional)</td>
</tr>
</tbody>
</table>

Impact on soil: unfavourable (possible recompaction below disking depth)

Legend: possible damage (+); minimised damage (-)

Figure 8.2 Soil loosening in tillage systems in the 1980s (in dry soil)

<table>
<thead>
<tr>
<th>1st version</th>
<th>2nd version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble tillage by disk (+)</td>
<td>Stubble tillage by tine cultivator (-)</td>
</tr>
<tr>
<td>SOIL LOOSENING (0)</td>
<td>SOIL LOOSENING (0)</td>
</tr>
<tr>
<td>Ploughing in lands + harrow (+)</td>
<td>Preparation by tine cultivator (0)</td>
</tr>
<tr>
<td>Levelling (+)</td>
<td></td>
</tr>
<tr>
<td>Preparation by spade harrow (+)</td>
<td>Seedbed preparation by rolling element combinator (-)</td>
</tr>
<tr>
<td>Seedbed preparation by combinator (-)</td>
<td>Sowing (conventional)</td>
</tr>
<tr>
<td>Sowing (conventional)</td>
<td>Sowing (conventional)</td>
</tr>
</tbody>
</table>

Impact on soil: unfavourable (recompaction can be occurred) Impact on soil: loosening effect is poor, however recompaction can be prevented

Legend: possible damage (+); minimised damage (-), neutral (0)

Figure 8.3 Efficiency of loosening systems in wet soil

Figure 8.4 shows versions of systems based on mid-deep loosening combined with ploughing. Version 1 is comprised of loosening and ploughing in separate tillage passes. Both jobs can be carried out in good quality, since stripping by cultivator improves the soil workability. Loosening is followed by ploughing with reversible plough and surface forming in a single same tillage pass. In the case of a spring-sown crop there is no need for any other intervention before seedbed preparation. Compaction is reliably alleviated and there is no major risk of recompacting. Due to the application of soil preserving techniques this system has very little environmental risk but it is rather expensive. In version 2, loosening is carried out with the aid of reversible plough with subsoiler shank. Ploughing is followed by surface forming in a separate tillage pass, using some crumbling element combined with crossboard. Compaction is alleviated in dry soil and there is a low risk of recompacting. Seedbed preparation and planting can be carried out in the spring in one or two tillage passes, depending on the crop. The environmental impact is highly positive.
Tillage systems based on mid-deep loosening

<table>
<thead>
<tr>
<th>1st version</th>
<th>2nd version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble tillage by cultivator (-)</td>
<td>Stubble tillage by cultivator (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>SOIL LOOSENING + crumbler roll (-)</td>
<td>Ploughing by reversible plough combined subsoiler shank (0)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Ploughing by reversible plough combined crumbling element (-)</td>
<td>Preparation by cross-board + crosskill roll (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Seedbed preparation by compactor (-)</td>
<td>Seedbed preparation by compactor (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Sowing (conventional)</td>
<td>Sowing (conventional)</td>
</tr>
<tr>
<td>Impact on soil: favourable (less recompack damage)</td>
<td>Impact on soil: favourable (less recompack damage)</td>
</tr>
</tbody>
</table>

Legend: possible damage (+); minimised damage (-), neutral (0)

**Figure 8.4** Adoption of soil loosening systems combined with ploughing (upper layer of soil is humid, subsoil is dry)

*Figure 8.5* presents a comparison of two systems based on loosening from which ploughing has been purposefully omitted. The two systems comprise the same number of tillage passes. *Stubble stripping with cultivator* before mid-deep loosening creates soil conditions stimulating the soil mellowing process, to improving its workability and to reducing its energy requirement. The *clods* resulting from loosening are crumbled with the aid of a combination involving disks in version 1, and with cage roller mounted on the loosening implement in the case of version 2. Where clodding is heavier, *crossboard* is applied to break up clods. In a humid soil with modest clodding, where, however, seeds emerged in the field after stubble stripping need to be controlled, combined cultivator is the implement of choice for secondary tillage. Favourable soil conditions resulting from loosening are preserved in both systems, thus each of them has favourable environmental impacts.

**A summary of the practical benefits of mid-deep loosening:**

- It is a ploughless primary tillage mode that is suitable for loosening compact layers anywhere between 25 and 45 cm below the soil surface that have appeared as a consequence of tillage defects.

<table>
<thead>
<tr>
<th>1st version (dry soil)</th>
<th>2nd version (humid soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble tillage by cultivator (-)</td>
<td>Stubble tillage by cultivator (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>SOIL LOOSENING (by ripper + disk combination) (-)</td>
<td>SOIL LOOSENING + crumbler roll (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Preparation by spring-loaded crumbler (-)</td>
<td>Preparation by cultivator (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Seedbed preparation by compactor (-)</td>
<td>Seedbed preparation by compactor (-)</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Sowing (conventional)</td>
<td>Sowing (conventional)</td>
</tr>
<tr>
<td>Impact on soil: fulfilling of required looseness and structure conservation</td>
<td>Impact on soil: fulfilling of required looseness by up-to-date tools</td>
</tr>
</tbody>
</table>

Legend: possible damage (+); minimised damage (-)
Tillage systems based on mid-deep loosening

Figure 8.5 Adoption of ploughless soil loosening systems

- If properly applied, it does not turn into an expensive deep tillage method that is difficult to carry out: taking good care of the soil pays off.

- This is a possible tillage technique for alleviating tillage defects and environmental damage.

- Higher yields may be produced in soils in condition improved by mid-deep loosening. Even more importantly, reliability of cropping can be restored and then maintained.

- As a consequence of improving soil conditions reaching deeper soil layers mid-deep loosening is suitable for preventing and alleviating environmental damage (anaerobic processes, water stagnating on the soil surface or over the compact layer, clodding), and cropping losses (higher energy requirement of tillage, killed crops, loss of produce).

- Applying mid-deep loosening to soils of average moisture content or to dry soils entails low risks thus its agronomical impact is also very good. This fact confirms the indispensability of mid-deep loosening in soil and environment protection.

- Loosening implements consisting of one or two tines have a small working width and the tyres of the tractor can press the loosened soil back in the next turn.

- To ensure improving the soil condition and that the effects of improvement last sufficiently long it is crucial that the interventions preceding loosening (stubble stripping) and those following it (surface forming, seedbed preparation) are also carried out without defects. Carrying out the tasks of crumbling the clods produced by loosening and of levelling the surface in one go can help preventing any major moisture loss, along with the need for any additional tillage passes that could be carried out under the force of necessity, which would likely lead to recomping the loosened soil.

In summary. As a result of tillage defects compaction can appear anywhere within the 40 cm deep soil layer. That is of importance from the aspect of cropping, with negative consequences to farmer and environment alike. The farmer has possibilities for preventing and bears a responsibility to alleviate damage. Compaction in deeper layers can be remedied by mid-deep or deep loosening. Care must also be taken to maintain soil condition that has improved in the wake of loosening (by preventing desiccation, alleviating moisture loss, adding organic material to the soil, protecting the soil biological condition, producing soil loosening crops). Tillage maintaining favourable soil condition creates a balance between the requirements of soil protection and those of cropping. In addition to remedying symptoms loosening the soil is also aimed at alleviating damage caused by climate extremes and at ensuring safe and reliable cropping.

1. Questions:

- What are the major symptoms of soil compaction?

- What are the advantages and considerations of medium-deep loosening?

- What are the major factors that influence the efficiency of subsoiling?
Chapter 9. Tillage with cultivator

The cultivator can loosen the top 25 cm layer of the soil. The cultivator element gently loosens and crumbles the soil and it also carries out a good mixing action. The cultivator tine body that penetrates the soil may be of a variety of shapes, including wedge, lance, goose-foot shaped or winged. The tool tine may be:

- **rigid**, which is either straight or curved, suitable for greater working depths as well,
- **semi-rigid**, when the rigid toolbar is combined with a spring to enhance the crumbling effect and, or
- **spring tine**, which is of an ‘S’ or curved shape.

The tine body and the tool bar can be adapted to different tillage tasks and circumstances. This is practically entirely ruled out in practice in the region by a shortage of capital, therefore buyers usually purchase designs that can be used for achieving a range of different purposes. Up-to-date cultivators are combinations of tillage elements. They incorporate a number of tillage elements for a variety of purposes to ensure retaining the loosening effect and to improve crumbling, mixing and surface forming effects (levelling plate, ring roller, high-speed rotary harrow, flat plate disk, mixing disk, hollow disk, pressing or consolidating disk. To ensure effective work by the combination attention must be paid to the effects of the various elements and those of the entire machine assembly, on the soil. Where the field is covered by a large amount of crop residue the basic machine and the rest of the elements of the combination should be of designs that are not easily blocked by masses of crop residues.

The benefits of tilling the soil with cultivator were recognised long after the introduction of this type of implement. The fact that it left the surface covered by crop residues in the case of both stubble stripping and primary tillage was considered to be a drawback. Leaving the soil surface covered by field residues, however was found – quite surprisingly, given the then prevailing views – to have favourable effects.

The benefits of applying tillage based on the cultivator and things to be taken into consideration

The agronomical benefits of tillage based on the use of cultivators and the things to be considered are laid out in Table 9.1. In weed killing the cultivator should not be expected to provide the benefits that are characteristic of inverting. Designs working a deeper soil layer are more suitable for eradicating perennial weeds, but for instance in the case of carrying out the interventions repeatedly as required for depleting the reserves of weeds with rhizomes, it has a better soil conserving impact than for instance the disk.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Moderated clod and dust formation = soil structure conservation</td>
<td>1. Lower efficiency on ever-wet soil</td>
</tr>
<tr>
<td>2. No pan compaction</td>
<td>2. Special constructions needed on compacted soils</td>
</tr>
<tr>
<td>3. Good loosening, crumbling and mixing</td>
<td>3. Special constructions needed to control perennial weeds</td>
</tr>
<tr>
<td>4. Good quality on humid and dry soils</td>
<td>4. Expert operation required</td>
</tr>
<tr>
<td>5. It can adopt on wet (trafficable) soil without great damages (better than other tillage processes)</td>
<td>5. Unchopped and green remains are decreased the mixing effect</td>
</tr>
<tr>
<td>6. Pressed surface = less moisture loss</td>
<td>6. It is a ploughless process – do not expect soil inversion but do expect advantages which cannot be fulfilled by other processes</td>
</tr>
<tr>
<td>7. Less risk = indirect fanning profit</td>
<td></td>
</tr>
<tr>
<td>8. High area capacity (better to ploughing)</td>
<td></td>
</tr>
<tr>
<td>9. Energy saving process</td>
<td></td>
</tr>
<tr>
<td>10. A cultivator is adaptable to more tillage tasks</td>
<td></td>
</tr>
<tr>
<td>11. Good variability in tillage elements (loosening, crumbling, levelling, pressing)</td>
<td></td>
</tr>
</tbody>
</table>

Table 9.1 Advantages and disadvantages of using heavy-duty/mulch cultivators

Practical advantages
• *Less clod and dust forming* in comparison to the plough or the disk i.e. lower risk of damaging the soil structure.

• Heavy-duty cultivators that can be used for working deeper soil layers (down to 20-25 cm) can break and *loosen the compact disk pan* layer that has been formed near the surface

• Depending on the tillage tools (tine body, tool bar, blade) and the soil moisture content there is a lower risk of tillage pan forming.

• Based on its higher quality the cultivator can be used in a soil moisture range that is somewhat different from the soil moisture ranges that are most suitable for the plough or the disk. This applies, on the one hand, to dry and humid soils when the soil water capacity is at 42-55 %. Cultivators with rigid tines and wing shaped blades can still be used in a humid soil but they must not be used when the blades start smearing the soil in the working depth.

• One hitherto hardly utilised benefit of tillage based on the use of the cultivator is its reduced dependence on the soil moisture content. *For the least damage appears in a soil that is wet but still just trafficable in the wake of spring tine cultivators.* Besides reduced puddling and smearing effect it also has a smaller compacting effect on the soil at the bottom of the working depth, in comparison to other implements.

• *The benefit of tillage* leaving a mulch cover on the soil surface appears in the form of *reduced soil moisture loss* as well. This is particularly important in the summer, on days of extreme heat.

• It has an *adequately effective direct weed killing action* in fields of low or medium weed infestation. In stubble stripping the cultivator can create soil conditions that stimulate the germination of viable weed seeds that have survived in layers near the soil surface. The cultivator is suitable for effectively controlling the emergence of volunteer crops and weeds. The cultivator’s indirect weed controlling effects should also be noted. In weed-infested areas repeated shallow cultivation can make weed seeds in the top layer germinate and emerge.

• In a soil tilled with cultivator – if the layer concerned has been infested – *weeds emerge faster* than in a ploughed field (resulting in a less smooth and crumbly surface) therefore their eradication needs good timing. In contrast to views held by many it is not the cultivator (or any other type of shallow tillage) that produces weed infestation: instead, the improved soil conditions are more favourable for the emergence of weeds and weed populations can be effectively reduced by repeating the intervention.

• Some of the working elements of combined cultivators that are suitable for loosening and mixing include: rotary element, spring tine or double spring tine, ‘S’ shaped or curved tool bar and the helical blade. In the combination the levelling function is carried out by the roller (crosskill roller, the crumbler, spiked etc. and to some extent by the so-called hollow disk.

• The working width of tillage with cultivator (6-12 km/h) is similar to that of disking and higher than that of ploughing. Higher speed is an advantage in the case of stubble stripping, in stubble treatment and in working loosened soil surface as well as in primary tillage in the summer.

• Tillage with the aid of a heavy-duty cultivator is a low energy-intensity intervention though a large working width combination comprising a number of working elements has a high draught power requirement. The energy-intensity is 25-35 % lower than that of ploughing and 10-15 % higher than that of disking, in the case of identical soil condition, working width and depth.

• *A tillage system based on the heavy cultivator is made up of a smaller number of tillage passes than one based on ploughing.* In the wake of primary tillage with cultivator (given the array of tools involved) there is no need for surface forming in the conventional sense of the term (e.g. by disking), therefore soils so prepared are not prone to recompacting. Accordingly, the favourable trend that is observed in the case of primary tillage with cultivator applies to the entire tillage system.

• *The cultivator working element combines well* with other tools thus the overall appearance of the soil surface in the wake of the cultivator – the combination of loosening, crumbling, mixing, surface levelling and compacting – is up to agronomical expectations.

• Soils worked to a depth of 25-35 cm with cultivator can take in and store water highly efficiently (in contrast to the widely held view that a soil can take in and store autumn and winter precipitation effectively enough
only if it has been ploughed). For rainwater or water from melting snow is taken in by soil of a structure that
is free of layers (e.g. tillage pan) hindering water transports.

• The possibility of preserving the soil structure takes more attention and care of a farmer who has newly
adopted the technique than the use of any other newly introduced method. After working the top 15, 25 or 35
cm layer of the soil with the aid of a cultivator will – if there is no compact layer underneath the loosened top
– meet the requirements of any crops.

**Things to be taken into consideration when using a cultivator**

Factors limiting or deteriorating the effectiveness of tillage with the aid of a cultivator may induce risks.
Accordingly:

• Spring tine cultivators do less damage to the structure of a dry or wet soil.

• Stronger cultivator design should be used in heavily compacted and too dry soils. Even a cultivator will do no
wonders in a grossly neglected soil.

• Tillage with the aid of a cultivator is *moderately effective in eradicating weeds* with stem or root rhizomes.
On account of its soil structure conserving effects cultivators are more suitable for depleting the reserves of
weeds with rhizome root structures than disks.

• Cultivator tines may collect and get blocked by large unchopped green and wet masses of crop residues. For
this reason, *stalk chopping should be carried out before putting the cultivator to the land* (for example in
combination with harvesting), just like before any other similar intervention.

• The effectiveness of the cultivator’s mixing action is reduced in a wet soil though even so the cultivator does
less damage than does conventional disking.

• Combined cultivators have a less extensive range of utilisation than conventional disks – for instance they are
not suitable for chopping maize stalks. This disadvantage, however, cannot offset its benefits.

• A combined heavy cultivator is a more complicated structure than the conventional disk. Particular care is to
be taken to ensure proper setting of the working elements one by one, to guarantee high quality work.

*In summary*, cultivators can be used for *shallow stubble stripping* after crops harvested early in the season and
its benefits include conserving the soil structure and mixing part of the chopped stalks and straw into the soil.
The combination includes, in the majority of cases, a surface pressing element as well, so there is no need for a
separate tillage pass to carry out this function. The pressed surface and the mulch cover left on the surface
together reduce moisture loss. In this way the *most important requirements for mellowing* are met (including
crop residues as nutrient, aeration and moisture for increased microbial activity).

*Cultivators should be used for primary tillage* – just like other suitable implements – after stubble stripping and,
if necessary, straw and stalk chopping. This is how the maximum working width specified for the given type can
be achieved. Soil loosened and crumbled with cultivator to a depth of 20-25 cm is good for winter cereals and
rapes, or for any second crop. Cultivators with greater working depths (30-35 cm) may be used for carrying out
primary tillage before wide-row crops, including sugar beets. The benefits of such tillage lie in loosening the
soil to the required depth and in conserving its structure.

*The benefits of primary tillage with the aid of a cultivator may be exploited in any season* for they outperform
any other tillage implements in terms of preserving soil structure. The risks of tillage with cultivator reaching a
depth less than 20 cm – as in the case of any other shallow tillage – lie in the possibility of the formation of a
tillage pan at 18-22 cm below the surface if the year is too dry or too rainy.

Tillage with cultivator is negatively affected by crop residues only if there are large masses of green, wet and
unchopped vegetation. In fields covered by well-chopped residues of cereals, peas, flax, rape, mustard, oil
radish, poppy, soybean or sunflower cultivators do a practically flawless job. High quality of work is done by
the cultivator in a stubble field after silage maize or after sugar beets if the field has not been subject to heavy
damage by traffic. If alfalfa stubble has been stripped by disking, the cultivator is more suitable for carrying out
the second intervention.
The limitations of loosening the soil (area capacity, time) and its required conditions (low moisture content in the layer to be loosened, completed stubble stripping in which biological processes have already started) point to the need to use some other implement – for example spring tine cultivators that can be used for working the soil to a depth of 32-35 cm – where the compact layer is not extended under 40 cm.

**Tillage systems based on the use of cultivators**

The most important advantage of tillage systems relying on the cultivator is that the soil can be worked gently right from the first tillage intervention (stubble stripping) up to seeding. Figure 9.1 describes the phases and the environmental impacts of three tillage systems of different impacts and effects. The three examples prove that the farmer has a wider range of different tillage systems that can be applied in a dry soil. Ploughing a dry soil usually entails greater risks, though those risks are not as great where reversible plough combined with some secondary tillage element is used. In this example a moderate soil conserving effect should be expected. The application of a disk-based tillage system entails low risks for the interventions following primary tillage alleviate any adverse effects. Despite the fact that it is applied to dry soil the cultivation-based tillage system consists of four tillage passes. If primary tillage is carried out in good time – before the soil dries out – the top layer condition will come close to the optimum and it will not be deteriorated later on as a consequence of the application of a reduced number of tillage passes. Clod and dust forming can also be avoided, i.e. the cultivator-based tillage system has a very good environmental impact.

The range of the possibilities for applying cultivators may be expanded by adding various tools. If larger masses of crop residues are left on the surface of the field the mixing action of the helical blade is supplemented by the covering action of the hollow disk

<table>
<thead>
<tr>
<th>PLOUGHING system</th>
<th>DISKING system</th>
<th>CULTIVATORING system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble tillage by disk (+)</td>
<td>Stubble tillage by flat plate disk (-)</td>
<td>Stubble tillage by cultivator (-)</td>
</tr>
<tr>
<td>Ploughing (reversible plough + Campbell roll) (0)</td>
<td>Disking + press (0)</td>
<td>Primary tillage by cultivator (-)</td>
</tr>
<tr>
<td>Preparation by disk /power harrow (+)</td>
<td>Secondary crumpling (as required) (-)</td>
<td>Secondary crumpling (as required) (-)</td>
</tr>
<tr>
<td>Seedbed preparation by compactor (-)</td>
<td>Seedbed preparation and plant (-)</td>
<td>Seedbed preparation and plant (-)</td>
</tr>
<tr>
<td>Sowing (conventional)</td>
<td>Soil conservation: medium</td>
<td>Soil conservation: very good</td>
</tr>
</tbody>
</table>

Legend: possible damage (+); minimised damage (-), neutral (0)

*Figure 9.1 Comparisons of a ploughing, disking and cultivatoring system in dry soil*

The following is a description of an example of the possibility to apply the cultivator-based tillage system in the spring, in humid and in wet fields (Figure 9.2). It is possible to decide what solution may be applied to keep the soil state from degrading if primary tillage was not carried out in the autumn. In a humid soil conditions suitable for seeding can be created through four tillage passes, in a way that enables preventing loss of moisture and soil state deterioration. In a wet soil environmental damage can be prevented by chopping stalks – that would hinder the use of the cultivator – in the autumn, right after or simultaneously with harvesting. Ways to prevent damage include minimising the number of tillage passes and by the application of tillage elements having little puddling effect in a wet soil. Versions of cultivator and compactor types comprising rotary elements should be used in order to mix crop residues in the soil. The systems presented here entail little environmental risks and they qualify as ‘soil conserving’.

