Soil Tillage in the Tropics and Subtropics

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Soil tillage is an integral part of crop production. The aim of these farming operations should be to influence the biological, chemical and physical characteristics of the soil in such a way as to create the optimum conditions for the germination and development of the plants.

These operations should also take account of the conservation and improvement of soils as an environment for the plants' growth to ensure high yields in the long term.

The second objective is equally important but is often difficult to achieve in both humid and dry tropical regions. Soil tillage consists of mechanical manipulation of the complex and sensitive "system" soil. The effects of this manipulation may be particularly pronounced in tropical and subtropical climates. The risks involved should be suitably recognized when planning and carrying out tillage operations: a greater danger of soil erosion by wind and water, increased destruction of organic matter and more evaporation losses, especially in areas with summer rains. High levels of salinity - often linked with high pH values - and the constant input of salts with the irrigation water cause further problems in the soil in these climatic zones.

The delicate balance of the soils - often characterized by a high degree of weathering - can easily be disturbed and produce serious and usually irreparable damage. Many steppe and desert regions have not been created by nature but by man and provide examples of incorrect land-use and soil tillage. Crop production is more problematic in tropical and subtropical climatic conditions than in temperate humid climates. In the latter zones mistakes in soil tillage can - to some extent at least - be remedied by the action of frost, low evaporation and reduced plant activity in the cold season.

Many cultivated plants derive from regions which are ecologically different from their present region of production. Breeding aimed principally at high yields results in plant varieties which make heavy demands upon their environment. When competing with weeds which have become properly adapted to their habitat, these crops cannot survive without protection and assistance from the farmer.

In this book we can present only a general framework within which the soil system is constantly protected in order to obtain an optimum environment for plant growth. We also describe technical equipment and systems for use in solving the complex problems.
For further reading, literature is given at the end of each chapter. It is obvious that soil tillage is a multi-disciplinary science, closely linked with soil science (physics), agronomy, economics as well as agricultural engineering.

2.0 THE OBJECTIVES OF SOIL TILLAGE

2.1 Some General Comments On Soil Tillage

Plants require an environment in which nutrients, water and air are available for their development, growth and reproduction. Leaving special cases aside (hydrocultures, greenhouses, etc.), the large majority of farmers has to cope with annual plants, growing in a natural soil in the open.

A soil can be regarded as a system, in which solids with certain textures (the soil minerals, i.e. clay, silt, sand, gravel and rocks), water (with dissolved solutes), air and organic matter are arranged in a specific form, known as structure. Plants develop best when they are able to extract the necessary elements - water, nutrients and air - from this soil system through their roots. Unless the temperature of the soil is a restrictive factor (excessively high temperatures may occur in tropical climates), the only important factor in the initial phase is the availability of water, enabling the seeds to germinate.

If the above conditions obtain, there is no reason for any manipulation of the soil. In their natural environment, plant species were able to survive in a balanced ecological system (competition) without any human interference. The introduction of a specific plant or crop does, however, inevitably disturb the balance; planting or sowing becomes necessary and the soil has to be opened up and even in the most primitive stage, be trodden. If one species is grown for production, all the others can generally be considered as weeds and will have to be eradicated (owing to their competition for light, water and nutrients). This too is an operation during which the soil has to be trodden and sometimes disturbed. The same applies to the harvesting operations.

Needless to say, this represents a typical example showing where certain manipulations in agricultural systems may cause adverse effects to the agricultural soil. Shifting cultivation inspite of certain advantages also can be detrimental to the agricultural development. Introduction of animal draught and motor traction does have advantages, such as faster and easier work, but also disadvantages, such as the risk of deterioration of the soil. In Modern Agriculture the soil has to serve, firstly, as an environment for nurturing young sensitive seeds and seedlings, and secondly, as a surface for carrying many tons of weight in the form of tractors, trailers and other implements.

The above paragraphs should clearly show that many of the objectives of soil tillage mentioned in the following pages ar "self-induced".

2.2 General Tillage Objectives

Although tillage has been practised for millenia all over the world, the reasons for applying it merit some discussion. Soil tillage is one of the operations performed in arable crop production whose objectives form part of the production process, but where the direct results differ from these objectives.
The aim of arable cropping may be to produce the maximum yield of certain crops, a special quality of a crop or the highest possible financial return. When the crop is not sold and labour is not paid - as in subsistence farming

- we have to weigh up the benefits obtained from the crop against the amount of work required rather than discuss the process in terms of costs and returns.