*The benefits of tillage with cultivator are summarised as follows:*

- It is suitable for gently loosening and crumbling the top 15, 25 or 35 cm of the soil.
Leaving a mulch cover on the soil is an important element of tillage with cultivator, which can be utilised in preventing the soil drying out and in improving the soil workability.

High agronomical quality may be expected in dry and in humid soils after stubble stripping and primary tillage, without increased environmental risks.

Applying the cultivator in a wet soil – which is still workable – makes it possible to prevent the appearance or aggravation of any major environmental damage.

The indirect economic benefits of tillage with cultivator lie in preserving the soil structure and in creating and maintaining the favourable state of the soil.

### Figure 9.2 Adoption of cultivatoring systems under spring crops

#### 1. Questions:

- What kind of cultivator types do you know?
- What can be the tasks of cultivators in a tillage system?
- What other tillage tools can be combined with a cultivator?
- What factors can limit or deteriorate the efficiency of cultivator tillage?
Chapter 10. Disk tillage

Disking is suitable for altering the physical state of the top (up to 20 cm) layer of the soil. The typical actions of disk tillage include mixing, crumbling and loosening. In a tillage system disks are used for stubble stripping, for chopping crop residues and for shallow ploughless primary tillage or as secondary tillage after other types of primary tillage, e.g. ploughing or loosening. Disking also used to be applied for crumbling the soil before broadcasting the seeds and then for mixing the scattered seeds into the soil. Conventional disks are not recommended for use in seedbed preparation.

The actual tillage tool of a conventional disk is the calotte or the truncated cone shaped disk plate mounted on an axle one by one or in groups. When in use in a field the disk plate is rotated by friction between the plate and the soil. Its cutting edge may be plain or scalloped; this is an important factor in cutting crop residues. To prevent blocking of the disk plates scrapers or block sweeps are mounted between them. In the case of conventional disks the angle between the disk’s plane and the towing direction may be set between 35 and 55 degrees. The greater the angle, the stronger the crumbling effect.

Agronomical expectations to be met by the conventional disk:

- The working depth should be adjustable, and it should be stable throughout a given tillage pass. The disk’s working depth – with vertical load being unchanged – drops and the unit traction resistance increases at higher working speeds. The reason for this is the soil’s increased vertical deformation and the disk plates’ increasing slip.

- It should crumble and loosen the soil to the depth to which it has been set. Offset disks are mounted in a way as will ensure that the crumbling effects of the plates in the front and those in the rear row complement one another.

- When trailed it should keep to the direction of the tillage pass and should not be set off this direction even by changes in the soil resistance.

- It should be adequately pulled into the soil even in compacted and dry soils.

- No patch should be left untilled between the disk units.

- It should not leave deeper furrows at the edges of the working width.

- It should chop and mix into the soil the stalk residues on the soil surface without getting blocked.

- It should leave an even soil surface behind.

The benefits of disk tilling and the things to be taken into consideration

The conventional disk can be applied for a wide variety of purposes, ranging from stubble stripping, through stalk chopping and primary tillage to secondary tillage after primary tillage:

- Dry straw and stalks (that are not or that are only slightly wet and/or unripe) can be effectively chopped by disking.

- It is suitable for a variety of actions such as crumbling, mixing, shallow loosening. Adequate crumbling is necessary both in stubble stripping, primary tillage and secondary tillage alike. Unfavourable soil conditions reduce the quality of disk tilling (Table 10.1).
Advantages and disadvantages of disk tillage

- By virtue of its structure a disk is suitable for mixing, which helps getting crop residues into the soil (instead of inverting as by the plough, in this case only part of the crop residues is mixed with the soil). The conventional disk is not suitable for evenly mixing fractions of the soil of different moisture content levels.

- By way of its area capacity and because it can carry out a number of actions required for stubble stripping (crumbling, mixing, loosening, chopping stalks) this is the most widely used implementation for stubble stripping. Rollers need to be mounted on or coupled to the disk frame.

- Disks can be used in dry or slightly humid soils up to 45-50 % saturation of the soil water capacity. When used in dry soil it produces more clods to be crumbled later on and more dust. In more humid soils the value of crumbling in the surface layer is reduced by disk pan formation.

- Disk tillage – if properly carried out – has a favourable impact on the soil microbial processes. It does not result in excessive aeration of the soil after crumbling, thus it does not aggravate the degrading of soil crumbs by aerobic humus decomposing microbes. This is definitely detrimental in the case of disk pan formation since it conserves anaerobic conditions.

- Disk tillage’s indirect weed killing effect is usually more effective than its direct effect on weeds. Weeds emerge faster in the soil’s shallow disked layer and if they do not grow too strong, they can be eradicated.

- Energy saving technique. Under the same soil conditions and working the same depth of soil disking takes 20-25 % less fuel (or even less than that, under favourable conditions) than ploughing. This applies to complete disk-based tillage systems as well.

- Lower draught capacity requirement. The specific draught power requirement of disk tillage is, according to measurements taken by the authors, 40-65 % lower than that of ploughing, under identical soil conditions and when working the same soil layer.

- Low fuel consumption. Depending on the soil clay content disking a 10-12 cm soil layer takes 5-14 l gasoline per hectare. Disking as secondary tillage after ploughing takes 3.5-11.5 l ha-1 of gasoline. (Mid-deep ploughing takes 17-22 litres per hectare.) Disking a stubble field requires 6-8 l ha-l, where there is heavy compaction it takes 10-14 litre gasoline per hectare. Shallow (8-10 cm) stripping of neglected, trafficked and desiccated soil takes as much fuel as is consumed by disking a deeper (14-16 cm) layer of humid soil.

- The large area capacity originates from the – possible great – working width and high (6-10 km/h) working speed. Disk tillage in different soils takes 65-75 % less working time than is required by ploughing.

- Disks – disk elements – combine well with other tillage implements. The disk element for instance on mid-deep and deep-loosening assemblies is used for crushing the clods produced by the loosening action and for surface forming. A row of flat plate disks may be mounted ahead of cultivator tines to help – by crumbling an inch or two of soil – penetrate the soil or they are mounted after the tines to crumble the clods.
Comparing different types of disks based on practical experience and measurements.

Conventional disk and disk of modernised structures:

The disk was invented in its flat plate form. The calotte or the truncated cone shaped plates were developed later, to improve the mixing action. These disk plates have an increased compacting effect on the soil – through a larger area of contact between blade and soil – particularly when the soil is either humid or wet.

Conventional disk and flat plate disks:

Flat plate disks have been reintroduced to enable preserving the soil structure. The flat plate disk cuts and slices the soil, and its pressure is limited to a narrow strip of the soil surface (underneath the cutting edge). In the case of calotte or the concave cone shaped disks the puddling and pressing effect extends to a certain width along the outer side of the plate beside its cutting edge.

The benefits and risks of disking as a primary tillage technique

At the time of the first introduction of the disk to regional farmers in 1909, one farmer author wrote with deep concern that “another thing I just cannot bear to see is that this tool will only be used by so many sloppy farmers to work in an even more careless fashion than they have so far”.

The risks entailed by disk tillage

The risks of using conventional disks stem from improper use, sometimes under the force of necessity and disregarding the soil moisture content. The consequences include disk pan formation, clodding, pulverising or the disked layer losing all of its moisture content.

- As a consequence of the disk plates’ slip the soil becomes compacted underneath the cultivated layer and the damage is greater in a wet soil or in a soil that has already been compacted. Upon secondary tillage after ploughing, if the relevant soil layer is wet, the disk compacts the soil by its own weight and as a consequence of the rotation of the disk plates, practically ‘halving’ the ploughed layer by a thinner compacted layer that is difficult for water or roots to penetrate.

- Conventional disk breaks up dry clods only to a certain extent and a lot of dust is produced in the course of this process. In this case it creates dust ‘polishing’ the clods, instead of crumbling them.

- The conventional disk is not the implement for secondary tillage in the spring in fields ploughed in the autumn or in the spring. Disking results in partial mixing of ploughed soil of a dry surface that is still wet at 10-15 cm below, without possibly crumbling it to an adequate degree, and the soil, left in clods, continues to lose water. Spring-sown wide-row crops emerge unevenly on such soils.

- In wet soils even the quality of the disk’s chopping and mixing action fails to meet the requirements, if there is a large mass of green and wet crop residue on the surface.

- Disking reduces the loss of soil moisture only if it is properly applied. Failing to press the surface after stubble stripping is a defect (Figure 7.34) that is reflected by clodding produced by the next tillage intervention and its increased energy requirement.

- Loss in yields associated with shallow disk tillage is related to the physical state of the soil underneath the cultivated layer. The first users in the early 1900s recommended disking after crops that had been grown after deep tillage, i.e. where there was no compaction in a deeper soil layer.

- The disk is not suitable for effective eradication of perennial weeds (having stem or root rhizomes, propagating roots or root stocks), for by cutting up vegetative parts it only helps spreading them. Annual weeds are killed by disking when they have grown to a stage where they have a few leaves and no massive root systems. Some 10-15 % of young weed plants can survive the second disking pass intact.

- The energy, time and cost saving benefits of disking can be exploited only if disking is carried out only once. If it is repeated twice or three times its benefits are lost and the soil structure is damaged.

- The energy intensity ratios of a heavy disk used on a dry stubble field without stubble stripping may be less favourable than those of the bladed cultivator combined with a consolidating element, working a deeper soil
layer. This then may lead to a series of agronomical defects in practice (increased moisture loss in fields where stubble stripping was not followed by surface forming, as a consequence of which the quality of the subsequent tillage operations will also decline).

In the early 1980s shallow disk tilling as primary tillage was applied on almost half of the area under winter cereals in this region. Disadvantages had to be faced only where the preceding and the subsequent crop was also sown after similar shallow primary tillage. Long term experiments and field studies confirmed the advantages of shallow disk tillage over ploughing in dry years in soils of any physical types in a good culture conditions (this latter factor is, indeed, crucial). The advantages appeared in terms of both high yields and lower resource requirements. Some ten years later, under the force of economic necessity, disking was applied increasingly frequently as primary tillage for wide row crops as well, and it was usually sanctioned by lower yields. The reason for the disadvantages lies primarily in the deteriorating state of the soils, rather than the depth of disking itself. Winter cereals’ need for shallow tillage can be exploited for reducing tillage costs only if there is no compact layer below 16-20 cm. If there is a compact layer near the soil surface, shallow tillage – even disking – turns into a risk factor.

Shallow disking in the autumn

The advantage of shallow tillage in the autumn – in comparison to similar shallow tillage in the spring – stems from better conditions for the soil soaking through and from the soil’s better workability in the spring. The application of this solution after maize may be hindered by the lack of the tools required for a perfect job (rotary element and seed drill whose work is not hindered by stalk residues). Compaction below 20 cm from the surface is a risk factor for cropping regardless of the timing of shallow tillage.

Shallow disking in the spring

Shallow disking prior to sowing maize was introduced in the USA in the late 1950s. This technique has remained highly popular in the US for this is one good way of economising and it enables producing the expected yield levels. It is also in line with the concept of soil conservation tillage according to which a minimum of a 30 % mulch cover is required on the soil surface even after seeding to give adequate protection against damage by wind.

Shallow disking in the spring should be regarded as a solution that may in some years be resorted to out of necessity, instead of, for instance, ploughing in the spring which would be an even less favourable choice. As a consequence of its – mostly – unfavourable impacts on the soil it may be an alternative to summer primary tillage only in soils that do not have compaction in deeper soil layers and only if it is carried out with particularly due care. Shallow disking in the spring would be a better solution if soils were improving rather than declining condition and if they were characterised by manageable levels of weed infestation.

The frequency of dry growing seasons, however, may prompt farmers to adopt practices in which the soil surface is covered by crop residues. Accordingly, primary tillage based on the use of the disk or the cultivator can equally be opted for.

Tillage system relying on the use of the disk

The reasons for the degradation of soil conditions lie not in disking itself but in poor disk tillage practices. A number of different primary tillage systems based on disking are compared below.

The conventional disk tillage system involves the use of simple and less efficient implements. The soil loses moisture between different phases of the tillage system as a consequence of which quality declines and soil damage may appear. An improved disking system is characterised by a smaller number of tillage passes and the application of combined techniques that do not disrupt the soil structure, resulting in improved overall environmental impact (Figure 10.1).
Figure 10.1 A conventional and a rationalised disking system under winter crops in dry soil

Figure 10.2 describes the risks of applying conventional disk tillage in the spring, along with a possible way to prevent doing harm. Creating a disk pan is a real risk in both humid and wet soils and this risk is aggravated by the application of unsuitable supplementary techniques. Loss of moisture, clod forming and puddling may occur between the different phases of the system. The improved disk tillage system shows a way of adapting to soil conditions typically encountered in the spring. Conditions that are suitable for sowing are created as a result of a reduced number of tillage passes and of applying interventions adapted to humid soils, and the system has an at least ‘medium’ environmental impact.

In summary, the value of disk tilling systems is characterised as follows:

- Disking is a form of ploughless shallow tillage providing all of the benefits that can be offered by the implement under the given circumstances.

- Agronomical disadvantages and the environmental risk of conventional disking stem from the implement’s design and from poor disk tillage practices. Assessing risk factors in advance may make it possible to mitigate the risks of the technique.

- In dry and humid soils disk tillage systems may meet agronomical and economic requirements without enhancing environmental risks if they are applied together with soil conserving interventions adapted to the relevant conditions.
The introduction of flat plate disks expanded the choice of implements that are suitable for soil preserving tillage and has made it possible to abandon using conventional disks in stubble treatment and in surface forming.

1. Questions:

• What are the advantages and considerations of disk tillage?

• What can be the tasks of disks in a tillage system?

• How did the judgement of disks changed over time?

• What kind of newer disk types do you know?
Chapter 11. The influence of biological factors

A soil is said to be in a ‘cultural state’ when its physical, biological and chemical features are suitably harmonised. Where any of the necessary factors is missing, no such harmony can be achieved. The soil biological condition is an indispensable quality factor affecting the process referred to as mellowing, crumbling, settling, workability and, ultimately, the energy-intensity of tillage. Tillage affects the activity of the soil-born flora and fauna through positive or negative physical changes. The soil biological condition also affects tillage. Biologically active soil is easier to cultivate than inactive soil. The following options are available for a farmer:

- regulate the soil biological activity,
- spare the soil structure and its carbon and organic material contents,
- stimulate earthworm activity in the soil,
- reduce moisture loss and help the mellowing process by covering the soil,
- grow soil loosening plants and catch crops,
- choose plants that can be produced economically and improve the biological activity of the crop sequence,
- reasonably practise the technique of ‘setting aside’.

1. Regulating the soil biological activity

Understanding microbiological changes in the soil may make the farmer rationalise his activities and prevent harmful effects and losses.

Aerobic microbes living in the original soil surface are moved underground by ploughing – thorough the process of inverting – as a result of which they find themselves in deeper layers of insufficient air supply, as a consequence of which the majority of such microbes die. The process of humification accelerates, that of decomposition slows down. In a while, the populations of aerobic bacteria that have survived the inversion on the surfaces of the furrow slices recover and their activity increases, and thus the decomposition of humus becomes the dominant process again.

Frequent invert of the soil and regular aeration boosts the activity of aerobic microbes thereby reducing the soil humus content, an essential component for soil structure building and for preserving workability (SZABÓ, 1992). Accordingly, tillage involving excessive aeration over a longer period of time is detrimental to the soil primarily through the decomposition of its humus content, because a soil that is short of organic matter settles faster, it is more prone to pulverising and silting up. This process was observed after the passage of 10 years in a long term tillage experiment on sandy loam soil. Data show that soil that was disturbed less over a longer period of time had a higher humus content than did an intensively and more deeply tilled soil. A soil on which direct drilling was practised, one that was regularly disked and a soil that was regularly loosened contained 46 %, 43 % and 19 % more humus, respectively, than did a regularly ploughed soil. There was a smaller (5 %) difference between ploughed soil and one on which ploughing was combined with loosening.

Aeration resulting from working the soil again and again also stimulates aerobic microbial activity and the decomposition of humus. The loss of organic material is aggravated by numerous cycles of clodding and mechanical crumbling (over decades or even centuries), and so is decelerating the process growing increasingly unlikely.

From the aspect of microbial activity the main disadvantage of a compact soil is that anaerobic micro-organisms (those favouring an environment short of air) produce a variety of toxic compounds. Instead of decomposing, crop residues begin rotting in such soil, plant toxins are produced and the slow decomposition of lignin can lead to soil exhaustion.
A *ripper* breaks through compact layers without inverting the soil. This results in only a modest increase in aerobic microbial activity under the tillage pan. At the same time the toxic end-products of anaerobic microbial activity, which have a harmful effect on roots even in very low concentrations, gradually disappear. Such loosening results in aeration and detoxification of the soil and the process of decomposition so encouraged makes nutrients available for plants even in deeper soil layers without increased loss of organic matter.

*Ploughless tillage* is biologically advantageous because aeration, aerobic microbial activity and organic material loss is increased only slightly, without degradation of humus materials that keep – cement – soil particles together.

*Rolling* reduces aeration in the top soil in the wake of the pressure applied to the soil, thereby slowing down aerobic microbes’ activity. At the same time, the process of decomposition of crop residues is not brought to a halt as a consequence of the reduced loss of moisture (unless the soil is too compact).

In the course of *seedbed preparation* microbial activity is increased somewhat in the wake of the loosening elements of the combinator and compactor but it is reasonably restricted through controlled compacting by the cage roller. In this way aerobic micro-organisms do not compete for nutrients with the emerging seedlings.

Preserving the soil suitably cultivated state and its workability depends, ultimately, on controlling the soil microbial activity along with the processes of building up and breaking down humus materials.

### 2. Preserving soil structure and organic material

The soil organic material content – humus – is a material and energy reserve for biological processes and it is also their waste and by-product. A fertile soil has an ample supply of calcium, and it has a crumbly structure and contains high quality humus, which is rich in nutrients. Humus materials determine the following:

- the evolution of soils *structure*,
- soil bearing capacity, compactability,
- the soil *nutrient* flows,
- the soil heat and *moisture* transport dynamic.

By contributing to the development of a stable and porous structure humus reduces the soil compactability and it also hinders pulverisation. Humus enhances the soil water retaining capacity (it can hold as much water as clay mineral structures), makes nutrients much more readily available for plants and it is itself a nutrient source and reserve.

The soil resilient and valuable structural elements are formed through the combination of and bonds between organic material and clayey particles. Organic residues are transformed through microbial and biochemical decomposing (*mineralisation*) and building (*humification*) processes. In most cases farmyard manure that has not matured sufficiently, and crop residues decompose quickly. Matured farmyard manure and composted materials do not decompose quickly even if they are spread on the surface in a thin layer. This feature may be exploited in the first years of direct drilling, to improve the structure of the soil. The mature manure available contents of nutrient elements is utilised in the first year, while the organic fraction, which does not decompose as easily, plays a more important role in improving the soil structure and in increasing its nutrient absorbing and its buffering (neutralising and protecting) capacity.

The components of different types of organic manure (farmyard, straw and green manure) loosen the soil when mixed into the top layers, improving aeration and water infiltration. This impact is particularly helpful in the case of clayey soils. Similar improvement in the soil condition may be encountered after adding farmyard manure – which is richer in colloids – to sandy soils that are short of organic matter. Organic manures also make a great contribution to the development of a water-resistant structure for they are a source of energy and feed for microbial processes, facilitating the growth of bacterial films and hypha webs on the surfaces of soil crumbles, holding soil aggregates in together. A ranking order of organic materials of importance from the aspect of soil structure development: 1. stubble and root residues, 2. green manure, 3. farmyard manure and 4. compost. This ranking order is yet another proof of the value of crop residues, justifying the prohibition of burning crop residue.
Easily decomposing parts of crop residues – composite sugar molecules – decompose in some 4-6 weeks. For lignin, which is more resistant to decomposing, the process takes some 8-10 weeks. It should be noted that

- crop residues go rotting and moulding instead of decomposing in a compacted soil,
- crop residue inverted into excessively wet soil decomposes slowly, therefore it should be just mixed into the top layer first and inverting should only take place after decomposing has begun and the soil has dried somewhat.
- residues inverted or mixed in the soil in large clumps cause local nitrogen shortage,
- temporary nitrogen shortage and toxicity may be encountered underneath patches of straw left on the soil surface, particularly when soaked over several times,
- decomposing is slow in acidic soils, but the process can be boosted by mixing 1-1.5 t ha-1 of some lime containing material in the soil,
- the decomposition of crop residues of the equivalent of a tonne of solids content per hectare can be facilitated in sand and other loose soils, in alkaline soils and in other soils of shallow fertile layer by adding 6-8 kg ha-1 of some nitrogen fertiliser,
- nitrogen-containing fertilisers should or should not be applied in chernozem or in meadow soils depending on the soil’s nitrogen contents, to assist decomposition,
- where harvest is followed by growing papilionaceous crops or other crops sown in late spring the decomposition of the residues of the preceding crop should not be accelerated by adding nitrogen,
- crop residues decompose in good time in a favourably humid and crumbly soil of a neutral pH value, if mixed or inverted into the soil to a depth of 15-20 cm.

Carbon-dioxide emission. The rate of CO2 emission also gives an insight in the state of the soil. At our experiment site at Hatvan-hőzsefmajor the highest emission rates (66-310 kg ha⁻¹ day⁻¹) were measured after primary tillage operations in the summer (August 2003). After primary tillage in September and October the emission rates varied between 4.0 and 8.5 kg ha⁻¹ day⁻¹. Smaller differences were found between the different tillage techniques after sowing. Ambient emission was taken as a basis (100 %) to which emissions after different tillage methods were compared. Data measured on the day of primary tillage and 2 weeks after sowing are presented in. Emission levels measured in the case of higher temperatures in and above the soil (2003) and lower moisture content (below 15 %, w/w) point to a need for reasonable summer tillage operations (pressing of open soil surface). Careful tillage and pressing both had a positive effect on the soil in the case of various forms of primary tillage (including ploughing followed by surface forming) in the autumn on humid soils (of moisture contents between 16 and 20 %, w/w).

In the case of primary tillage the soil carbon-dioxide emission (flux) is affected by: (1) soil disturbance (depth, mode), (2) surface cover, (3) soil moisture, (4) the temperature on the top and in the soil, (5) crop residues mixed into the soil, and (6) wind. Sowing results in an evenly loosened top layer (and not as loose, in general, as it was after primary tillage), while higher soil temperatures may facilitate soil biological processes (at the time of sowing in the late summer or in late spring). Our experiments and studies have shown that applying tillage preserving the soil structure can not only help reducing CO2 flux rates but it can also help balancing the decomposition and the accumulation of organic materials.

Tillage techniques where emission between 0.10 a.m. and 12.00 p.m. (1) exceeds the ambient emission rate by not more than 30-40 % on an average or (2) the initial higher level falls back and differs from the ambient emission level by not more than 30-40 % may be regarded to be organic material conserving cultivation methods. The levels measured on ploughed soil after surface forming should be noted: they exceeded the ambient level by 19 % as a three year average. This is another proof of the need for rationalising the technique and application of ploughing. Organic material loss may also occur in soils originally richer in organic material, if they are frequently and intensively cultivated, if they are not supplied with organic materials and if their moisture contents are not preserved. Soil conserving tillage results in opposite processes.

In an undisturbed soil – in its pristine condition – there is a balance between humus building and humus decomposing processes. Such a balance can be reached in the top soil if it is left without tillage for a longer period of time, and if it is not compacted. Frequent disturbance – intensive tillage of multiple passes – destroys
The influence of biological factors

the soil humified and mineralised organic material contents ultimately by stimulating aerobic microbial respiratory processes. In this case the soil structure also declines and fertilisers become less effective. Tillage may, ultimately, be preserving, balance keeping or loss increasing, depending on its effects on the soil organic material contents. Loss of organic material can be more reliably prevented on the basis of sound knowledge of its causes.

- The frequency of ploughing may be reduced from once a year to once every two, three or four years. The quality of ploughing may be improved by adapting the technique and its application to the soil moisture content and by attaching some secondary tillage element to the plough assembly, because this can reduce the ploughed soil carbon-dioxide emission (carbon flux).

- The soil should be protected from extreme desiccation in the summer, and no technique resulting in clodding (such as conventional ploughing or disking) should be applied under such conditions. In the season concerned the only consequence of leaving the field without pressing after tillage is loss of water but over years this leads to losing substantial amounts of carbon, which, in turn, leads to a general deterioration of the soil condition in a longer run.

- The spring, summer and late summer tillage seasons match the time of the soil biological activity. Any tillage intervention that could lead to excessive increase in aerobic (too much disturbance) or anaerobic (compacting, puddling, smearing) microbial activity should be avoided during this period, because these circumstances are detrimental to cropping.

- Continuous soil conserving land use and tillage practices contribute to improving the soil structure and its workability by restricting the processes of humus decomposition to a reasonable extent and by reducing the loss of organic materials (carbon).

3. Stimulating earthworm activity in the soil

The number and activity of earthworms is an important indicator of the soil condition. Tillage that destroys their burrows or that creates conditions that do not meet their requirements – such as large clods of soil after ploughing in the summer – is clearly not favourable for earthworms. The effects of tillage on wet soil depend on the extent of the disturbance caused. Tillage aiming at mixing and crumbling the soil without upsetting the order of soil layers does not have a negative impact on earthworm activity either.

In field experiments set up on different types of soils (brown forest soil, chernozem brown forest and meadow alluvial soil) in the early nineties we found that earthworms definitely need good soil condition. Inverting the soil caused disruptions, and changes in the soil had the most dominant effects. For example, in the case of ploughing (followed by surface forming) during or at the end of the summer when earthworms are still active, the burrows are relatively quickly restored. However, soil left in furrows – with large volumes of air between clods of dry soil – is not a suitable habitat for earthworms.

Soil coverage was found to have favourable impacts: larger numbers of earthworms were found to be ‘working the soil’ where the field was covered with mulch. Although coverage did not offset, at least it mitigated the effects of the dominant weather conditions of the given year. The smallest number of earthworms was found in the soil in the driest year in a four year period. In addition to soil coverage and soil moisture content during the active period the degree of soil disturbance should also be taken into account. The habitat was more favourable in a dry year (2003) under a 35 % mulch cover, where the soil was worked with cultivator leaving a mulch cover behind, than under a 65 % coverage rate where soil was left undisturbed, probably on account of its more favourable physical state. Fewer earthworms were found in soils after ploughing or disking than in soils after conservation-oriented tillage (with ripper, cultivator or after direct drilling) and the differences were greater in dry years.

No earthworms will be found in a compact soil, where the pressed layer is up to 3-4 cm thick. Earthworms need moisture, air and food (crop residues) for their soil-improving activities. Conditions are less favourable for earthworms in excessively cloddy, desiccated and pulverised soils, just like under a smeared or crusted soil surface. The use of chemicals has also been reported to reduce earthworm populations. In different habitats (in the top 15 cm layer under sugar beets) disturbance of the soil was found to have a greater impact on earthworm activity than the application of reasonable doses of manure, soil-disinfectants or chemicals at reasonable times. Chemicals, however, should be delivered before the period of earthworm activity.
Earthworm activity is, ultimately, encouraged by: 1. Soil conserving tillage to a depth of 25 cm, loosened state down to 40-45 cm. 2. Humid and favourably structured soil (preventing the soil drying out during the spring and in the summer). 3. Leaving soil cover even outside the growing season (tillage leaving mulch cover on the soil). 4. A gradual deepening of soil disturbance and mixing crop residues gradually in the soil. 5. Growing crops of favourable biological impacts (in addition to cash crops). If no such crops are included in the crop sequence, chopping and breaking stalks and evenly spreading and mixing them in the soil are essential requirements. 6. Optimised dosage and timing of delivery of chemical substances.

In summary. Earthworms favour modestly disturbed soils loosened to an adequate depth, in fields where the top soil is humid and is mixed with crop residues, where the surface is covered, that is conditions that can be created and maintained by structure conserving tillage. A large number of earthworms, their burrows and castings are indicative of favourable physical and biological soil conditions. In humid soils covered by crop residues (after stubble stripping) worms are active even during a drier period but no earthworms will be found in desiccated soils. Compacted or excessively pulverised soils are no habitats for earthworms.

4. Soil coverage

Covering arable fields with crop residues serves a number of important goals, such as:

- to reduce moisture loss,
- to encourage and maintain favourable biological activity in the soil,
- by meeting the above two goals to improve workability and make it possible to avoid more drastic interventions.

The importance of reducing moisture loss is underpinned by the necessity of creating favourable biological soil conditions (mellowing; encouraging the decomposition of crop residues) at the beginning of the growing season as well as by the need to improve workability, whereby mechanical damage and the energy intensity of tillage can be reduced. Summer tillage operations can be assigned to groups in relation to land surface incline and surface cover, on the basis of moisture loss.

On days of intense heat soils suffer great losses of water through the large surface increase resulting from deep disturbance. For this reason, creating a good seedbed for crops to be sown in the autumn is rather an uncertain undertaking (see Group 1). Shallow disturbance combined with pressing the soil surface that is left without coverage is a better solution but even so the farmer must be aware of the certainty of heavy moisture losses (Group 2). Soils lose the least amounts of water after shallow disturbance and surface pressing, under an at least 30 % mulch cover (Group 3).

Stubble tillage experiments are an expedient way to study relationships between soil coverage and moisture loss. In a given summer period (characterised by ample precipitation) soil without pressing, comprising large clods with a large surface (CD) lost even more water than did soil without disturbance (UD), despite the fact that it could take in more water. Reduced surface, for instance after pressing with the aid of ring shaped rolls (CDRR) was found to be more effective in reducing moisture loss than after surface forming with the aid of crumbler rolls (CDCR). Stubble stripping with the aid of flat plate disk crumbler combined with surface pressing elements (PD) and cultivator (K) effectively reduced moisture loss throughout the entire period (of 53 days).

Surface cover after stubble stripping is determined by the decomposition of straw. This process is affected by the climate – temperature changes, soaking through and drying out – the soil nitrogen contents and its biological activity. During the 53 days of our study cover was least reduced in the wake of the flat plate disk crumbler and the cultivator, while it disappeared fastest on soil where stubble stripping was carried out by conventional disk (Figure 5.11). In the case of autumn sowing a higher rate of coverage by the residues of a crop of a similar type may even be unfavourable.

Stimulating the soil biological activity and keeping it at a favourable level are indispensable pre-requisites for mellowing and for the development of adequately aired and friable soil structure. Its characteristics include durability of structure, good carrying capacity and workability, favourable air, heat and moisture transports, adequate biological activity and nutrient supply as well as minimised presence of weeds. The number of tillage passes and the energy intensity of tillage can be effectively reduced on a soil in favourably tilled condition. Practical experience and measurements have proven that the best quality of tillage can be achieved and damage can be minimised when the soil is in a mellowed condition and is adequately humid. In the above stubble tillage
The influence of biological factors

Experiment reducing soil moisture loss contributed to the loosening of the soil and ultimately to the higher quality of primary tillage in the autumn through the process of mellowing. Such effects appeared under a shallow layer of stripping with flat plate disk crumbler (PD) or cultivator (K). The soil was less effectively loosened underneath a layer worked with conventional disks combined with some surface forming element and it was not loosened at where no stubble stripping was carried out at all.

5. Growing soil loosening plants and catch crops

Plants also play a major role in protecting arable soils. The soil surface is shaded and covered by dense live vegetation during the growing season. The aggregation of soil particles in shade takes place in soil so protected against rain directly beating on its surface (since this is not a biological process, when the shading is removed, the crumbles turn into dust in dry weather and silt away under raindrops).

Straw, stalks and roots – considered to be by-products – can be taken into account as a source of materials for replenishing the soil organic matter stocks, depending on their quantity and quality. Some plants are referred to as soil loosening plants because of their vigorous root growth. Catch crop is a relatively new term. Such plants are grown with the aim of protecting the soil and the environment, covering the soil and preventing nutrients from getting washed into deeper layers or off the surface in areas where fertilisers are applied on a regular basis.

Soil loosening plants are grown as main crops as well (e.g. winter oil seed rape), while catch crops are grown as secondary crops. Some of the more widely known soil loosening plants including white mustard, oil-seed radish, winter oil-seed rape, and white sweet clover (many would also include sunflower in this category).

According to UJJ (2006) any vegetable of a vigorous growth can be grown as a catch crop (e.g. radish, onion, spinach), along with intensively growing field crops (e.g. rye, buckwheat, phacelia) annual papilionaceous (peas, crimson clover, soybean, melilot), and cruciferous crops (mustard, oil-seed radish, spring-sown oil-seed rape and turnip).

Soil loosening and catch crops improve soil conditions for cropping in a regime based on a small number of main crops (cash crops), e.g. by contributing to maintaining a favourable condition created by tillage focusing on loosening the soil. Reaching deep and penetrating even the soil structural elements, these plants improve the soil physical and biological features, water, air and heat transports and making the soil more friable. Growing loosening and catch crops cannot eliminate gross tillage defects but it can slow down the deterioration of the soil condition.

Such crops meet the requirements of soil and environment protection particularly if they produce large masses of vegetation above the surface as well as in the soil. They have positive impacts

• by covering the surface of the soil even out of the growing season, protecting it from erosion, deflation, capping and plating.

• by keeping the soil surface mellowed by shading.

• by loosening moderate compactness with their root growth, making it possible to prepare the soil for the next crop with reduced energy input and by causing less damage.

• by improving the soil biological activity and by making it more friable (Figure 5.13) and thereby more workable.

• because they do not require manure or fertilisers. By contrast, they take up nutrients remaining in the soil after the preceding crop and through removing much of the soil nitrogen content, and they reduce the load of chemicals on the environment.

• since some of them reduce nematode populations (having nematicide effects).

• for frozen crop residues protecting the soil from silting during the winter months and from capping in the wake of desiccation.

• since integrating catch crops in the crop sequence makes it possible to protect the soil with a longer and more effective coverage (Figure 5.14).

• the next crop can utilise the benefits of lasting effects of the catch crop (Table 11.1).
The influence of biological factors

Growing catch crops may be limited by shortage or lack of rain in the summer months, their production can be enabled by tillage or seeding techniques that have the benefit of reducing soil moisture loss.

Careful attention should be paid to the timing of sowing after the harvest of the main crop because no vegetation providing adequate coverage may be expected of the catch crop if it has failed to emerge evenly and vigorously, and poorly developed catch crop roots will not improve the soil workability either.

Furthermore, the farmer should be aware of the need to avoid growing plants as catch crops which could turn into weeds that are difficult to deal with later on.

Catch crops should not attract the same pests or be susceptible to the same diseases as the crops preceding or following them. If the seeds can stay viable in the soil for a longer period of time without germinating it can come out later as a weed.

The requirements concerning soil and environment protection are subject to certain conditions (Table 11.2).

<table>
<thead>
<tr>
<th>Crops</th>
<th>Favourable after-effect</th>
<th>Possible risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mustard, Oil-seed, radish</td>
<td>Good mulch = surface conservation = weed limiting; soil biological loosening = better workability</td>
<td>During a long period of drought Good stubble chopping required</td>
</tr>
<tr>
<td>Phacelia</td>
<td>Adequate surface cover and weed limitation from 5th week after shooting: biological loosening</td>
<td>Slower shooting – poorer conservation effect during the first weeks</td>
</tr>
<tr>
<td>Rye</td>
<td>Good mulch = surface conservation = weed control</td>
<td>Increased water utilisation in dry seasons</td>
</tr>
<tr>
<td>Green pea</td>
<td>Available N nutrient = less fertilisation requirement</td>
<td>Poorer surface cover in dry seasons</td>
</tr>
</tbody>
</table>

Table 11.1 Catch crop effects in a long-term soil tillage experiments

General principles applying to catch crop growing:

- Soil moisture conserving tillage helps minimise the risks of production.
- Plants of modest demand for water, providing good soil coverage should be chosen.
- With regard to the frequent shortage of precipitation in the summer, the soil must not contain any major defect preventing the passage of water in the soil.
- The phases of the tillage system on a compacted soil: loosening and pressing, seedbed preparation and drilling in one go. The lasting effects of loosening may be taken into account for the purposes of the next crop as well.
- Tillage based on the use of cultivator should be expected to enable preservation of favourable soil condition, if it is supplemented with the single tillage pass of seedbed preparation and sowing.
- *Direct drilling may be applied* without facing major risks in areas that are free of weeds (at least of perennial species).

Table 11.2 Soil tillage tasks under catch crops

General principles applying to catch crop growing:

- Soil moisture conserving tillage helps minimise the risks of production.
- Plants of modest demand for water, providing good soil coverage should be chosen.
- With regard to the frequent shortage of precipitation in the summer, the soil must not contain any major defect preventing the passage of water in the soil.
- The phases of the tillage system on a compacted soil: loosening and pressing, seedbed preparation and drilling in one go. The lasting effects of loosening may be taken into account for the purposes of the next crop as well.
- Tillage based on the use of cultivator should be expected to enable preservation of favourable soil condition, if it is supplemented with the single tillage pass of seedbed preparation and sowing.
- *Direct drilling may be applied* without facing major risks in areas that are free of weeds (at least of perennial species).
Catch crops should be grown, in particular, on soils that are short of organic matter, as well as where the depth of tillage aiming at improving the soil condition is limited, in areas exposed to erosion or deflation and on farms where crop residues are removed from the field, to be used for other purposes.

*Special cropping systems are required on sandy loam soils that are prone to settling:*

- **On a farm with a sufficient range of machinery** the seeds of the catch crop can be sown directly after cereals, without stubble stripping. This will result in a smaller green mass, but it takes less time for adequate soil coverage to develop.

- **Where there is a modest range of machinery** seeds may be broadcast on the soil surface without stubble stripping. This should be followed promptly by mixing them into the soil just under the surface using cultivators with blades, or disks, and the surface should then be pressed.

- Where the farmer aims to produce a large green mass that is to be mixed into the soil eventually, the catch crop **should be sown towards the end of the summer** (after stubble stripping and stubble treatment).

- **Where the soil needs protection** the catch crop may be left on the field until the spring. Shallow soil structure preserving tillage (e.g. using cultivator with blades) should then be quickly followed by seedbed preparation and sowing the next crop in one go.

Covering the soil and using catch crops as a means of soil protection should play an increased role, in view of weather conditions that are bound to grow increasingly extreme in the future.

### 6. Improving the biological impacts of the cropping sequence

The range of plants grown and their sequence have indirect impacts – through tillage and cropping processes in general – on the appearance and aggravation of defects in soil condition. The following should be carefully considered in this regard:

Owing to the necessity of growing a small number of different cash crops plants that have favourable *preceding crop effects* may be dropped out of the cropping sequence.

Plants that can be grown profitably in a given site tend to have the same – usually long – growing seasons, their sowing and harvest may have to be carried out during the same time from year to year. Sowing plants of long growing seasons year after year may lead to depleting the soil moisture reserves in drier years and to deteriorating soil workability. The frequency of *dry tillage periods* result in alternating processes of crumbling and pulverising, while repeated harvesting and tillage periods with *abundant precipitation* lead to other types of damage (e.g. traffic induced soil damage, compaction, puddling, smearing).

A simple and unvaried cropping sequence may lead to weed infestation. Negative processes may be aggravated by failure to apply means of mechanical weed control – in particular, stubble stripping and treatment – and by random application of chemical weed control.

*Crop rotation* should maximise the positive effects different crops can have on one another. Favourable biological effects have economic benefits as well (through reduced tillage costs), though cutting costs or increasing revenues may not necessarily be the only goal. Maintaining the standards of cropping without damaging the environment should also be an important goal of farming. The following should contribute *to improving the biological impacts of the cropping sequence:*

1. Tillage focusing on preserving the soil structure, organic material and moisture contents.

2. Alternating the time periods within the year of soil loading and recovery, i.e. different growing seasons, different periods sowing and harvesting during the year.

3. Reasonable plant nutrition.

4. Proper treatment of crop residues.
5. Integrating soil loosening and soil structure improving plants in cash or forage crop growing (as primary or secondary crops during a given season)).

6. Dual cropping – e.g. undersowing, oversowing, mixed sowing, growing a second crop – with the aim of soil protection (catch crops) or for the purposes of soil nutrient management, producing animal feed or sowing seeds.

7. Reasonable application of the practice of setting aside land to let it rest and recover.

Tillage focusing on conserving soil structure, organic material and moisture is a fundamental pre-requisite for favourable biological effects to materialise (this applies to cropping after growing papilionaceous crops as well). Differences in tillage depth, seed bed quality, nutrient and moisture requirements may help the farmer avoid unvaried cropping patterns. Different crop requirements are usually accompanied by different preceding crop effects and different types and quality of crop residue masses that require different treatments. Varying the tillage depth contributes to utilising the root zone potentials and to preventing the creation of a compacted tillage pan. Varying the time period of soil stress and recovery during the year provides benefits in terms of protecting the soil structure as well. Adapting to different requirements has favourable effects on crop protection as well, contributing to effective weed, pest and pathogen control and restricting their reproduction.