The financial benefit obtained from crop production is obviously the final outcome of a complicated process depending upon many variables, such as the type of crop, soil-type, climatic conditions, type of farming, standard of mechanization, prices of crops, implements and inputs, interest rates and tax, and soil tillage is one of these variables.

Two aspects need to be emphasized in this connection:
1. A change in the proportion of tillage costs usually leads to a considerably smaller change in the proportion of total production costs.
2. Tillage may influence other production costs.

Both aspects may be very important. For example, a 20% reduction in tillage costs saves only 2% of the total production costs when tillage accounts for 10% of the total input. The actual proportion of tillage costs in the total costs depends upon the input of each production factor, such as water (irrigation), fertilizers, chemicals, etc. A mere 2% saving is insufficient to persuade farmers to adopt a new soil tillage system, especially if no higher yields can be expected or an increased risk is possible. As regards the second aspect, tillage operations are in fact often intended to facilitate other field-work by changing the structure of the soil. For instance, it is usually easier to sow in a seedbed than on untilled soil, or the construction of a ridge with a very small number of clods may considerably reduce the work required for harvesting tuber crops.

So, when analysing the ways in which tillage may influence crop growth, we should distinguish between its effect upon the soil structure and weed population and the effect of the soil structure and weed population upon crop growth.

As far as the soil structure is concerned, it should in theory be possible to predict the tillage effect of any specific implement if the soil and performance parameters are adequatly described. This would permit a description of the soil structure in terms of its bulk density, structural homogeneity and strength (see Fig. 1). When describing the relationship between soil structure and crop growth, other aspects of the soil structure, such as air, water, temperature and mechanical resistance, are relevant. The relationship between these two groups of structural features should be established if the connection between tillage and crop growth is to be understood. The farmer generally knows from his experience what the effect of a certain soil structure (as a result of tillage) will be on the growth and development of the crop.

The relationship between tillage prior to crop growth and the yield at a much later date is generally so complex that a clear connection between tillage and yield can be expected only when a specific restrictive growth factor is affected by tillage. The relations within a production system are shown in diagram form in Fig. 2.

The influence of tillage upon other field-operations is not necessarily restricted to one growth period. In tropical regions in particular, the long-term effects of tillage must be given consideration. For example, if a tillage operation for optimizing the sowing conditions increases soil erosion by creating a soil structure susceptible to erosion, this damage is an indirect result of the tillage operation. Since the effect may continue for many years, that operation is likely to have a detrimental effect upon economic yield.

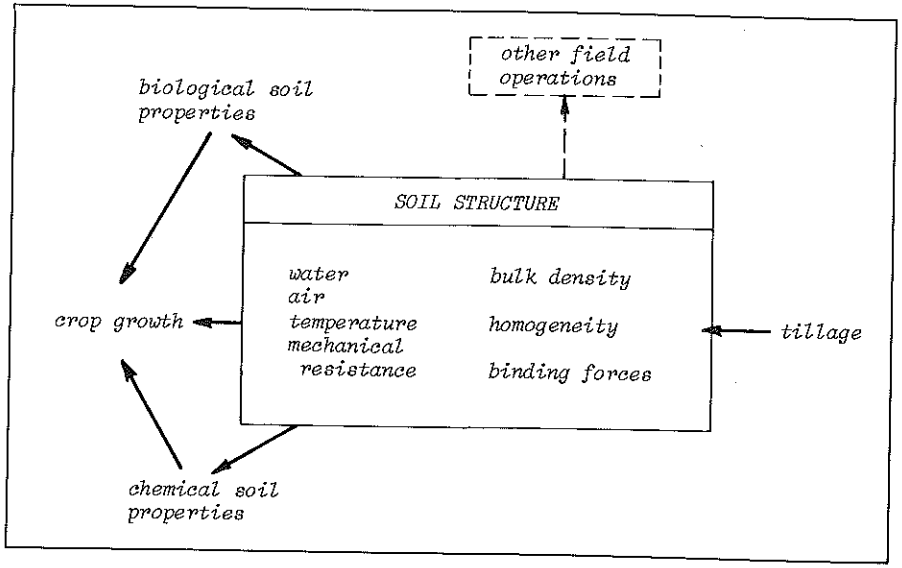

Fig. 1. Soil tillage and its sphere of influence on soil structure. - Source: Curfs.