The preceding crop effect is made up of a variety of factors, including:

- site (exposure, soil, precipitation),
- effects on the soil:
  - nutrient contents (favourable, neutral, unfavourable),
  - moisture content (favourable, neutral, unfavourable),
  - organic material content (favourable, neutral, unfavourable),
  - structure (favourable, neutral, unfavourable),
  - state: the depth of tillage required for the next crop.
- yield (main and by-product),
- pests, pathogens, weeds (restricting, neutral, aggravating),
- harvest time (the length of time available from harvest to the time of sowing the next crop), in view of the quantity and distribution of rainfall during the given season,
- the impacts of the procedures of its production technology (tillage, application of manure/fertilisers, crop protection, irrigation),
- crop residues, since their quantity and choppability determine whether there is a need for ploughing before the next crop, whether the residues should be inverted or left on the soil surface, whether there is a need for chopping the stalks to make tillage easier.

Accordingly, the state of the soil after the preceding crop is a highly important factor, determining – among other things – whether it is possible to reduce or eliminate tillage defects and to cut tillage costs.

The preceding crop is considered to be ‘favourable’, if:

1. It is harvested early (e.g. in the middle of summer), offering the benefit of stubble stripping in reducing soil moisture loss.
2. It has a good biological after-effect (legumes, perennial papilionaceous crops, soil loosening crops).
3. It takes up small or moderate amounts of water.
4. It leaves a small quantity of crop residues or it leaves residues that can be easily and well chopped by the stubble stripping implement and can be left on the soil surface or part of which can be mixed into the soil.
5. The crop residues need to be chopped, there is no time constraint.

6. Its sowing had to be preceded by deeper primary tillage, as a consequence of which the next crop needs a less deep or no primary tillage at all.

7. The soil is dry there is a choice of several tillage techniques for primary tillage before the next crop, indeed there may even be no need for primary tillage at all.

8. The soil is compacted, the available length of time is sufficient for loosening the root zone.

9. There is a low occurrence of pests, pathogens and weeds, and they do not necessitate deeper and more costly primary tillage (ploughing).

10. Harvesting does not result in any soil damage that would necessitate deeper and more expensive primary tillage.

The preceding crop is considered to be ‘modestly favourable’, if:

1. There is a shorter period of time between the date of harvest and that of sowing the next crop.

2. If the crop residues need to be chopped before tillage.

3. If it was preceded by deep primary tillage or ploughing yet the quantity of crop residues (maize, perennial papilionaceous plants) necessitate inverting.

4. If it has a positive biological after-effect (papilionaceous, loosening plant) only after soil conserving tillage.

5. If it takes up a medium amount or large amount of water, having a negative impact on the next crop and its tillage costs in a dry year.

6. In certain cases (e.g. after sunflower) ploughless tillage should be opted for.

7. If the soil is compacted, the shortage of time makes it difficult to carry out the required loosening.

8. In the case of extreme weather conditions there is a narrow range of applicable tillage techniques.

9. The state of the soil may deteriorate during the harvest period and this may necessitate deeper and more costly primary tillage.

10. The presence of pests, pathogens and weeds drives up the costs of primary tillage.

The preceding crop is ‘unfavourable’, if:

1. It is harvested when the next crop is to be sown. Good organisation and a rationalised tillage regime is required for effectively managing and completing all of the operations required for harvest and sowing in a short period of time.

2. Crop residues need to be chopped to make tillage easier.

3. It has no favourable biological after-effect.

4. It takes up plenty of water, having a negative impact in a dry year both on the productivity of the next crop and on the tillage costs. The soil will not grow ‘mellowed’ by the time of seeding in drier years.

5. In a wet season the time of both tillage and sowing may be delayed, the soil may be damaged and in some cases it may not be improved before the next season.

6. Defects in soil condition that had been created earlier cannot be remedied and new defects may appear.

7. It was sown after shallow primary tillage, its harvest resulted in traffic induced soil damage and the next crop is rather exacting with regard to the condition of the root zone.
8. The shortage of time calls for minimum tillage, while the mass of crop residues necessitates primary tillage involving inverting.

9. Cropping in monoculture increases the costs of weed and pest control and this necessitates deeper and more expensive tillage.

10. Weather extremes reduce the range of suitable tillage techniques and particular care is required if causing damage is to be efficiently prevented.

In summary: ‘Preceding crop value’ is the sum of the effects on the performance of the next crop and the required production techniques, which may be improved by conserving tillage, or may be deteriorated by wrongly chosen or performed tillage operations. The preceding crop requirement is a sum of the biological and agronomical requirements assisting the production of the next crop, some of which are met by soil conserving tillage.

7. Reasonably applied methods for letting the soil rest

Letting the soil rest – through fallowing or by what is referred to as ‘set-aside’ – is a technique for revitalising the soil as a means of soil protection or in order to limit the production of crops for human consumption. Set-aside for economic purposes is an approach that has been successfully applied in the European Union for some time.

If a farmer undertakes not to grow crops for human consumption on given percentage of his arable land, he is paid a given amount of cash in compensation. Set-aside payments are subject to conditions, including

• the duration of setting aside,
• the width and overall size of set-aside land,
• the utilisation of set-aside land (food crops may not be grown but energy plants, green forage and green manure plants may be produced),
• a variety of environmental regulations that have to be complied with in the area concerned.

Conventional and novel means for letting the soil rest.

Fallow is a piece of land that is regularly tilled (for weed control) but not used for crop production for a while. The goals of fallowing include:

• facilitating nutrients decomposition,
• conserving soil moisture (through no water uptake by cash crops),
• reducing the load of chemicals on the soil,
• restricting weed-infestation,
• preventing or reducing over-production.

The methods of fallowing:

• Black fallow: Regular mechanical eradication of weeds on set-aside land.
• Green fallow: Production of a catch crop of a short growing season, in the spring or in the summer, to reduce the costs of fallowing.

The best way to give the land a rest is where the soil surface is not left uncovered (such as in the case of the green fallow version), i.e. where some cultivation is carried out while cropping is suspended.

Waste land is land that used to be regularly cultivated and utilised, where – unlike in the case of fallowing – not only cropping, but tillage in general is suspended (in some cases even for longer periods of time). The purposes
of keeping land as ‘waste land’ have been defined by classical authors on tillage: 1) to let the soil rest, 2) to restore the productivity of soil, 3) it is necessitated by economic factors.

A number of questions to be answered with regard to keeping land uncultivated:

• Environmental benefits or damage entailed by land lying waste (to what extent does it fit in with the rest of the landscape, does it turn into a source of pests and pathogens?).

• Economic aspects of utilising land as waste land (the economic benefits of withdrawing arable land from cropping and those of recovery, costs relating to environmental protection).

• Pieces of land kept as waste land can be utilised after a time for the production of renewable fuel sources by:
  • planting energy woods,
  • producing energy plants for which the site is suitable.

The following need to be done when production is started again on areas kept as waste land:

Dealing with crop and weed residues as well as tackling thriving weeds:

During the growing season:

• total chemical treatment or stalk chopping.

• repeated shallow stubble stripping to stimulate weeds’ germination,

• primary tillage of the depth required for the production of the selected energy crop (ploughing may be the best form of primary tillage during the first two years).

Outside the growing season:

• chopping or – in the case of large masses – burning residues,

• shallow tillage, cutting up and mixing in the soil any un-chopped or un-burned residues.

Tillage and growing tasks:

• in the case of compacted soil loosening to a depth of 30-35 cm, crumbling the surface layer and producing densely sown energy plants;

• in the case of an adequately loose soil ploughless tillage, growing densely sown green manure plants, leaving mulch on the surface, ploughing as necessitated by weed growth or shallow tillage, production of densely sown energy crop;

• in the case of a large mass of crop residue and weeds mid-deep ploughing and pressing, followed by the production of densely sown energy crop;

Green fallow or the above mentioned scheduled set-aside system may – for environmental and economic reasons – be more favourable instead of keeping land waste.

8. Questions:

• Why the biological condition of a soil is is important?

• How can we influence the biological activity by tillage?

• What is role of organic material in the building up of soil structure?

• What does the term catchcrop mean and how they act in soils?

• Why cropping sequence is important?
Chapter 12. Soils with special cultivation requirements

1. Slope field

Tillage takes up to 10-25 % more energy on slopes, even under favourable conditions. Besides the gradient itself, the costs of tillage are increased by other factors as well, including other disadvantages of the site (eroded patches, shallow fertile layer, rocky or gravelly subsoil, high clay content etc.), use of non appropriate machines regarding local circumstances, neglected soil condition etc. (e.g. as a consequence of long years of shallow tillage).

The gradient of a slope must not exceed 17 % if it is to be used as regularly cultivated arable land. In addition to crop coverage and surface cover the arable land’s value in terms of soil protection is determined by the quantity and quality of root and stubble residues, the mode of tillage and cropping (whether or not of a conserving type) together. The protective effects of crops depend on growing season, crop density or soil cover. Growing annual crops does not provide adequate protection on sloping arable land. Dense stands of perennial crops covering the soil adequately and for a long time provide better protection.供油 plants with nutrients in accordance with ecological conditions and the crops requirements contributes to soil protection indirectly. Field sizes (width, length) must be adapted to the gradient of the slope and to the terrain conditions.

On slopes of gradients between 5 % and 17% the primary goal of tillage is to prevent or delay surface run-off, thereby increasing the water infiltrating capacity of soil. Since uphill/downhill tillage facilitates erosion the direction of tillage and sowing should be of a contour pattern. Surface run-off is reduced by rough, wavy, mulch-covered surface, ridge-till, surface left in ridges after autumn ploughing and loosening without subsequent surface forming. The soil is more permeable to water if it is adequately loosened and if it is in a condition that impedes run-off (compaction must be prevented or, once formed, loosened). Even seedbed preparation should not result in soil structure composed predominantly of dust and small crumbles, which is not resistant to the force of flowing water.

Grassland management should be adopted on pieces of arable land in areas of gradients between 17 and 35 % and those on northerly slopes. Grass cover provides much more effective protection – owing to density of vegetation and permanent soil coverage – than do crops on arable land or plantations, with the additional benefit of indirect protection of arable lands at lower altitudes.

Forestation should be the preferred way of utilisation of slopes of gradients in excess of 35 % as well as of areas of smaller gradients that are not suitable for other form of land use. In addition to its economic benefits woods may play a vital role in the future in soil protection and in improving the quality of the environment.

2. The size of the field

The size of a field should be considered as adequate if during tillage the total time used by machines for making their turns plus the total of other idle running time does not exceed 15 % of the total working time (which means a minimum field length of 800 meters). Using large machines on small fields or machines of small working widths on large fields necessitates a high number of turns need to be made, along with a lot of idle running, entailing increased waste of energy. For example, taking the costs of mid-deep ploughing with a 38 kW tractor on 0.5 ha to equal 100 %, the cost of the same operation on a 50 hectare field will equal 53 %. The cost of such ploughing on 50 hectares using a 184 kW tractor will equal only 24 % of the costs of the same on half a hectare. The costs of the operation of machinery in wheat production, if the specific cost of a 100 hectares field is taken to be 100 %, on a 50 ha, a 20 ha and on a 5 ha field the corresponding percentages of the specific costs will equal 103-110 %, 111-125 % and 140-165 %, respectively.

Some of the disadvantages of small fields: lower of productivity, increased turning time ratio, decreasing rate of utilisation of fuel, increased edge-effect, lack of coordination of crop protection operation with similar interventions on neighbouring fields. In setting or changing field size particular attention has to be paid to environmental duties and to preserving or restoring the original landscape.
3. The soil clay content and its texture

Texture is a feature of soil affecting its workability and the required tractive power (energy requirement), which is affected by its clay, humus and moisture content. Cultivating heavy-textured soils requires implements designed for use in such circumstances.

Heavy soils are workable in narrow range of moisture contents (so-called ‘minute soils’). The frequency of defects is substantially affected by the choice of machines that are suitable for special soil conditions, and by the machines field capacity, which determines whether the farmer is can fully utilise the short period of time in which his soils are workable. Soil resistance to tillage implements – and consequently the energy-intensity of tillage – is further increased by unsuitable soil moisture contents and compactness. Soil resistance that increases together with the ratio of the clay fraction in the soil (its heaviness) can only be overcome by increased energy input even if the soil is not excessively compact and if the soil’s moisture content is suitable for the intervention concerned.

Within the category of light structured soils sandy soils with low humus contents are – as a consequence of rapid settlement while drying out after saturation – often just as difficult to work on as in case of heavy soils.

In heavy and dry – not excessively compacted – soils the energy-intensity of mid-deep ploughing, loosening combined with disking and mid-deep loosening may be up to 18%, 33% and 46% higher than that of the same operations on light soils. In heavy textured soils the energy-intensity increment is greater in the case of loosening than in the case of ploughing, though the energy-intensity of loosening is lower than that of ploughing regardless of the heaviness of the soil.

In a light soil only modest clodding is observed whatever the moisture content and the optimum range of moisture contents for ploughing is also rather broad (16 - 25%, w/w). The higher the clay content, the more prone the soil is to clodding and the narrower is the range of moisture contents in which ploughing may be carried out (in medium heavy soils: 18-23%, w/w, in heavy soils: 20-24%, w/w).

The relationship between heavy texture and workability are illustrated in Table 12.1.

<table>
<thead>
<tr>
<th>Soil texture*</th>
<th>Empirical soil moisture level – workability – probable structure deterioration</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIGHT Kₐ ≤ 35</td>
<td>- Dry: highly workable in non-compacted state and expected less damages</td>
</tr>
<tr>
<td></td>
<td>- Humid: highly workable without soil damages; tillage duration is short</td>
</tr>
<tr>
<td></td>
<td>- Wet: slight structure degradation; short tillage duration</td>
</tr>
<tr>
<td>MEDIUM Kₐ=35-50</td>
<td>- Dry: workable adequately in non-compacted state; probability of structure damage is moderate</td>
</tr>
<tr>
<td></td>
<td>- Humid: highly workable; probability of structure deterioration is minimal; tillage duration is adequate</td>
</tr>
<tr>
<td></td>
<td>- Wet: probability of tillage damages is real</td>
</tr>
<tr>
<td>HEAVY Kₐ=50-65</td>
<td>- Dry: hardly workable; probability of clod formation is great in particularly on compacted state</td>
</tr>
<tr>
<td>very heavy Kₐ=65-80</td>
<td>- Humid: highly workable; tillage duration is changeable</td>
</tr>
<tr>
<td></td>
<td>- Wet: hardly workable; probability of structure deterioration (smearing, puddling) is great</td>
</tr>
</tbody>
</table>

*Table 12.1 Coherence between soil texture and workability

Wasting soil moisture after stubble stripping or in fields left with undisturbed stubble, definitely qualifies as wrong practice, whatever the soil texture, because it leads to deteriorating quality and increasing energy-intensity of tillage.
4. The effects of soil moisture

The impacts of soil moisture on tractive power can be expressed in terms of changes in soil cohesion \((\text{the force keeping particles together})\) and adhesion \((\text{the force sticking particles to objects})\). The higher the soil moisture content, the greater the force required for deformation (adhesion growing stronger). Working a given soil within the soil moisture range that is favourable for tillage and within the optimum working speed range ensures minimising specific traction resistance and fuel consumption.

*In a medium-heavy soil* at the speed that is the best suited for ploughing, both specific traction resistance and fuel consumption will be lowest in the moisture content range of 19-23 %, w/w. Both energy requirement and soil damage increase outside this range.

In a particular (not over compact, medium-heavy) soil of a clay content between 48 and 50 %, the optimum soil moisture content is 17-20 %, w/w and 17-18 %, w/w, for mid-deep loosening combined with disking and for mid-deep loosening, respectively, form the aspect of energy requirement. Even more precise information can be produced by taking other factors (e.g. compactness of the soil, stubble residues, physical state, type of the tractor, working speed) into account in assessing the energy requirement of tillage. Soil moisture content is an important factor in regard to accomplishing the goal of tillage.

_Humid soil is the most favourable for ploughing from the aspect of moisture content:* this is when effective (95-100 %) loosening is accompanied by favourable crumbliness (clods in excess of 3 cm making up 26-30 % of the soil).

Fewer clods are produced by loosening a humid soil of a 20-23 %, w/w moisture content but loosening grows less effective (to below 90 %) under such circumstances. Accordingly, _loosening is more effective in a dry soil_ of the moisture content between 14 and 19 %, w/w, according to measurements taken in medium-heavy soils. Soil rippers combined with some surface forming implement produce the highest quality of work in soils that are dry in the root zone and humid in the top 15 cm layer.

Soil is easiest to cultivate when it is humid, this is when the least damage is caused and this is when the lowest ratio of clods to be broken down later on is produced (Table 12.2). In the case of a medium-heavy soil the moisture content range qualifying as ‘humid’ – 20-21 %, w/w – is the optimum range for creating a crumbly structure (SITKEI, 1967). The lowest traction resistance will be measured when the soil is not compacted and the machines are trailed in the optimum working speed range.

<table>
<thead>
<tr>
<th>Clod diameter (mm)</th>
<th>Expected clodliness in a wheat seedbed %</th>
<th>Cultivator use</th>
<th>Rotavating (12-16 cm)</th>
<th>Disking (18-20 cm)</th>
<th>Loosening (35-40 cm) + Disking (18-22 cm)</th>
<th>Ploughing (18-22 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>25-30</td>
<td>7</td>
<td>16</td>
<td>7</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>1-5</td>
<td>25-30</td>
<td>16</td>
<td>22</td>
<td>15</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>5-10</td>
<td>20-30</td>
<td>30</td>
<td>40</td>
<td>24</td>
<td>33</td>
<td>16</td>
</tr>
<tr>
<td>10-30</td>
<td>10-20</td>
<td>37</td>
<td>22</td>
<td>40</td>
<td>19</td>
<td>32</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>0-10</td>
<td>10</td>
<td>0</td>
<td>14</td>
<td>20</td>
<td>39</td>
</tr>
</tbody>
</table>

*Table 12.2 Clod size and distribution (%) at different primary tillage in humid (water content is 21 %, w/w) soils*

One additional advantage of techniques – using cultivators or disks – that are suitable for dry soils is that in many cases there is no need for surface forming in a separate go. The suitability of humid soil for ploughing is also confirmed by the reduced clod ratio. Loosening also produces a smaller percentage of clods. In a medium-heavy soil, however, effective loosening is not possible if the soil moisture content exceeds 21 %, w/w.

Failure to tillage adoption to soil moisture content results in increased damage to soil structure along with higher energy-intensity. The risks of using tillage implements will be lower in certain soil moisture content ranges depending on their structural designs and their impacts on the soil. Using implements out of optimum soil moisture ranges results in increased risks of defects and higher tillage costs. Cultivation of humid soil minimises damage and costs.
Soils are most friable when they are in humid (and non-compacted) state. Tillage of a humid soil produces less soil condition defects and its costs and energy input are also favourable. Tillage in extreme moisture content ranges, however, results in more defects, more soil damage and increased fuel consumption input. Gradually aggravating damage may escalate into environmental damage.

5. Advice on tillage and sowing in wet soil

Completing tillage operations in good time prior to sowing is crucial for the farmer in a short term. Indeed, a farmer will have to settle for compromise in regard to quality of tillage and even the timing of sowing. So, the farmers long term interest lies in minimising damage, because damage caused to soil that is not in a suitable condition for tillage or seeding will multiply in a season of extreme weather conditions.

**Soil moisture and fuel consumption.** Due to its construction and elements a tillage implement has a range of moisture contents in every particular soil within which both its traction power requirement and the tractors fuel consumption is favourable. In given medium-textured soil tillage with cultivator takes the least energy input in a soil moisture range of 17.5-22.5 %, w/w (which is when the soil is humid). Mid-deep ploughing has a somewhat different optimum soil moisture content range (19-24 %, w/w). The importance of measurements is underscored by data measured in wet soil. It is possible to operate a tractor on this particular soil up to a moisture content of 25-28 %, w/w, at which point some minor damage is caused. More traffic-induced soil damage appears when the soils moisture content is between 25 and 28 %, w/w or more (as is the case at the time of ploughing in the autumn in years of average precipitation). Traffic-induced longer lasting soil damage in the case of a soil moisture level of or more than 28-29 %, w/w. Whatever, the implement use, fuel consumption is higher in the case of tillage in a soil of more than the optimum moisture content. The difference is clear, in the case of mid-deep ploughing some 25 l ha-1 fuel is used, while in the case of mid-deep or shallow tillage with cultivator 6 and 9 litres less fuel will be required, respectively.

**The quality of tillage in wet soils.** No friable soil structure can be expected to be produced in soils that have dried only a little after having been soaked through to a greater depth, in spots that had been waterlogged for quite a while. In such cases one of the key considerations is to minimise damage. Accordingly, soil structure that is suitable for seeding should be created through minimised traffic, minimised smearing and puddling. Primary tillage should result in a soil condition that necessitates little secondary tillage and can be promptly followed by seedbed preparation and drilling, preferably in one pass.

**Damage to be expected in wet soils.** One fundamental requirement is that no machine should be driven and no tillage operations should be carried out on wet fields. The less suitable a soil is for traffic and tillage the more vulnerable it is, and the more serious the damage is caused by traffic by compacting, puddling or smearing. Depending on how carefully the interventions are carried out and on the impacts of the tillage implements on the soil in the case of new operation, compaction may reach a tolerable extent or it may grow to a degree where it is difficult to tackle. New compaction is caused in the course of ploughing as a consequence of the stress underneath the plough-share, underneath the tractor tyre running in a furrow and in the course of the manoeuvres in the headland area (and during traffic between lands in the case of ploughing in lands). Less new compaction is caused when tillage is carried out with cultivator, if the implement is fitted with spring tines and its surface forming elements avoid puddling in the course of crumbling and levelling.

In the wake of conventional disks (i.e. not flat-plate disks, and not an assembly in which the parts are separately spring-loaded) it is possible to identify the ratio of new compacting across the whole of the area underneath the cultivated layer. This is particularly dangerous where primary tillage was carried out using disks in the preceding season as well, and occurrence of compaction can be detected in the soil even by the current tillage operation. Soil compaction can be checked by carrying out a spade test. Soil samples should be taken using spades at several spots in the field to see the depth to which the loosened layer extends and from which the compacted layer begins. If the soil is loose down to the depth of the spade (approx. 25-28 cm), it is in an adequate condition. If, however, there is a heavily compacted layer underneath a shallow loose layer (of 10-15 cm), disking again would be a very risky intervention.

Attention must be paid to the degree of puddling. If there are too many puddled clods, there will be a need for additional tillage before seeding, adding to traffic-induced soil damage. Puddled clods can be broken down without causing much damage with the aid of an implement that is suitable for use in the given circumstances (e.g. cross-board combined with slicing roll).
Soils with special cultivation requirements

The soil workability should be checked field by field – indeed, at several places in a given field, if necessary – for the surface does not provide a precise picture of the layer that should be cultivated.

When there is no way to avoid tillage in wet soil an implement causing the least damage under the given circumstances should be chosen, for example a rotavator with V-shaped blades, with the aid of which the soil can be rendered suitable for sowing. Less damage is caused by cultivators with (properly spaced out) spring tines combined with mixing and levelling elements, than by ploughs and disks. These do not cost as much as an entire machine. Extreme weather conditions are increasingly often warning farmers of the necessity of timely preparations not only for tillage in dry soils but also in wet soils.

Possibilities and methods in a season of extreme weather conditions:

Planting without primary tillage after a rainy summer. This technique may be applied for sowing winter oil rape and cereals by farmers who carried out high (or fairly good) quality stubble treatment after their preceding crops harvested early in the season and have implements suitable for seedbed preparation and seeding in one pass. If there is a vigorous volunteer crop and weed population in the field and there are a few dry days, a chemical spraying can be used at the expense of little traffic-induced soil damage. If there is no time or way to do so and the crop to be produced is different from the previous crop the only solution for minimising damage is disturbing the soil (to eradicate weeds) and seeding in a single pass. Pressing rolls have to be set with a view to moisture content: in this case the surface of the soil in which the seeds have been sown must not be pressed as heavily as in the case of dry soils. The risk in this case lies in the possibility of the presence of a compacted layer below 20 cm under the surface. If there is a large quantity of weed seeds near the soil surface, chemical crop protection needs to be focused on in the spring.

Direct drilling on stubble, after a rainy summer. Winter cereals are often preceded by crops harvested in late summer or in the autumn. Harvest may be delayed and traffic-induced damage is almost inevitable. Straw chopping is important but stalks may in some cases not be ripe enough for chopping at the time of harvest. The area performance of direct drilling machines and the quality of sowing is not undermined by the rows of stalks broken during harvest and the soil also suffers less damage by traffic. This soil conserving method should be taken into account as an option in the case of sowing spring cereals as well. Farmers, however, should be aware of the risks entailed by this technique when there is a compacted layer at a depth below 12-16 cm. This type of risk can be revealed in time by carrying out a spade test.

Preparations need to be made for reasonable chemical weed control (weeds flourish earlier and in more dense populations in direct-drilled winter cereal stands after weed-infested sunflower or maize than in fields under cereals sown in conventionally cultivated soil). Protection against the Western Corn Rootworm (Diabrotica virgifera virgifera) or against fusarium may become more difficult, since they have a better chance of surviving in a field covered by stubble residues. Another question to be contemplated is whether spring barley should be sown after ploughing in the spring or by direct drilling in soils left without tillage out of necessity after sugar beets under which the soil remained weed-free up to harvest but then was subject to traffic in the autumn.

Omitting winter ploughing in waterlogged fields during summer. Instead of low quality spring ploughing causing loss of water, puddling and smearing, better soil condition is produced by careful tillage using cultivator. From among the above techniques direct drilling may entail reduced risks in the case of maize and sunflower as well. If this method is opted for, seeding should really be 'direct', for diskig a wet soil does more harm than good. Below 12-14 cm under the soil surface the soil may become so compacted that a much worse state can be created than where only planting is carried out. When such a solution is applied out of necessity the yield is as modest as the expenditure.

The top layer of clay soils that have been immersed several times during the growing season is prone to silting heavily. Colloids washed by rainwater into deeper layers – particularly in places where what is known as tillage pan has already appeared – aggravate the damage by accumulating in the compacted layer. Since such soils go smearing below a depth of 10-15 cm, two methods may be applied successfully.

One method is when a shallow top layer is cultivated, crumbled, aired (with flat plate disk, cultivator) and helped warm up, with minimised traffic and clodding. Deeper tillage is possible only when it can be carried out without puddling in the layer to be worked.

The other method is referred to as loosening with the aim of drying, to facilitate the drainage of moisture. A ripper with a crumbling element is applied to the soil whose surface layer has dried (the slot-widening element improves effectiveness. No more disturbance is advisable. Puddled and smeared clods in the top layer will be
sufficiently crumbled through the process referred to as mellowing by frost and tillage will be much easier in the spring. The effects of loosening carried out in order to remove excess moisture from the soil last a shorter period of time than those of tillage resulting in cracking dry soil. It still provides great benefits – though this method is applied out of necessity – making it possible to prevent accumulation of water in the field during the winter and to carry out the necessary tillage operations and sowing in the spring.

Ploughing wet soil in late season. The most important task in the wake of a delayed harvest is to see whether the soil is suitable for ploughing and, if it is, to minimise soil damage to be caused by the intervention. Soil that is not suitable for tillage should not be disturbed. A farmer should know that damage caused today will be aggravated in another season of extreme weather. Some time ago in areas of high quality soils postponing the task of ploughing to the spring was not considered to be good practice. Today, however, the primary goal should be to conserve the soil and to avoid damaging its structure. A modest goal should be set for the autumn, to cover large amounts of stalks left on the surface with soil by some cultivation technique enabling increased water intake in comparison to the permeability of stubble compressed by traffic. The following tasks should be carried out:

- **Opportunities for making tillage easier should not be wasted.** Often, in the wake of a rainy season maize stalks are not quite ripe and dry enough to deal with in a simple way and the farmer has to decide whether it is better to go and chop the stalks in one pass together with harvesting the grains or to do it in a separate pass, or to use the conventional disk to deal with the maize stalks.

- **The structure of a soil that has been puddled by disk can** – at least in the ploughed layer – be improved by ploughing but the intervention will cause some damage as well. Large smeared clods will be created on the surface and the soil will be puddled underneath the ploughed layer. Ploughing wet soil inevitably leads to **tillage pan formation.** This **plough pan** will be deeper in the soil than a disk pan and in this case the soil can hold more water in the next season.

- **Inverting is less effective in wet soil** and a farmer should not expect a clean surface after ploughing a field of maize stubble. Large smeared clots will crumble away during the winter but in the spring the farmer should use implements with spring-mounted tools rather than the conventional levelling implements. Soil pressed by the plough share and compacted by tractor wheels, however, is not going to be loosened even by frost.

- **The depth of ploughing should not be the same as in the previous year.** No deepen the tillage depth – particularly in soils deeply soaked through – increases the risk of tillage pan appearing or extending in the soil.

- **The depth of tillage in a given tillage pass should be kept even.** A compact layer already existing in the soil is more resistant to tillage even in a wet soil. In such areas farmers sometimes feel compelled to ‘raise the plough’ a bit. Attention should be paid to the soil during work. Serious compaction is indicated by muddy soil in the wake of water stagnating in the layer and on the surface above the tillage pan.

- **Particular attention is to be paid to uneven surface resulting from applying the conventional technique of ploughing in lands.** It is not possible to effectively improve the soil structure in a wet soil, even avoiding the production of more and deeper open furrows should be regarded as an achievement. Water accumulates in the open furrows appearing along the line of casting between lands as the snow melts and it is not possible to produce an even soil condition by tillage in the spring.

The possibility of ploughing – perhaps a little frozen – soil under snow cover is disputed by many. Decision on doing so needs careful consideration, depending on moisture content. If the soil layer to be ploughed is muddy and prone to smearing, work should be postponed for any damage caused to soil structure will lead to lots of difficulties in the next growing season. Primary tillage (ploughing, for instance) in winter is more advantageous than the same intervention in the spring only if it results in better soil condition both until the time of seeding and thereafter, throughout the growing season. Such advantages should include **absorption and storage of rainwater, even moisture distribution, even drying in the spring, reduced loss of moisture, an improved chance of producing a good seedbed and reduced susceptibility to drought damage.** If at the time of the autumn ploughing these benefits do not seem to be fairly likely to be secured, primary tillage (not necessarily ploughing) should be left to the spring.

### 6. Mitigation of tillage-induced waterlogging damage
Waterlogging is the accumulation of harmful excess water on the surface and in the fertile layer of the soil. Extreme water transports and water contents – including waterlogging – may be caused by a variety of complex reasons. Waterlogging may result from high subsoil water levels, the soil’s reduced or lost water infiltration and draining capacity alone or by more than one of these in any combination. Water is absorbed in the soil through two processes (each depending on the other): water infiltration and drainage.

**Water infiltration capacity** – i.e. water intake through the surface – is characterised by the time it takes for a given amount of water that has fallen on the surface to seep into the soil. Water infiltration is affected by the soil’s clay content. Water seeps into compact, dusty or silted soil a lot slower than into a soil of more favourable structure.

**Water drainage capacity** – i.e. water intake in a soil segment – is characterised by the quantity of water that can pass through a given soil segment in a given period of time. Drainage capacity is affected by clay content and soil structure (that is, whether it is loose or compact, dry or wet etc.). High clay content and compacted structure impede drainage substantially.

**Water infiltration and drainage** determine how much of the rain or water from melting snow seeps into the soil and how much runs off the field. Infiltration and drainage is determined by the layer in a given soil segment having the poorest hydraulic conductivity properties. Water transports in the soil are crucially affected by the presence of any layer of low hydraulic conductivity and the depth at which it is to be found also makes a difference. Waterlogging is detrimental to the soil’s chemical and biological properties and it further deteriorates its physical state (since soils that can go waterlogged are already in a bad shape). If the soil sits up first above the compact (watertight) layer caused by tillage defects and then later on in its surface layer as well, water transport comes to an end in the entire ‘cultivated’ layer. When parts of an arable field come under permanent water coverage for a while, the field is no longer characterised by more or less standard features and its economic value declines.

**Circumstances of farming have an indirect impact on damage by waterlogging:**

1. Simplified cropping structure, growing cash crops having identical or longer growing seasons with harvesting and sowing (entailing damaging the soil structure) carried out during the same periods year after year.

2. **Lack of crops of different characteristics** in the cropping sequence, without plant species having favourable impacts, repeating traffic-induced soil damage year by year, always in the same places.

3. **Failure to carry out interventions improving the quality of primary tillage** – e.g. stalk chopping, stubble stripping, treatment after stripping – repeating the same secondary tillage operations, re-compacting loosened soil.

4. **Weed infestation**, increasing weed cover during as well as outside the growing season (on stubble fields), making harvesting and tillage more complicated and more resource-intensive, necessitating repeated interventions.

5. **Suspending the application of techniques aimed at improving the soil** as a consequence of which parts of fields regularly coming under stagnant water coverage tend to remain waterlogged for longer periods of time.

6. **Making the same mistakes** in tillage year in, year out. Managing excess precipitation is impeded by aggravating physical defects in the soil structure.

7. **Unavailability of tillage implements** causing less damage to wet soil (e.g. rotary secondary tillage element that can be mounted on conventional plough).

8. **Lack of expertise and adaptability.**

9. **Economising – out of necessity.**

Some of the above (items 3, 4, 6, 7 and 8) can be tackled by an individual farmer but the rest (items 1, 2, 5 and 9) can only be remedied on a regional scale.

Deteriorating soil condition is often disregarded in years of average precipitation because of the minor yield losses having hardly any impact on the profitability of farming. Solutions are then sought for only when it is
already too late, when damage or loss has already occurred. External factors affecting the economic environment of farming (supply and demand, energy and machine prices etc.) also may have a role in that. When tillage operations that should be carried out to improve the condition of the root zone in compacted soils (mid-deep and deep loosening, deep ploughing) are neglected, both waterlogging and drought will cause a lot heavier damage.

The impacts of excess rainwater in winter, and of damage by waterlogging on next year’s cropping:

- poor soil condition aggravates, the affected area expands during harvest and autumn tillage,
- interventions aiming to improve the soil condition are not carried out in excessively wet fields,
- primary tillage is not carried out in the autumn in fields covered by water,
- loss of water (instead of infiltrating into the soil, water runs off the field),
- plants sown in late summer and in autumn are drowned,
- additional risks of defects in secondary tillage in the spring that follows primary tillage in the preceding winter, or in the course of primary and secondary tillage in the spring,
- uneven or patchy germination caused by seedbed imperfections, shallow root development and seedlings dying as a result of a compact layer being close to the surface,
- sowing less exacting crops in soils of quality reduced by waterlogging (often beyond the optimum seeding time), assuming unusually high economic risks,
- if no interventions are carried out to improve soil condition, another extremely wet period will cause even greater damage and loss.

Consequences of waterlogging in the winter and in early spring on the year’s crop production:

- the soil layer loosened in the autumn settles back by the end of the winter,
- soil condition defects aggravate and expand in the course of spring tillage,
- temporary suspension of biological activity in the soil,
- loss of rainwater (run-off, drainage),
- young plants in fields sown in late summer and in the autumn are killed by waterlogging,
- structure damage (smearing, compacting) in the course of tillage in the spring in fields where no cultivation took place in the winter,
- rapid drying and settling of the tilled soil layer when the water has gone,
- risks caused by defects in primary tillage in the spring, defects in the seedbed and in germination and early growth,
- depending on water cover, delayed seeding in usually biologically inactive soil of unfavourable condition in the root zone.

Wet soil is much more exposed to damage in a rainy period – and for quite some time thereafter – than does dry soil in a dry period. Preventive measures should include: (1) regulating soil moisture dynamics; (2) mitigating the effects of temporary excess water (Table 12.3 and .12.4).

Water-induced waterlogging subsides without intervention if no more water ends up in the area and there is a high rate of evaporation. Since this may take quite some time, water should be drained from waterlogged areas as quickly as possible. This requires drainage trenches or canals, natural or man-made reservoirs etc. Draining water from one field should not lead to damaging another.
After the removal or drainage of excess water the soil physical condition should be improved simultaneously with making it suitable for crop production. Attention must be paid to the soil moisture level at which the soil is trafficable and the farmer should seek to avoid aggravating conditions that are already far from what is considered favourable. Where soil moisture varies significantly within a given field major traffic-induced soil damage may be prevented by using rubber tracks or dual wheels on the tractors.

Where the soil was tilled first, then it was immersed in water and has dried sufficiently again, the top shallow layer should be loosened (making sure that clodding is minimised) to assist aeration and warming.

Primary tillage should be carried out with the aid of tillage implements causing as little compaction in the tillage depth as possible. Soil compacted and pressed by water needs to be loosened to foster biological activity. Damage may be minimised by using cultivators with spring tines, helical shares or wedge-shaped blades for working the topsoil layer.

<table>
<thead>
<tr>
<th>Factors increasing damage</th>
<th>Factors mitigating damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Physical condition limiting rain water infiltration</td>
<td>1) Physical condition promoting rain water infiltration</td>
</tr>
<tr>
<td>Harmful compaction on the surface, and near to surface (disk pan) and to a depth of 20-40 cm layer (plough pan)</td>
<td>Adequate looseness to a depth of 0-40 cm, non-compacted state at the depth of soil disturbance</td>
</tr>
<tr>
<td>2) Uneven surface causing tillage defects: Dead furrows, open furrows, plough pan underneath</td>
<td>2) Creating and maintaining smooth surface in a level site to prevent water flow</td>
</tr>
<tr>
<td>3) Soil condition limiting water loss trafficked, over-compact surface (untilled stubble)</td>
<td>3) Soil condition helping evaporation adequate loosen state promoting water transport to the surface</td>
</tr>
<tr>
<td>small surface</td>
<td>possible large surface for evaporation</td>
</tr>
<tr>
<td>great mass of stubble residues (without chopping)</td>
<td>clean surface/chopped residues and mixed into the soil partially</td>
</tr>
</tbody>
</table>

*Table 12.3 Soil condition factors increasing and decreasing water surplus in soils*

Seedbed preparation and planting in one traffic is better than applying conventional methods if the aim is to increase the likelihood of producing better conditions for sowing, reducing costs and traffic-induced soil damage. Direct drilling without suitable tillage is ruled out in soils that have dried out to a certain extent after they were under water cover for a longer period of time, because of the shortage of air in the lower soil layers, the low temperature of the soil, its subdued microbial activity and the dominance of anaerobic micro-organisms. Strip tillage is more suitable in such soils for it disturbs the soil in strips that are wider than the seeding line and deeper than the seeding depth.

<table>
<thead>
<tr>
<th>Risk increasing factors</th>
<th>Risk decreasing factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage tools causing harmful compaction at the depth of cultivation and tools smearing and puddling of soil: plough, conventional disk, rafter leveller, flat and ring-shaped roll – and tool elements – and use of outworn and dull disk plate, plough share, coulter</td>
<td>Tillage tools compacting and smearing wet soils slightly: spring blade cultivator, pick tine rotavator, plough with slotted board – and tool elements: soil driven rotary element, plain plate disk mounted individually, crumbler roll, cross-board leveller, seeding lane compacting roll</td>
</tr>
</tbody>
</table>

*Table 12.4 Soil tillage factors increasing and decreasing water surplus in soils*
Attention should be paid to the following in a growing season after waterlogging:

- **Shallow stubble stripping** to create the conditions for deeper tillage to improve the physical state of the soil. Gentle crumbling of the top layer helps the mellowing process and thereby it improves the quality of subsequent tillage operations. Cultivators cause less damage, disks have larger area capacity.

- **Loosening** compacted soils of inadequate aeration to gradually increased depths (e.g. in two passes) is more efficient and more effective in that they improve the results of subsequent interventions, than loosening the soil to the required depth in one go.

- **Mid-deep loosening** (35-40 cm) can be carried out on fields with vigorous weed and volunteer crop coverage after stubble stripping.

- **The aeration** and activity of subsoil of inadequate or no air content can be improved by breaking and loosening the heavily compacted layer. Crumbling and pressing the surface layer as well as loosening should be carried out in a single pass.

- **Inverting and tilling** the compacted layers can be carried out simultaneously with a plough combined with some loosening element.

- Soils whose structure has been degraded by waterlogging should not be ploughed in the summer. Ploughing excessively wet soil in the autumn is just as harmful: it should also be avoided.

Efforts made to improve soil condition by tillage should be supplemented by cropping structure adapted to site conditions (preferably by producing crops of growing seasons of different lengths and timing). The crops produced under such conditions should include species that are tolerant of the unfavourable conditions after waterlogging, plant species whose roots loosen the soil and can produce acceptable yields in relatively short growing periods. Accordingly, crops to be used as green fodder, green manure or even energy crops can be grown in such areas.

The most important tasks to be carried out when water has gone and the field has dried after a longer period of waterlogging:

- **Air the top** and then deeper soil layer to restart aerobic processes,

- **Loosen the top soil** layer and mix stubble residues into the soil,

- when the top soil has become more workable, loosen the compacted layer and then immediately break the clods so produced and level the surface,

- **loosened soil must not be recompressed**,

- **minimise traffic** involved in the tillage systems,

- avoid frequent use of tillage implements producing tillage pan,

- **vary the depth of primary tillage** from year to year,

- adopt soil conservation tillage practices and regularly apply interventions aimed at improving improve the soil’s condition.

**Supplementary tasks:**

- introduce organic material (stubble residue, farmyard manure and green manure) in the soil,

- produce crops loosening the soil structure (oil rape, oil radish, mustard).

Tillage preventing damage can provide the requisites for predictable cropping and enables preventing environmental damage as well.

Tillage offers a variety of effective methods and techniques for preventing tillage-induced soil damage caused by waterlogging. Deeper tillage is required for preventing soil damage by waterlogging where a harmful
compacted layer has appeared within or at the bottom of the regularly cultivated soil layer, hindering reliable crop production, disrupting the water transport in and impeding the protection of the soil.