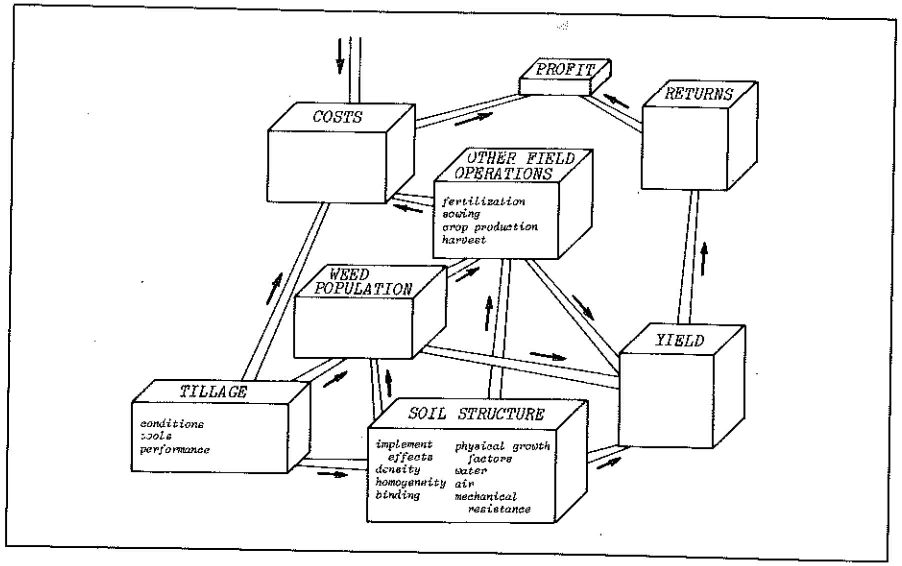

Fig. 2. Scheme of soil tillage objectives. - Source: Kuipers.

2.3 The Objectives Of Groups Of Tillage Operations

Different tillage operations have different purposes. Generally speaking, there are four groups of tillage operations which, in a complete system, are performed in the following sequence (see Fig. 3):

a. Stubble or post-harvest cultivation. This consists of shallow operations carried out shortly after the harvest to clear the field of weeds and crop residue and to restore the soil structure. This group also includes tillage during fallow periods (for water conservation, weed control and improvement of the soil structure and fertility).

b. Main (primary) tillage. This is normally the deepest operation which is performed during the period between two crops to control weeds, restore the soil structure in the arable layer where most of the roots will develop and to prepare the land for seedbed preparation.

c. Seedbed preparation. These shallow operations are intended to prepare a seedbed or make the soil suitable for (trans)planting. They include weed control and structural improvement for germination and early growth.

d. Crop management tillage operations. These are very shallow operations controlling weeds, breaking up surface crusts to improve water infiltration and crop emergence and for forming ridges which encourage early growth and facilitate the harvesting of root crops.

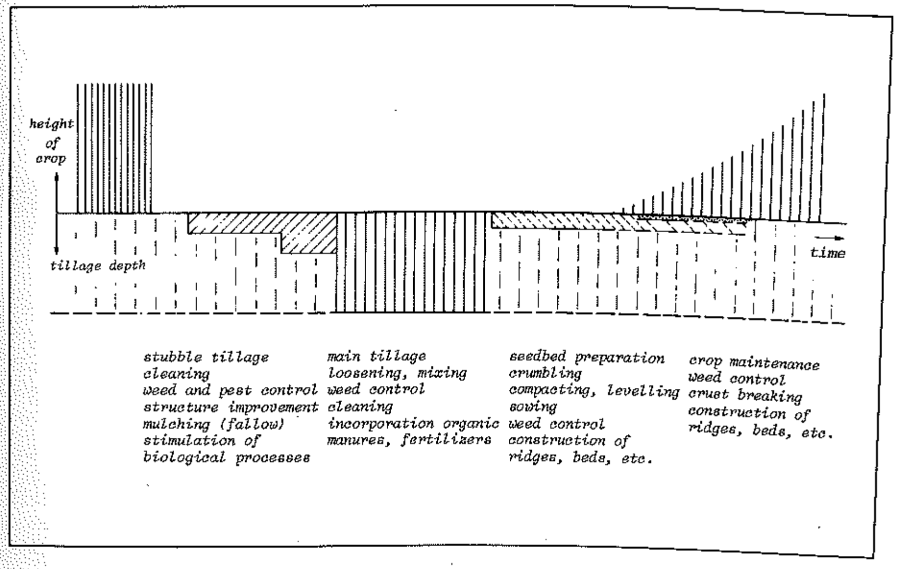

Fig. 3. Soil tillage practices during a cropping season. - Source: Kuipers.