*Water that cannot be stored in the soil is lost to farming.* Soils should be kept in a state in which the quantity of water they can take in and store is maximised. Since very dry periods also occur frequently under extreme climatic conditions, only the part of water that even a soil in good condition cannot store can be considered to be a surplus amount.

7. Over-dried soil – alleviation of drought damage

Any kind of tillage is very difficult – if it is possible at all – to carry out in an extremely dry soil in a way that will produce a good physical state. *Dry soil is even more difficult to cultivate if it is compacted.* Soil resistance takes more energy to overcome and breaking up – in some cases in several tillage passes – the resulting clods of various sizes also takes increased amounts of energy.

Loosening dry soil produces more large-sized clods than ploughing, because the more compact state of the deeper layers makes the soil more prone to clod or clump formation. A moist loam soil (20-24 %, w/w) contains a smaller proportion of clods that have to be broken down. In such soils loosening is less, ploughing is more effective. Tillage with cultivator or disk produces good soil condition in dry soils as well.

A ranking order of different tillage techniques may be set up from the aspect of their effectiveness in terms of reaching the goal of tillage in a soil of the given moisture content. *In a dry soil* rotavating produces the smallest amount of clods (> 30 mm) to be broken down later on but the proportions of the various aggregate fractions are not quite equal to the optimum, so rotavating is ranked third behind the use of heavy cultivator and disk as means of primary tillage. Loosening the soil in combination with disking is not as favourable as the first three techniques but it still produces a smaller proportion of clods than does shallow or mid-deep ploughing and in dry soils it even meets the requirement of effective loosening.

On dry soil tractor wheels cause less damage but the tillage implements produce clods, tillage takes an increased energy input and at the same time the depth of the cultivated layer may be reduced. Although, repeated mechanical interventions to break down the clods leads to the dust formation.

A farmer focusing on reasonable tillage will understand that in addition to the quantity of precipitation the soil moisture content is also affected by the way it is managed. Years of cropping by applying techniques that result in wasting soil moisture will be punished in a dry year by a substantial drop in yields. A farmer must be know – particularly before tillage operations in the summer – that applying tillage techniques wasting soil moisture jeopardises the following year(s) yields. It is even more important to check the soil at this point to see whether it is in a condition suitable for taking in and holding more rainwater. If the farmer finds a compact layer at 15-20 cm under the surface, the soil will not be suitable for reliable cropping in a dry or in a rainy season either. The farmer should also try and determine the tillage techniques that could ensure conserving the soil water content if it is found to be adequate at this point, should the following months bring less than the optimum rainfall.

8. Advice for dry seasons and for dry soils

*From stubble to seedbed*

Chopping stalks and straw should be part of harvesting. Shallow stubble stripping leaving a mulch cover on the field is a reliable method for conserving soil moisture. Even smaller quantities of rainfall will be absorbed effectively in a covered and adequately loosened soil. When the soil is dry the farmer should use tillage implements that do not result in clodding (such as cultivators, flat plate disks), coupled with some secondary tillage element. Good stubble stripping is a prerequisite for high quality primary tillage in a dry season.

Harvest removes shading vegetation cover from the field and the stubble remaining on the soil surface does not prevent, only slows down the heating and drying out of the undisturbed soil. Straw shredded and evenly spread by the harvester on the soil makes it possible to carry out better stubble stripping and it even delays drying out for a few days.

When the next crop is sown weeks after the harvest of the preceding crop, loss of water can be reduced by creating a new shading and insulating layer. Loss of moisture will be increased, rather than reduced, in a field...
where the stubble stripping is not followed by pressing or where no stubble stripping is carried out and no vegetation coverage is left on the surface.

On the hottest days the soil elasticity and workability decreases in parallel with the loss of soil moisture. Primary tillage in the autumn will become more difficult and it will take a lot more energy in soils that have dried out and hardened though.

The quality of the soil in the wake of tillage is largely affected by the application of a secondary tillage element attached to the tillage implement. In a dry period stubble stripping should be carried out with the aid of an implement crumbling a shallow surface layer, leaving a mulch cover while doing some mixing as well, combined with a pressing element that is a standard component or one that can be mounted on the machine.

The soil water transport regime – the balance of the amount of water entering the soil, stored and utilised in it and the amount evaporating – is also influenced by land use practices during the past several years. The advantage resulting from the smaller water requirement of crops harvested in the summer can be enhanced by good stubble tillage. This advantage, however, can be lost in 2-3 weeks – or in a few days of extreme heat – by neglecting stubble treatment. The soil water balance will be positively affected by leaving half to two thirds of the stubble residues (a mulch cover) on the surface and mixing up to half of the residues in the top layer. The remaining stubble residues can be similarly dealt with by the next (consecutive) tillage intervention (stubble treatment or primary tillage).

Gradually deepening, from stubble stripping to primary tillage, it may help to reduce loss of water, and to improve soil workability. Gradually increasing the tillage depth also helps mixing in stubble residues.

Treatment – the second phase of stubble tillage – may be mechanical or chemical, it is carried out with a focus crop protection (control weeds that have emerged, disrupting pests’ life cycles).

Stubble stripping and treatment improves the state of the top layer, providing better conditions for assessments of deeper soil layers. The condition of the soil should be checked with the aid of the spade test to a depth of 25-28 cm or with soil probe or penetrometer down to 40-45 cm. The depth and mode of primary tillage should be determined in view of the findings and conclusions of the examination.

In a dry season the farmer should choose a primary tillage technique that will improve or at least preserve the previous crop effects and conserve the state of the root zone, because the state of the soil in the root zone – whether it is loose enough in a sufficiently deep layer or whether it is compacted – has an impact on the soil susceptibility to drought (Figure 12.1).

Loss of moisture must be avoided and implements producing clods should not be used. The aim is to create an evenly crumbled and formed surface, preferably by a single tillage pass. Surface forming is aimed to reduce cloddiness and pressing the surface.

If ploughing is necessitated for crop protection, it should not be carried out on the hottest days, and the plough should be coupled with some secondary tillage implement. Dry – but not desiccated – soil is suitable for mid-deep ploughing, and soil that has become sufficiently crumbled in the wake of stubble stripping takes the smallest energy input.
A variety of methods are available for primary tillage in dry soils. The methods of cultivation that enable minimising the loss of water – through the smallest number of tillage passes and by creating the best possible soil condition in the given circumstances – should be favoured from among the possible tillage techniques.

The depth of primary tillage in winter should be determined in view of the soil condition and the mode of tillage should be adapted to its current moisture content. Land should not be left after ploughing with large clods and open furrows distorting the surface, even if seeding is not going to take place before the next spring. The quality of cloddy soil surface after ploughing may be improved by secondary tillage using flat plate disks or combined clod breaking rolls that do not produce as much dust as do other possible implements.

Seedbed for crops to be sown in late summer or in the autumn should be created through minimised soil disturbance and structure damage (which is not an impossible task, if soil moisture has been conserved). A good seedbed can be prepared if the preceding interventions – stubble stripping, primary and secondary tillage – were carried out well and there is no need for extra (corrective) tillage passes.

The most important tasks of dry-farming include:

- maintaining the soil capability of absorbing water,
- minimising the loss of soil moisture.

Advice on reducing drought-related damage:

1. knowledge of the condition of the soil – regular checks are required,
2. avoiding damage by compacting in the cultivated surface layer,
3. loosening tillage pan close to the surface by means of tillage (preferably right in the next season, before the structure of the soil becomes even worse),
4. preserving soil structure, preventing clodding by applying suitable techniques, reducing and preventing dust formation,
5. improving and preserving the soil carrying capacity by conserving structure and organic matter content,
6. reasonable management of the soil moisture – creating and maintaining soil conditions that will effectively take in and retain water,
7. *reasonable management* of stubble residue and organic material,
8. *mulch the stubble residues* on soil surface after harvest,
9. improving the biological impacts of the cropping sequence,
10. improving the effectiveness of crop protection.

**9. Questions:**

- What are the soil conditions that require special management practices?
- How does the moisture content of the soil influence the cultivation requirements?
- What cultivation methods can be used among extreme weather conditions?
- How can we mitigate the tillage induced waterlogging damage?
Chapter 13. Some cultivation problems. Soil condition improvement possibilities

1. Soil affected by traffic and compacted in the tillage layer

Various forms of indirect damage and loss caused by compacting include increased soil resistance and higher fuel consumption determined by the position and dimensions of the compact layer, poorer quality of the soil (clods and large clumps) resulting from cutting through the compact layer as well as the extra energy input of secondary tillage passes.

Tillage techniques of different modes and depths differ from one another in terms of specific fuel consumption even where the soil is not in a compacted and neglected state. The fuel consumption of mid-deep ripping (its depth exceeding that of deep ploughing) and that of tillage using cultivator equals 75 % and 55 % of deep ploughing, respectively. When cultivating compacted soil fuel consumption is also affected by the position of the compacted layer under the surface and its thickness. The energy-intensity of deep ploughing and that of tillage with cultivator is boosted by compaction at 18-22 cm below the surface (in most cases: disk pan) by some 20 % and 50 %, respectively, while the energy consumption of mid-deep ripping is increased most by compaction below 40 cm. The position of the compact layer and the quality of primary tillage affect the quantity of fuel required for creating soil conditions suitable for drilling. A trend of increase is the most notable among the relevant data, for actual fuel consumption may vary in soils that are have a looser or a heavier texture, higher or lower soil moisture content than the soil we dealt with.

In assessing the fuel consumption of tillage regimes attention should be paid to the depth and mode of primary tillage, the position of the compacted layer and the number of secondary tillage passes necessitated by the poorer quality of primary tillage. In the case of the tillage regime based on ploughing the highest fuel consumption is observed in fields where there is a compact layer at 28-32 cm below the surface, while in the case of loosening (ripping) the maximum fuel consumption is measured on land with a compact layer below 40 cm from the surface. The state of the top layer – after or without stubble stripping – also had an impact on the fuel intensity of a given tillage regime on a given type of soil in a given type of condition. Fuel consumption may be 8-10-12 % higher in the case of loosening a field without prior stubble stripping even if there is no compact layer in the soil, because the surface is either trafficked or dry. This fact underscores the necessity of proper stubble stripping and of keeping the layer below 20 cm from the ground (the root zone) in a favourable condition.

2. Cropping losses on compacted soils

Compaction qualifies as deterioration of soil and it entails a complex range of different types of damage and losses, including losses resulting from damage by climatic impacts, increased resource requirements of tillage and production technologies as well as lost profits. Yields will be lower as a consequence of reduced rates of nutrient and water utilisation even in soils of good nutrient supplies, but they will be dramatically lower where the soil is shorter of nutrients. Examples of yield losses measured on compacted soils of different levels of nutrient supplies should prompt farmers to prevent deterioration of their soils.

Loss of yields on soils with compact layers at different depths

Yield rates under favourable conditions are characteristic of the given types of soils when they have sufficient nutrient supplies. Compacting under the ploughing depth after deep ploughing repeated year after year resulted in the smallest yield loss (10 %) on loam and in the greatest loss (22 %) on clay soil.

The yield is smaller despite ample nutrient supply – as shown in the example in Table 10 – if a compact layer develops close to the surface as a consequence of disking or secondary tillage defects. The greatest (55 %) loss is observed on a sandy loam soil of poor water transport and balance regime and it is slightly smaller on clayey loam soil (42 %). The loss in yield was increased by the effects of compacted soil aggravating damage caused...
by drought for in the years under review (1983-1996) there were more dry growing seasons than seasons of average or abundant precipitation.

Results of our monitoring showed that compaction has less of a yield reducing effect in soils with at least medium or good nutrient supplies. This was found in the case of two different crops of different susceptibility in the field experiments, on soils of medium-heavy texture and medium nutrient supply.

*Maize* performs particularly weakly on a soil deteriorated by a compact layer close to the surface and one below the regular tillage depth. A compact layer near the surface usually disappears in the next growing season but if the tillage depth is not changed, the layers below 22 or 28 cm will gradually extent and more compact.

*Winter wheat* tolerates compaction (up to 2 cm in thickness) below 20-22 cm from the surface, suffering a yield loss not exceeding about 20 % (this may be one of the reasons for quite a number of farmers not taking disk pan formation seriously enough). Compaction in the top layer as a result of poor seedbed preparation causes greater losses (22-33 %), though the proportions are still not as large as in the case of the more sensitive maize. Yields of wheat are reduced primarily by the combined effect of compaction below the depth of shallow tillage and in the root zone, as is proven by average yield rates over growing seasons of different conditions.

The aggravated combined effect of poor nutrient supply and compaction highlights the necessity of improving the soil condition. There may be a difference of up to 67 % between yields under the best and yields under the worst conditions.

In the case of poor nutrient supply the worst impacts on the growth of maize result from compaction caused by defects in seedbed preparation underneath the layer affected by shallow cultivation and in the layer below mid-deep ploughing (a, b, c, d and e), i.e. the combinations that impede root growth in deeper soil layers. Compaction underneath the depth of deep ploughing (g) causes a smaller loss of yield (10 %) for in this case the roots have larger room for root growth than in the case of the other types of soil condition. PROCHÁZKOVÁ et al. (2006) published similar phenomenon under maize in the 4th year. Air capacity of soil was poorer in the given layer (10-20 cm) considering the disk-pan however it was adequate under ploughing or direct drilling. The most sensitive crop to compacted soil is *sugar beet*. A number of studies have proven that from among the different soil conditions in fields under sugar beets compacting below deep ploughing – where the conditions are somewhat more favourable for root growth than in fields with seedbed defects – causes the smallest yield loss. Seedbed defects cause the most severe losses in soils deteriorated by plough pan. Traffic-induced soil damage extending to greater depths reduces the root yield by about 50 % and the produce will consist of distorted roots. Similar findings have been reported by Czech scientists (e.g. ZAHRADNICEK et al.).

One important conclusion drawn from studies of soil conditions under sugar beets is that there is a risk of deteriorating the favourably loose structure of the soil resulting from the regular deeper tillage operations (ploughing, ripping) right until the seeds are sown. Favourable soil condition – regardless of the tillage implement – to a depth of at least 40 cm must be created, all of the other relevant agro-technological requirements must be met and defects in secondary tillage and seedbed preparation must be avoided, if a good harvest is to be expected in terms of root mass and sugar content.

Different types of crops are sensitive to soil compaction to different degrees. An order of different crops can be set up from the most sensitive to the least sensitive, as follows: *sugar beets*, potatoes, carrots → *maize* → soybeans, peas → alfalfa, various grasses → winter oil rape, winter barley, winter rye, red clover → spring barley → sunflower → *winter wheat* → rye → grasses (BIRKÁS 2000, based on findings of Hungarian and foreign authors).

**Yield quality is also affected by soil compaction, because of the following:**

- delayed or untimely maturing and ripening, heterogeneous quality,
- reduced resistance to pathogens leads to further deterioration of quality,
- uneven stand (plants in patches over compacted soil will be smaller and less vigorous, forced ripening results in variations in grain moisture contents),
- diminished sugar and protein contents (output) – reduced quality,
- uncertain marketability.
Cropping losses are also increased by growing costs of crop protection (necessitated by weakened plant reduced resistance), fertiliser application (on account of reduced efficiency), fuel requirement (as a consequence of increased traction power requirement – fuel consumption of tillage), machine repairs (more deformation, breakage), increasing tillage time requirements, harvest losses and other damage (e.g. erosion).

3. Amount of stubble residues

In determining the tillage system the range of available primary tillage techniques is also influenced by the quantity of stubble residues, by whether the stalks have been or can be chopped or perhaps by the presence of amounts of green and unripe residues, along with the tasks to be carried out before primary tillage (stalk chopping with the aid of an implement designed for this purpose or using disks). This problem could be reduced by introducing machines that can be reliably used for sowing in soil with stubble residues on the surface, with a low rate of error.

Things to be considered and things to be done:

• The goal of tillage is achieved at the expense of less traffic damage if stubble residues are chopped into the smallest possible pieces (of more or less the same size), hard stalks are crushed and evenly spread on the field simultaneously with harvesting (mounting an adapter on the harvester) or in a separate pass after harvesting.

• If stalk crushing was not carried out properly or it was not carried out at all, chopping stalks using disks on wet or compacted soils can lead to tillage defects.

• Stubble residues are much more difficult to work into compacted or cloddy soil, where the tillage elements can be blocked by soil, resulting in increased waste of time and energy.

• One technique to prevent damage and loss is alternating the inverting or mixing the residues in the soil and leaving them on the surface.

• The benefits offered by good stubble tillage must be exploited: 1) Stubble stripping should be kept shallow, leaving mulch on the surface (to protect the soil). 2) An even soil surface should be produced therefore stubble tillage should be carried out using an implement combined with some surface forming element. 3) If the soil moisture content is higher, straw must not be worked into the soil to avoid the so-called pentosan effect (decomposition only begins in a humid but well aired soil). 4) Patches of straw left on the surface after harvest must be spread by stubble stripping since that could lead to a temporary nitrogen deficit which would decelerate decomposition. 5) Stubble residues as a source of organic material supply, a valuable material. Straw should be evenly spread and mixed into the soil without creating straw clumps, even if there is a lot of straw on the surface.

To improve the quality of stubble tillage and to avoid creating piles of straw accumulating in patches (see: delaying the emergence of certain subsequent crops) straw choppers should be viewed from the aspect of whether they meet the most important requirements (whether they can produce an even spread of more or less the same small sized bits of straw. The highest quality of chopping and the best possible distribution is particularly important in the case of larger quantities of straw or stalks (produced by irrigation or abundant precipitation). A rainy period is not a sufficient reason for pulling large masses of straw off the field and letting it be wasted there or simply burning it. Stubble residues are a source of organic material supply for the soil. If there is no other way to utilise them (industry, litter) stubble residues should be returned into the soil. The nitrogen requirements of the microbes decomposing the stubble residues should be supplied depending on the soil nitrogen supplies and the amount of organic matter to be worked into the soil.

Larger amounts of wet stubble residues should not be inverted in wet soil compacted by vehicles, for decomposition is slow under such circumstances or it is replaced by rotting, releasing substances that are harmful to crops.

Decomposing well-chopped and evenly spread straw mixed partly into the soil by shallow tillage begins in the top layer of stubble stripping. This process takes 4–6 weeks for easily decomposing parts and up to 8–10 weeks for the rest. The final phase of the process takes place in the layer loosened by primary tillage. Working stubble residue gradually into the soil can rule out rotting and ensure that the micro-organisms decomposing organic matter do not deplete the soil of nitrogen. It can also help reducing mechanical soil damage. The benefits of care and tending to the soil will appear during growing season.
In this geographical region maize is preceded and followed most often by winter wheat. When applying this sequence of crops the following should be taken into account:

• No maize should be grown in a field in two successive years, to avoid proliferation of pests and pathogens.

• The quality of stalk chopping has a fundamental impact on preparing the soil for wheat.

• The area under maize will be stabilised or increased by a new form of utilisation of the produce (as a source of energy). With a view to increasingly extreme climatic conditions preparations must be made in terms of machinery and technology for producing soil conditions that are suitable for seeding even if large masses of maize stalks remain in the wake of harvest on too wet or too dry fields.

• If harvest was completed later than usual but the soil is workable, the masses of stalks remaining on the field should be worked into the soil using technologies (inverting by ploughing, mixing with cultivator) that enable the best intake of water despite compaction by traffic.

4. Weed-infested arable land

Weeds seem to have gained much ground during the recent decade. This may be a consequence of a variety of factors, including a change in the theory of reducing weed-infestation (management instead of control) but practices are still characterised by extremes. Further causes include:

• As a consequence of previous herbicide use (among other factors) a number of weed species have become difficult to eradicate by chemicals.

• Weeds susceptibility to herbicides has been changing, weeds are growing resistant, protection against is growing less and less effective.

• The potentials lying in stubble treatment (stripping) to help weeds emerge and to control weeds are not effectively utilised partly in order to save on tillage costs or for other reasons, despite the fact that stubble stripping creates a good seedbed for weeds, which, once emerged, are easier to eradicate by means of (mechanical, chemical) stubble treatment.

• Shortcomings in adaptation to the more exacting requirements of integrated weed management (timing, precision, sound knowledge of weeds and chemicals).

• Frequent application or poor quality of ploughless tillage (disking in most cases).

• Failure to exploit the weed control potentials of ploughless tillage and its consequences. 1. When weeds that can germinate on land after stubble stripping, with seeds already matured, are mixed into the soil, the new seeds end up in soil under favourable conditions (better for germination than when ploughed under), thus they start germinating in large numbers in early summer and in the spring as well. 2. After the shallow tillage of the topmost layer weed seeds near the surface are exposed to light, breaking their dormancy, and those seeds also start germinating. 3. Towards the end of their growing season the fields of wide-row crops become increasingly weed-infested, particularly in rainy Augusts and Septembers (Figure 4.22). If stalks – with the seeds – are ploughed under, the new generation of weeds will appear after the next ploughing, adding to the multitude of weed seeds that have landed in the soil in the meantime. If this is followed by ploughless tillage (e.g. before sowing wheat), more favourable conditions will prompt more weed seeds to germinate.

• Neglected state of ruderal areas (along roadsides, field edges, banks of canals etc.), along with those that are frequently covered by water.

• Micro-climates resulting from extreme weather conditions – rainy and sunny periods alternating in quick succession – are favourable for the activity of weeds (plus some pests and pathogens).

Weed-infestation is unfavourable because:

• most weeds produce large amounts of seeds and, if left uncontrolled, they can thoroughly infest the regularly cultivated layer in about 2-4 years,

• dense populations of tall weed species take up a lot of water, further reducing the soil workability,
• there is a greater chance of failure in farmers efforts to reduce the number of tillage passes – that is traffic-induced soil damage – in weed-infested fields, regardless of the quantity of rainfall,

• weed-infestation demands deeper primary tillage – of increased energy input – even if it were not required by the soil condition,

• more costly tillage (ploughing) needs to be carried out on a weedy soil instead of the less expensive use of disks or cultivators,

• green or dry, unchopped masses of weeds reduce the effectiveness of the tillage elements (necessitating increased numbers of tillage passes),

• delivering weed seeds to other fields helps spreading weed-infestation,

• a weed-infested field is a good habitat for pests and pathogens, becoming less and less likely to meet the requirements of a cultured environment.

Frequently ploughed soils also tend to become weed-infested, i.e. ploughing – inverting – is not sufficient for effective weed control. All phases of the tillage system (stubble stripping and treatment, primary tillage, seedbed preparation) should be applied in a way as will contribute (besides their primary functions) to prevention and effective weed control as well. New concepts need to be learned and applied, such as tillage for crop protection, relying on stubble stripping effect stimulating germination and stubble treatment effect controlling weeds, along with primary tillage adapted to the prevailing circumstances.

In addition to biological factors (circumstances facilitating gradation) variations in the culture of tillage (one farm is well-tended, another is neglected) are favourable for the spreading of animal pests (the common vole, the hamster), along with shallow tillage (disking) repeated year after year (undisturbed soil is a good habitat), the neglected state of road sides, trench and canal banks as well as the lack of systematic protective measures. These animals seem to be highly tolerant of weather extremes (drought or abundant precipitation makes not much difference: experts say extreme proliferation will lead to a collapse of their populations, over time). Coordinated actions on a regional scale – or at least in adequately large areas – have to be taken for effective mitigation of damage. Tillage can also contribute to reducing damage, for shallow tillage that spares their habitat does not disturb the life of these rodents but they do not like to be disturbed by deeper tillage (particularly deeper, 40-45 cm ripping) at all.

5. The state of the soil, fertilization and precipitation

One of the main functions of cropping and tillage regimes is careful management of the available soil moisture, dampening unfavourable impacts of extreme weather conditions. The frequency of years that can be regarded as ‘average’ has declined during the past twenty years, with increased occurrence of extremely dry and extremely wet years. At the same time, soils, crops and production have grown more sensitive to the climate (RUZSÁNYI, 2000).

Extreme climatic events have stronger impacts on poor soils in unfavourable conditions, as has been confirmed by findings of long term experiments carried out at various sites (Debrecen, Keszthely, Karcag and Kompolt). In experiments conducted near Gödöllő on fields of sandy loam soils (low quality site for cropping) three different soil condition types were separated in a cropping system in which wheat and maize was grown alternately. When small doses of fertilization were applied (relative to the soil nutrient content), winter wheat produced higher yields in average years under every soil condition. The difference between the yields on soils in good and medium condition – in line with wheat substantial tolerance – amounted to about 0.25 t ha-1, while the difference between the yields on soils in good and poor condition equalled up to 1.55 t ha-1, with a significant (1.3 t ha-1) difference between the yields on soils in medium and poor state as well. In dry years the yield dropped by 1.2 t ha-1 on soils in good condition, with hardly lower yields in rainy growing seasons. On soils in medium condition (with a plough pan in the soil) yields dropped following a similar pattern, though the losses were greater in rainy years.

When small doses of fertilization were applied the yields of maize fell short of the amounts required for profitable cropping (4.22 t ha-1) even in years of average precipitation and on soils in good condition. In rainy years yields increased by up to 10 %, in dry yields they dropped by up to 21 %. On soils in medium condition a rainy season produced 8 % higher a dry season produced only 5 % lower yields. Yields are lower in dry years than in years of average precipitation, whatever the soil condition, but they are particularly low in fields of soil
Some cultivation problems. Soil condition improvement possibilities

in poor condition containing a compact layer (disk pan). Accordingly, poor soil condition and no manure application results in a lower yield in any given year.

On sandy loam soils in good condition with a favourable supply of fertilizers maize yielded an average of 5.58 t ha⁻¹ in years of average precipitation. Where the top 40 cm of the soil was loosened, in dry and in excessively wet seasons the yield dropped by 15 % and by up to 25 %, respectively. The yield loss on soil in medium condition equalled 12 % in an average year and 21 % in a dry year, without any loss in a rainier than average year. Attention should be paid to the yield loss on soil in poor condition: 21 % in an average year, 22 % in a dry year and 22 % in a wet year. The most important conclusions: 1) not even ample precipitation can offset tillage defects, regardless of the application of massive doses of manure. 2) if both the soil condition and the fertilization supply are favourable, smaller – tolerable – losses are suffered in dry years. 3) a medium soil condition (affected by plough pan) does not reduce the yield in a wet year if the loosened layer is regularly soaked through and no excess water builds up above the tillage pan.

The importance of creating and maintaining favourable soil conditions is underscored by the harmful effects of shortage of water or surplus water during years of extreme weather conditions. According to RUZSÁNYI (1997) the proportion of water that can be utilised by plants does not reach 100 % (the maximum rates equal up to 60-75 %) even if the soil is more or less loosened. If there is a compact impermeable layer in the soil (in our cited experiments described above: disk pan and plough plan) an increased percentage of the rainfall will be lost, increasing the soil moisture deficit that is frequently encountered in any growing season. In a rainy season, tillage pan closer to the surface, turns into a factor reducing yields, because of the water stagnating above the impermeable layer. The closer the compact layer disrupting water transports is to the surface, the more important is a harmonised nutrient supply as well as precipitation satisfying the crop current demand for water. The rates of utilisation of manure (and fertilisers) are known to be affected by the soil’s

- humidity,
- looseness,
- organic material content,
- lime content and
- microbial activity.

Soil condition affects each of the above factors. One additional form of loss that is related to soil compaction is the lower rate of utilisation of natural precipitation. The depth of the soil layer that needs to be loosened is not necessarily identical with the required tillage depth. Disking or mid-deep ploughing do harm when a compact impermeable layer develops underneath the regular tillage depth. Accordingly, keeping deeper loosen soil layer is just as important from the aspect of mitigating damage by extreme weather, than is eliminating tillage pan. Plants that have a good nutrient supply need less water for building up organic matter. Reasonable nutrient supply, therefore, helps utilising the soil water supply through harmonising the soil nutrient uptake.

The features of the site can increase or reduce the energy-intensity of tillage they can improve or deteriorate the soil bearing capacity, the gravity of damage and the direct and indirect consequences of different forms of damage. The best conditions for cropping are provided by

- an even and level field, optimum field size (length, width, shape),
- a sloping field protected against erosion, with field size adapted to circumstances,
- smaller mass of stubble residue, or a larger but well-chopped mass, evenly spread on the soil surface,
- modest weed population – kept below level where it can cause damage – reasonable crop protection,
- medium-heavy soil texture, highly workable soil or soil of any type of texture but kept in a properly cultivated, friable state,
- dry soil or wet but still trafficable soil if compacting does not increase disadvantages that are determined by soil moisture,
- humid, highly workable soil,
Some cultivation problems. Soil condition improvement possibilities

• soil adequately loosened to the depth of the bottom of the root zone,
• favourable water transports and balance in the soil (linked to soil condition),
• favourable nutrient supply and utilisation.

A number of the above factors (soil condition, nutrient supply, the manageability of stubble residues, weed-infestation) can be influenced by farming, thus it is possible to reliably reduce the energy-intensity of tillage, along with the risks of damaging the soil.

6. Questions:

• What is the effect of compacted layers in the soil?
• Why the management of stubble residues is important?
• How can we manage weed problems?
• Describe the relationship among soil conditions, fertilisation and precipitation!
Chapter 14. Precision farming

1. Main characteristics of precision farming

Every agricultural intervention inevitably presumes an accurate knowledge of the arable sites. In the 1980s the so-called industrialized agricultural practice organised the farms into producing blocks, taking into account the heterogeneity of arable sites only partly despite of the existing technical facilities. Although the yields were very high, they were achieved by high energy inputs (fuel, fertilizers, plant protection agents etc.) and by low efficiency. Materials that were not used up by the agro-ecosystem endangered the environment potentially. Energy and environmental crisis, reducing agricultural efficiency, reducing supports, as well as the increasing Earth’s population and the rapid growth of starvation revealed that agriculture is in a global crisis.

Information-technology (IT) and its spread was a real breakthrough in handling the crisis. The utilization of the information technology (IT) in farming happened in the form of precision agriculture. The principle of precision farming is to connect geo-positioning systems with traditional farming practice (Pecze, 2001).

In plant growing precision farming includes (after Győrffy, 2001):

- remote sensing,
- utilization of data gained by remote sensing with the help of geo-positioning systems
- species and variety-specific sowing,
  - Plant number (plant width, row-width),
  - Adjustment of the sowing depth
- plant-tending based on survey,
- nutrient replacement determined by the nutrient reserves and the actual state of plant development,
- integrated plant protection,
- yield-modelling,
- preparation of statistical analysis

We summarized the most important differences in traditional and precision farming in the following table:
Table 14. 1 Main characteristics of traditional and precision farming

<table>
<thead>
<tr>
<th>Traditional farming</th>
<th>Precision farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit of treatment and organisation: <strong>field</strong></td>
<td>Unit of treatment and organisation: <strong>arable site</strong></td>
</tr>
<tr>
<td>that is regarded as a homogenous</td>
<td>that is regarded as different from one</td>
</tr>
<tr>
<td>arable site</td>
<td>point to the other and at “field level!” as heterogeneous</td>
</tr>
<tr>
<td>Nutrient management based on average</td>
<td>Nutrient management based on GPS and point-like sample taking</td>
</tr>
<tr>
<td>sample taking</td>
<td></td>
</tr>
<tr>
<td>Average survey on plant deceases and</td>
<td>Plant protection treatments based on GPS</td>
</tr>
<tr>
<td>damage and intervention if necessary</td>
<td>and point-like plant survey</td>
</tr>
<tr>
<td>Sowing with same plant number and</td>
<td>Plant species and plant variety-specific</td>
</tr>
<tr>
<td>variety</td>
<td>sowing</td>
</tr>
<tr>
<td>Same machine operation practice</td>
<td>Machine-operation adjusted to the arable</td>
</tr>
<tr>
<td></td>
<td>site</td>
</tr>
<tr>
<td>Unified plant stock in space and time</td>
<td>Unified plant stock organised into</td>
</tr>
<tr>
<td></td>
<td>homogeneous blocks at arable sites</td>
</tr>
<tr>
<td>Few data influencing decision preparation</td>
<td>A lot of data influencing decision preparation</td>
</tr>
</tbody>
</table>

In traditional farming practice the field is the smallest unite. Through spreading satellite GPS-systems we are able to determine our position on a given site at any time and continuously. As a result different plant growing treatments can be carried out on sites smaller than a field-size. E.g. it is possible to consider the differing physical and chemical soil conditions on a given site and to trace weed infestation and the damages caused by pests and pathogens within the field.

The available computer systems and as a result the collected data base by geo-information systems (GIS: Geographic Information System) enable us to make an overall picture about our agricultural area and we can make well supported economic decisions based on the collected information. Decision-making helps us to realize agro-technical treatments adjusted to the differences of the given arable site.

Plant protection, producing quality products, protection of our arable sites and last but not at least lower costs and higher economic efficiency support the use of precision farming in future widely. With the use of precision farming we can increase the intensity of production and reduce environmental pressure and at the same time we can increase the quality at lower costs as well. Applying the system on larger areas – on several thousand hectares - is also justified, because it can reduce the specific costs. It is obvious, that precision farming is one of the basic tools of sustainable farming nowadays (Pecze, 2001)

2. Positioning

Precision (site-specific) farming first of all aims to apply cultivation that is adjusted to time and space-condition, therefore accurateness of positioning systems is inevitable.

Site-specific farming does not only mean that we can give the position of the farm machines, but with coordinates we can also determine the accurate position of the sites where the samples were taken with different sensors. So after having decided about the necessary treatments we can return to the site of sample taking and data collection and we can carry out the required treatments at site. A good example is the yield-map that is made up by data collected at every second and that is a basic mean to precision farming practice.

Data can be processed either real-time or post. Based on the GPS-collected data we can also detect hidden links between the single characteristics.

EGNOS (European Geostationary Navigation Overlay System) system was launched as a precursor for the European Galileo programme some years ago, which helped to make geo-positioning more accurate. EGNOS satellites seem to stagnate if we watch them from the Earth, because they move on a geo-stationary course above the Equator at a height of about 36,000 km having the same angular velocity as the Earth. These satellites
broadcast corrected site positioning singles towards the users (like the US NAVSTAR GPS and Russian GLONASSZ). As a result they can achieve an accuracy of ± 1-2m on average which means a reliability of 95%..

We may assume that the RTK (Real Time Kinematic) systems with an accuracy of ± 2,5 cm will spread in farming practice in the future. Utilizing them we can carry out mechanical plant tending, sowing, application of plant protecting agents and fertilizers as accurate as we do it manually nowadays.


Global Navigation Satellite Systems (GNSS) have been controlled solely by the army so far but nowadays they offer their services for the civil users as well. At present the US NAVSTAR GPS (the acronym GPS is the abbreviation of its name) and the Russian GLONASSZ also transmit signals for civil users. The European Galileo-system has originally been designed for civil users only.

All the three systems have three sub-systems:

1. sub-systems of the satellites (space segment),
2. sub-system of ground monitor-stations,
3. sub-system of users (receivers).

Sub-systems of the satellites (space segment):

Designing the sub-system of satellites we should consider that ground monitoring stations have to receive the signals of at least four satellites to provide location.

<table>
<thead>
<tr>
<th>Sub-systems</th>
<th>NAVSTAR GPS</th>
<th>GLONASSZ</th>
<th>GALILEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of planned satellites</td>
<td>24</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Number of orbits</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Number of satellites per orbit</td>
<td>4</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Remarks</td>
<td>29 with reserve satellites</td>
<td>Due to financial problems altogether 15 satellites on 2 orbits</td>
<td>3 reserve satellites, planned: 2010-2011</td>
</tr>
</tbody>
</table>

Table 14.2: main characteristics of the presently used navigation systems

Sub-systems of ground monitor stations:

Ground monitoring stations of the three systems have the task to control (measure) the changes in the satellite orbits, to synchronize and to calibrate the clocks and to estimate the satellite orbit to be expected for the next 24 hours.

Sub-system of users (receivers):

Through the development of the global positioning systems there are more and more people that want to make use of the system. At user level the sub-system can only receive signals so there is a one-way-communication system.

3. Sample-taking strategies

The principle of site-specific sample taking includes marking the sites of sample-taking within the field of observation, where we do the measurements and the data of measurement (as reliable as possible) give us conclusions about the characteristics of the total area.

Sample-taking strategies can be as follows:
Traditional (randomly arranged) sample-taking:

Traditional sample-taking means soil-sampling per 5 hectares, possibly not on one single site, but samples were taken on 25 sites randomly arranged. The samples taken this way are mixed and the unified sample is analyzed, giving the base for the homogeneous treatment of the field. This type of sampling strategy does not enable us to consider the diversity of the field, there is a great chance to make a random failure and we cannot evaluate the changes between the times of soil-sampling therefore this method of sampling cannot be applied by precision plant growing.

Sample-taking alongside typical (management) zones:

This type of sampling takes the soil samples from area units marked by former experiences. Within the marked zones soil samples can be taken randomly, because they do not influence the values of the aggregated samples with alternating data. Management zones cover the whole territory of the field and make a precision treatment possible.

Sample taking according to chosen typical areas:

Based on former experience this type of methods marks individual areas on the field (e.g. based on soil maps or former yield-data), or direct sampling is also possible based on satellite images. It returns to these marked areas nearly every time when taking soil samples. This way we can trace the changes on the same part of the field. A disadvantage of the method is that it does not offer a complete image of the field and very often precision treatments cannot be carried out accurately. An advantage is that it is time and cost efficient.

Sample-taking alongside a grid:

Grid-sampling divides the field into treatment units and presumes that parts have similar soil characteristics within the treatment unit. There is no doubt that this method is labour and cost demanding, but it is necessary to site-specific treatments. A great advantage is that data gained between the sample taking times can be compared and can be evaluated according to different aspects (state of nutrient supply, environment protection etc.). Grid-sampling covers the field totally and no uncertain parts remain during the treatments.

Some sub-types of grid-sampling:

a) within the grid randomly

b) within the grid diagonally

c) in the centre of the area covered by the grid randomly

d) in systematic points

4. Remote sensing

Remote sensing is the acquisition of information about an object in our environment (mostly about the surface of the Earth) without making any physical contact with the object or phenomenon. Further more we should mention the analysis of the collected data together with professional, technical background. Remote sensing spread by using areal sensor technologies on satellites. This is one of the most efficient method of data collection.
5. Information systems that support agro-environmental management

GIS-based analysis presupposes the development of an integrated geo-information system. With the use of GIS-based analysis we can realize, track and prevent as well as reduce and eliminate some phenomenon on time.

Most important elements of the thematic modules in a multi-level information system that support rural development and agro-environmental management:

• registry and topographic systems of land branch,
• remote sensing based surface cover and culture-plant monitoring system,
• large-scale spatial soil information systems,
• aircraft based digital map-development system,
• as well as the agricultural support-control and checking system.

6. Future tasks to be carried out with the use of precision farming

6.1. Precision plant protection

The application of precision plant protection opened new perspectives in both the plant protection research and the plant protection practice. Precision plant protection can be seen as a GIS-based decision supporting system and way of farming, which considers the spatial heterogeneity of pest infestation at the arable site.

As it is well known the infestation of plant pathogens is very rarely homogeneous within a given area (field) their occurrence and spread is rather heterogeneous.

The aim of precision plant protection is to detect the varied damaging organisms accurately and to apply preventive technologies that can track this heterogeneous occurrence. Under extreme conditions we can find pathogens only on a very little part of the cultivated area, or the pathogen organisms are represented only under the threshold value, so we do not have to apply local treatments. With decisions like that we can save costs and reduce pesticide pressure on the environment (plant protection agents) considerably.

Precision plant protection includes three main activities:

• space and time data and phenomenon acquisition on plant pathogens and on plant protection with high accuracy,
• GIS based data processing and analysis,
• High level automated site specific field work

Whether the above three work processes are realized together on time and technical equipment or separately we can talk about on-line or real time realisation.

The main principle of the on-line method is that data acquisition is based on image-recording or detection. Further right after data analysis and processing we get the result, the process control command for the machine doing the treatment.

General scheme of a precision plant protecting treatment:

• Data acquisition
• Forming a decision logistic system (algorithm) f
• Selecting the system of equipment for application
• Application of plant protecting agents

**Precision weed control**

Applying precision weed control we consider the weed composition according to species and morpho-ecological groups on the investigated area. Investigations are carried out not only according to the aspects of chemical weed control, but also in all non-chemical applications (physical, mechanical etc.) belonging to the scope of integrated weed-control. It is almost indifferent whether process control is directed to a sprayer, mower or thermal equipment.

Generally we can say that it is reasonable to use precision methods in practice if there is a possibility to abandon local treatments due to the heterogeneity of weed population.

Weed survey should record the following criteria of weed species:

• Average cover
• Frequency
• Sequence of dominance
• Morpho-ecological spectrum
• Distribution of life-forms
• Ratio of mono-and dicotyledons

Steps of weed-control planning process:

• Marking the field contours by GPS
• Making a sample-division plan
• Visiting the sampling areas
• Weed-cover survey
• Evaluation of technological variants determining an ecological optimum
• Programming the weed-killing machine process control
• Carrying out the application
• Post-checking, data-saving

### 7. Precision soil cultivation

We can save much energy and costs if we apply a site-specific soil cultivation system. In the case of high energy-demanding treatments (e.g. loosening) it is first of all important to determine the necessity of cultivation and to measure soil compaction according to the scale of heterogeneity.

Soil compaction is one of the most frequent soil defect, which can be led to technological or cultivation failures in most of the cases. In spite of the fact that soil compaction shows typical and well recognizable symptoms (water stagnation, crusting etc.), they are generally detected too late only if plant stock shows the stress symptoms. It is basically important to recognise the scale and site of compaction so that we can eliminate it and apply a site-specific soil cultivation method.

### 8. Site-specific application technique

„Variable-rate application” (VRA) is the name of the process through which we apply propagation material, fertilizer and plant protection agents etc. according to the site-specific requirements within the field. The technology, which carries out VRA, is called variable application technique.
VRA can be:
• Map based VRA: Application is based on prefabricated electronic map
• sensor based VRA: The application is controlled by signals transmitted by real-time sensors

Elements of a system suitable to controlled application:
• VRA-sensors
• Positioning system
• Signal processing-regulating unit
• actuators

Types of VRA-sensors:
• detection
  • soil and plant sensors
• control
  • pressure gauge
  • flow-meter
  • tachometer

Detection (soil and plant) VRA-sensors measure the following factors:
• soil organic material content,
• soil moisture content,
• reflections from crops and weeds
• soil nutrient supply

Sensors operating on the principle of reflection are suitable to distinguish soil and vegetation. Soil and the different green plant parts reflect at different wavelength (selective spectroscopy). Similarly unhealthy plants or those showing the symptoms of nutrient deficiency reflect the light differently than the healthy ones.

Pressure gauges in sprayers transmit electric signals proportionate to the liquid pressure. They are used to measure the pressure of liquids if we apply liquid materials.

Flow-meters measure the quantity of liquid flowing through a given cross-section at a time unit. They can measure mass-flow or volume-flow as well.

Tachometers measure the rotational speed of an axis. Sensors like this suit to determine the rotational speed of an axis, but they do not give accurate results for driving speed, because there could be a slip when the wheel contacts the soil. Tachometers using radar or ultra-sound technologies principally measure the driving speed more accurately on the basis of radio or sound waves reflection independent from slipping, although at lower speed their accuracy is lower too and the existing crop can disturb detection as well.

Signal processing and regulating unit determines the quantity to be applied. Microprocessors receive the signals transmitted by the sensors and calculate the actual applicable quantity with the help of a stored algorithm on the move. Principally the algorithm compares the inputs coming from the sensors and the map with the outputs.

Actuators: give an adequate response to the signal of the regulating unit (open-close, turn the axis etc.). They give a response to electric, pneumatic or hydraulic signals.
9. Questions:

• Compare the major elements of traditional and precision farming!

• Describe the technical background of precision farming!

• Why sample-taking is important?

• What are the major application areas of precision farming?
Chapter 15. Nutrient supply and cultivation

1. Aim and importance of fertilization and nutrient supply

Fertilization means directly the supply of crops with nutrients and indirectly the increase of the soil fertility.

Characteristics of soils of good fertility:

Soils greatly differ in the respect how they can satisfy the needs of the plants. Natural fertility of most soils can only facilitate moderate yields, but they can be improved by different treatments.

Soil fertility is the composition of different attributes:

• Depth of the soil layer (determines the soil volume, which is available for the root system). Most arable crops require a soil layer of about one metre without layers that hinder root development.

• Soil structure: Soil structure determines pore density and distribution that is inevitable for water and air supply to the roots.

• Soil reaction is the regulator and indicator of chemical processes and nutrient decomposition.

• Soil nutrient content, which includes the nutrient fraction that are available for the plants at different rates.

• Nutrient storability is the capability of the soil that can store nutrients in available forms that derive from fertilizers and nutrients that are not so easy to uptake from fractions.

• Humus content and quality.

• Sufficient number of soil organisms, which can assure efficient nutrient decomposition.

• Low level of toxic materials in the soil (e.g. high salt content in saline soils, Al in extremely acid soils, pollution induced by human activities).

Fertile soil has the following characteristics:

• mobilizes nutrient reserves,

• turns the nutrients in fertilizers into easily available forms,

• fixes the easily available fractions with sufficient power in order to protect them against leaching,

• assures balanced nutrient supply through self-regulation,

• stores and assures water for the crop at enough quantity,

• maintains a good rate of water and air for the roots,

• fixes nutrients in easily available form.

2. Most important nutrients in the soil and crop and their role

2.1. Macro-elements

Nitrogen
Nitrogen is the most important matter of proteins and proteids in living organisms. Nitrogen is the most important yield determining factor.

Nitrogen content of mineral soils varies between 0.02 – 0.4%. Higher plants are autotrophic as for carbon but regarding N this is not so. Atmospheric N provides N-reserves for the life on Earth, which can enter into the biologic cycle in two ways. The primary and natural way is the microbial N-fixation and the second possible way is the production of fertilizers.

N-cycle happens in nature in three steps:
- N-fixation
- Nitrification
- Denitrification

N-fixation
N-fixing free and symbiotic microorganisms fix atmospheric N. The quantity of N fixed by free N-fixing bacteria is not significant. The quantity of N fixed from the atmosphere may amount about 20-40kg/year according to measurements and assessments.

N-fixing bacteria living in symbiosis with leguminous plants fix much more nitrogen than free living ones. Different Rhizobium species are symbiotic N-fixing bacteria. Rhizobium species live in symbiosis only with definite legume species. Therefore we classify the 16 known nodular root building bacterium strains into 6 groups.

Nitrification
N-compounds to found in the soil, in plant residues and manures are decomposed by micro-organisms into inorganic formula.

N mobilized by mineralization can reach 1-2 %- of the yearly organic N-content. The rate of N-mobilization is influenced by C/N ratio. N-immobilization occurs at C/N ≥ 30 on average.

Denitrification
Denitrification causes N-loss as much as 15-30%. Through nitrite → nitrate → ammonia → molecular N transformation process N fixed symbiotically or by the industry gets back into the atmosphere and can be reused again by plants through the processes described above. Denitrification is the nitrate-N reduction process which results in N (N2) in gas form. The process is done by denitrification bacteria. The process is intensive if there is no air in the soil and the soil is neutral or alkaline and there is a great amount of organic material in the soil. Then bacteria use up the oxygen of the nitrates to oxidize organic material.

N-deficiency and –surplus in the plants
Symptoms of N-deficiency occur early and are clear. The plants do not reach the normal height, we can observe dwarfism. A typical symptom is the so called rigid halt, which can be observed not only on the stem but on the leaves as well. N-deficiency causes carbohydrate surplus in the plant metabolism, which result in anthocyanin forming. N-deficiency inhibits chloroplast and chlorophyll synthesis, which result in light green and yellowish-green colour and turns into yellowing when N-deficiency increases.

Most important N-fertilizers
Ammonium-nitrate – NH4NO3
This is the most commonly spread solid N-fertilizer. It contains 34% of N theoretically. Its advantage is that it contains nitrogen in the form of ammonium and nitrate at a rate of 50-50% respectively. Plants are able to utilize both nutrient ions, therefore no unfavourable companion ions remain in the soil.

Lime and ammonium nitrate – NH4NO3 + CaCO3 or CaMgCO3
It is marketed under the names of „Pétisó” or „Agronit”. Both have ammonium nitrate as agent, which is mixed with lime in Pétisó and with dolomite in Agronit. Pétisó has an agent content of 25, and Agronit 28%.

**Ammonium-sulphate – (NH4)2SO4**

This is one of the longest known N-fertilizer. Before it could have produced synthetically it had been produced of coal as by products of coke and gas production. It contains 21.1 % N-theoretically. This fertilizer has the highest acidifying effect, because the total N quantity is present in the form of NH4+-ions.

**Urea**

It is an organic N-compound. This was the first organic, biological origin material that could have been produced in a laboratory (Wöhler 1828). In 1920s industrial production started. This is the most concentrated solid N-fertilizer, its theoretical N-content amounts 46.6%. Its pH-value is physiologically light acidic. Plants utilize its N-content in the form of ammonium as well as nitrate compounds.

**Phosphorus**

0.75% of the earth crust consists of phosphorous. We can find 0.02-0.1% of it in the soils, which is greatly influenced by the mother rock. Soil phosphorus is in organic and inorganic bonds. Their ratio is about 50-50%.

Original soil inorganic phosphorus content is built up from the bulk crystals of hard soluble hydroxyapatite - Ca5(PO4)3OH - and even harder soluble flourapatite - Ca5(PO4)3F - and only by very slow physical-chemical weathering process.

Water soluble mono-calcium-phosphate – Ca(H2PO4)2 – and citrate-soluble di-calcium-phosphate – CaHPO4 brought to the soils through fertilizers can transform into harder soluble phosphates in the soil relatively quickly.

**P-deficiency – surplus in the plants**

Similarly to N- P is also an essential building stone of the cells. Phosphate ion is the structural element of materials that regulate life processes and transmit genetic information further on they play an important role in the form of ADP and ATP in the energy household and metabolism of the cells.

P deficiency produces in nearly every plant species the same not very typical symptoms. Plants showing P-deficiency – if the growth-prohibition is not obvious – in most of the cases shows the symptoms of N-surplus, or optimal nutrient supply. “Rigid halt” is typical for P and N-deficiency besides prohibited growth. P-deficiency goes together with anthocyanin-formation, which can result in reddish colorization depending on the basic colour of the foliage. Symptoms occur first on the older leaves.

Phosphorus-surplus– differently form N – occur under open-field conditions very rarely, because phosphate ions are strongly bound in the soil. Large P-doses can endanger Fe- and Zn-supply of plants.

**Most important P-fertilizers**

Raw phosphates

Raw materials of producing phosphor fertilizers (apatites, phosphorites) can be used for P-fertilization alone as well.

Mono superphosphates

Liebig produced it in 1840 through dissolving bone-flour by sulphuric acid. As a result water-soluble Ca-phosphate is produced. Mono-superphosphate are produced by dissolving fine ground raw phosphates in sulphuric acid of 62-67%, as a result we receive mono-calcium-phosphate and water-free Ca-sulphate – the superphosphate.

**Concentrated (enriched, double, triple) superphosphate**

If raw phosphate is produced by the mixture of sulphuric-and phosphoric acid the result is an enriched superphosphate. P2O5 content is 18-36% depending on the ratio of the two acids. The production of so called double and triple superphosphate happens through dissolving in pure phosphor-acid. The agent content depends on the P-content of raw phosphates used in the second phase.
Potassium

Potassium deferring from nitrogen and phosphorus is not a building element of organic materials. The role of K+ ions is important in their effect on swelling plazma-proteids and proteins as well as enzymes i.e. in structure stabilization and activation. K+ ions activate more than 40 enzyme reactions mainly during the formation of protein and carbohydrate compounds of high molecular weight. As an effect of potassium plants can retain more water so they can better survive short term drought.

Potassium deficiency and-surplus in plants

The first visually detectable symptom of K-deficiency is the so called state of “drooping” the cause of which the disturbed turgor-control due to K-deficiency.

Initial K-deficiency occurs in prohibited growth, which later on totally stops, because the plant cannot mobilize the easily moving K from the elder leaves quickly enough to cover the high K-requirements of shoot-meristem and younger leaves totally.

If there is a K-deficiency mobile K+ ions efflux from older leaves therefore the first visual symptoms occur on older leaves.

Most important K-fertilizers

Similarly to phosphorus fertilizers the raw materials of K-fertilizers are minerals, too. An important difference is that their production is simpler and easier after definite mechanical cleaning than that of raw phosphates.

Potash of 40% - (KCl, KClNaCl)

It is produced by mixing finely ground sylvite with potassium-chloride. The K2O-content of the mixture is about 38-42%. Potash of 40% is a fertilizer with favourable effect for plants giving a positive response to Na (e.g. beets).

Potash of 50 or 60%

During production KCl has to be separated from NaCl. The reason is that solubility of the two salts differs with the changing temperatures.

Potassium -sulphate (K2SO4)

It is produced by exchanged decomposition of concentrated KCl and MgSO4 solutions. Its agent content is 48-52%. It is advisable to apply it in chlorine-sensitive crops (potato, tobacco, and grapes).

Calcium

Ca-content of inorganic soil is very high compared to the quantity of other cations that are very important for plant nutrition. Being either as a part of crystal lattice or hard soluble salt, Ca gets free during the weathering processes very slowly and has a role in soil farming processes.

For the soil fertility it is important that sorption complexes be saturated with Ca2+. This state of condition assures long-lasting crumbling structure. Furthermore Ca-ions being fixed to the sorption complexes or being free in the soil assures an easily available Ca-source.

We should distinguish between the tasks of Ca2+ in the soil and in the plants. In this respect Ca2+ as a fertilizer has greater significance. Soil life, crumble stability and soil forming and decomposing processes require to adequate function much larger quantity of Ca that needed by plans to their life cycles. Liming means first of all soil fertilization. If we can maintain the soil’s Ca-household with liming then we assure enough Ca-nutrition for the plants, too.

Magnesium

Mg behaves in the soil similarly to Ca in many respects. We can find it in several minerals (biotite, serpentine, vermiculite, chlorite and olivine). Further more its carbonates and the dolomite are also very important Mg-containing elements of the soils.
Nutrient supply and cultivation

In plants Mg as an important component of chlorophyll has an important role in assimilation processes. Besides its structure forming it is a very important enzyme activator, too therefore Mg-deficiency is accompanied by restricted assimilation as a result of reduced phosphorylation. Good Mg-supply increases the photosynthetic activity. It also has a role in forming of carbohydrates. If there is a deficiency carbohydrate content of plants (e.g. starch content in potatoes).

**Sulfur**

Similarly to nitrogen sulphur is an essential component of amino-acids, peptides and proteins. There has not been any S-deficiency in our country so far, because, S-requirements are abundantly covered by applied fertilizers and atmospheric deposition. At some parts of the Globe e.g. in USA and Australia S-deficiency had earlier been detected and considerable higher yields were produced as a result of S-fertilization. Through the application of more concentrated P-fertilizers and reducing S-deposition from power plants soils S-reserve would be not enough and plants should be supplied with S adequately.

### 2.2. Microelements

**Iron**

Its role in plants is based on valence change, through which it regulates enzymatic reactions. Most important iron-containing enzymes include cytochromes, peroxidases and catalases. Further more it takes part in respiration, energy exchange, photosynthesis and protein building.

Inorganic iron salts applied for soil fertilization do not bring any result generally, but we can expect a positive effect if apply Fe-chelates on the leaves or acidic fertilizers.

**Manganese**

Manganese functions as an enzyme-activator in plant-life cycle. Its role is similar to Mg and Fe. In the soil it occurs fixed to silicates, carbonates and oxides in the form of di-, tri- or four monovalent. Manganese benefits the formation of carbohydrates in plants. Sugar-beet supplied well with Mn produces higher sugar content. Oats is sensitive to Mn-supply, Mn-deficient plants show the symptoms of “dry-leaf-spot” including spinach and rice.

**Copper**

Cu promotes the synthesis of carbohydrates and proteins, protects the chlorophyll against too early decomposition. Soils of high organic material content, sandy podzol soils are poor in copper. Oats, barley and wheat are most susceptible to copper-deficiency. Cu-deficiency has a negative impact on the formation of generative organs. Insufficient Cu-supply results in bad development of billet and spike and spikes remain empty.

**Zinc**

It has an enzyme-activator role in the life cycle of plants. It activates peptidases in the protein metabolism. It stimulates auxin-production in interaction with Mn.

It occurs in plants in very low quantity, but this is much higher than the Cu-content. Its uptake is influenced by the pH-value and the phosphor content. We know more enzymes (e.g. enolase) that can be similarly activated by Mg2+, Mn2+ and Zn2+ ions. Zn specifically activates dehydratase and peptidases.

Maize, hop, flax, beans and fruit trees react on Zn-supply especially susceptibly. Zn-deficient apple trees have the decease of dwarfism.

**Molybdenum**

In spite of the other microelements plants can uptake Mo- in much larger quantities without toxic effects. Fixation in acid soils can cause Mo-deficiency. Cruciferous, brassicae, cauliflower, Brussels sprout have high demand on Mo. Dicotyledons have higher demand on Mo than monocotyledons. Mo is required to facilitate the activity of bacterium radicicola on the roots of legumes, which can be explained by its role in the activity of nitrate-reductase enzyme.

**Boron**
Boron is the only precious metal element among the essential micro-elements. Its mechanism has not been cleared completely yet, but it has a role in carbohydrate formation and assimilation processes. It greatly influences the quantity and quality of yield through its effect on flower and yield formation. It increases the sugar content of fruits and sugar-beet and the starch content of potato. B has an important role in carbohydrate metabolism and assimilation. Good B-supply assures the undisturbed process of photosynthesis through promoting carbohydrate-transportation.

2.3. Planning the nutrient supply

Economical and professional nutrient supply can only be facilitated if we know the soil nutrient content and its agrochemical characteristics. Planning fertilizer application we should consider the following aspects:

• Nutrient-supply of the different plants and the adjusted method should meet the requirements of the soil of the arable site;
• If we apply fertilizers we should provide the quantity of nutrients that plants require during vegetation, as well as the quantity we harvest with the crop and by-products (straw, stalk, beet-top etc.);
• Available nutrients in the soil should not reduce and they should only increase at a rate which is not damaging to the soil to the soil cultural condition and the environment.

Fertilization directives of the Plant-protection and Ago-chemical Centre were established by considering these aspects. We summarize the principles of nutrient supply and introduce an example of application as follows:

MÉM-NAK Advisory System

Steps to be carried out in the application of the system:

• Determination of arable field sites,
• Planning the quantity of yield,
• Planning the level of nutrient-supply of the soil,
• Determining the specific demand on the agent,
• Determining the demand on the fertilizer agent of the planned crop yield,
• Corrections,
• Planning the application

1. Determining the arable field site

We determine the soil type and agronomic characteristics of the field ad categorize it as one of the possible arable sites.

• Chernozem soils
• Brown forest soils
• heavy meadow and gley forest soils
• sandy and light soils
• saline soils
• soils with shallow fertile layer or heavily eroded sloping soils

2. Planning the quantity of yield
To plan the quantity of yield we consider the yields of the previous 5 years. To do this we can use yield level limits summarized in tables, which provide the yield limits that can reasonable planned for the individual filed sites.

3. Planning the level of soil nutrient-supply

Based on data of soil analysis we can determine the nutrient supply of the categorized field in respect to N-, P2O5- and K2O-content.

4. determining the specific demand on the agent

With the help of the soil nutrient content we can select the specific fertilizer demand of the field crop to be grown from the table.

5. determining the fertilizer agent demand of the planned crop yield

We can calculate the fertilizer-agent demand of the planned crop yield if we multiply the specific demand on fertilizer agent and the quantity of the planned crop yield.

6. Corrections

Factors listed below modify the calculated demand on agent:

- **Effect of the pre-crop**
  - reducing effect of leguminous plants on N-demand: except for arable sites IV and VI on soils with moderate or better nutrient supply, as well as in case of legumes with yield levels higher than moderate the calculated N-fertilizer agent after one-year legumes can be reduced by 30 kg/ha, after perennial legumes – in the first year – by 50 kg/ha. In case of alfalfa we can calculate with a deduction of further 30 kg N/ha in the 2nd year.
  - Ploughing high mass of organic materials (maize, sunflower or other crops leaving high amount of stalk mass and plants of wide C:N ratio: we deduct the K-content of the organic material content from the calculated K-fertilizer agent, we have to calculate with especially in the case of maize stalk 5-10 kg K2O/t of harvested grain crop, sunflower 20-30 kg K2O/t of harvested achenes, winter wheat-straw – either ploughing in or stubble-burning – 5-10 kg/t of harvested grain crop. In order to decompose organic material in time and on arable sites IV, V and VI we have to mix 0.8 kg N to every 0.1 t of dry matter (calculated from the quantity appropriate to the harvested grain crop), i.e. we have to increase the calculated N-ratio with this quantity, if it does not reach the quantity of 150 kg N/ha. On better arable sites, and if we exceed that level we can abandon nitrogen complementation.

- **Effect of farmyard manure application**
  Nutrient supply of moderate quality bedding manure:
  - In the first year: 15:15:40 kg (N, P, K)
  - In the second year: 10:10:20 kg (N, P, K)

- **Effect of irrigation**
  If we produce with irrigation we can reduce the NPK-fertilizer agent demand of the planned yield by 15-20 % on arable sites I, II, and III with fields of nutrient supply better than moderate.

- **Effect of damaging chemical characteristics of the soil**
  If the lime content of the soil is higher than 20% or its pH(KCl) value is below 5 we need to increase the calculated quantity of P2O5 (in case of superphosphate fertilizer) by 15-20% at any rate of supply.

7. Planning the application
The calculated fertilizer agent doses should be re-calculated for the actual fertilizer available before application and considering the content of agent. We plan the distribution of fertilizer doses i.e. the quantity of applicable basic and top-fertilization.

3. Questions:

• What are the major characteristics of a fertile soil?

• Present the role of nitrogen in plant nutrition, N-fertilisers.

• Present the role of phosphorus in plant nutrition, P-fertilisers.

• Present the role of potassium in plant nutrition, K-fertilisers.

• List the most important trace elements.

• What are the major steps of the calculation of fertiliser requirements?