A complete sequence of tillage operations may not be necessary or not possible because the interval between the two crops is too short or the circumstances unfavourable; in such cases the system is simplified while still achieving maximum efficiency.

"Incomplete" systems are very common in tropical regions. In particular, groups (a) and (b) are often combined to form one "stubble tillage" operation. In the case of rice production on flooded fields, groups (a), (b) and (c) may be performed as one set of (puddling) operations while the crop management tillage operations may be omitted.

Although soil tillage generally has the same aims irrespective of the climatic conditions, the priority of the various objectives differs. High and stable crop yields can be achieved only if the soil tillage system employed is suitable for the region and adapted to the cropping and production system.

Soil tillage can be defined as a sequence of mechanical manipulations of the topsoil in which all the operations are dovetailed and adapted to the overall production technology. Three principal objectives can be mentioned:
- Elimination and permanent control of the original vegetation (often considered as weeds);
- Creation of conditions favouring the germination, emergence and growth of the cultivated plants;
- Conservation and improvement of the soil as the growth medium for cultivated crops.

2.4 Some Mechanical Aspects Of Soil Tillage

From the physical point of view tillage is exerting a pressure on the soil system. This pressure is somtimes applied merely to create tensions elsewhere in the soil matrix. The pressures vary widely in magnitude and direction and depend upon the dimensions of the soil/tool contact area. These processes rarely last more than one or two seconds and may be so brief that they can be defined as an impact.

The soil moisture content has a major influence on its strength or consistency, and thus on how the soil will react to a certain (type of) pressure. Fig. 4 summarizes the various consistencies as the moisture content changes.

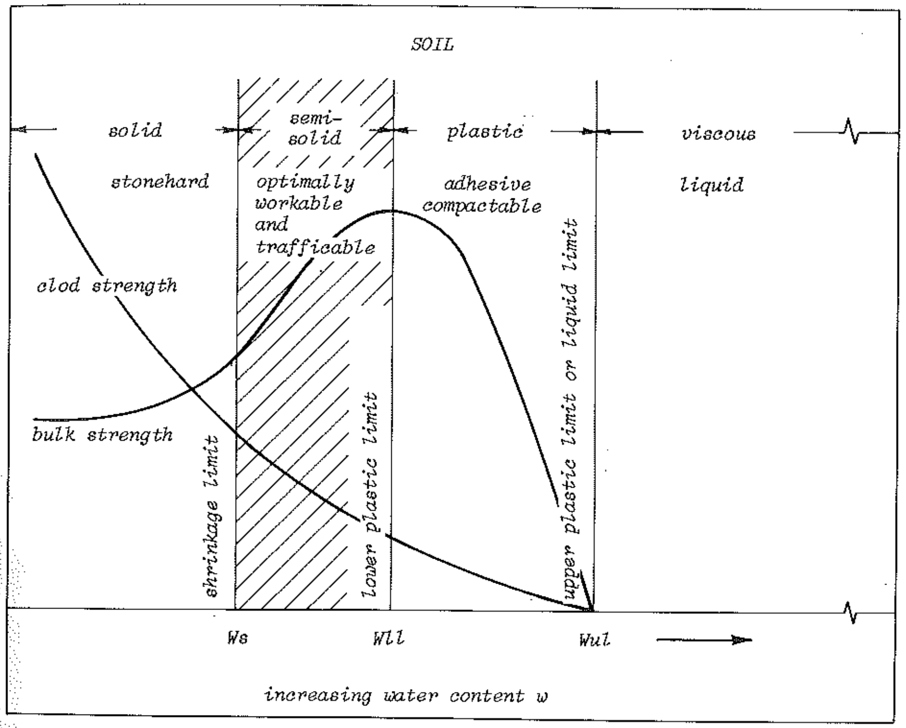

Fig. 4. Effect of moisture content on the consistency and workability of the soil.

The way in which the soil reacts to pressure determines the effect of the tillage operation. The following types of basic reactions can be distinguished:
- reduction of volume (compaction),
- cutting,
- shear plane formation (crumbling, pulverization),
- transport,
- deformation.

Compaction will occur when soil is subjected to pressure and the resistance to volume reduction is less than the energy required for plastic flow or other reactions. A cohesive soil (e.g. clay) is compacted by stress (depending upon the duration of the stress), while a friction soil (e.g. sand) is compacted by vibration (packing of particles). Compaction occurs, for example, when the soil is loaded by rollers or tractor wheels. Rollers are intended to produce compaction while, on the other hand, compaction caused by traffic is usually undesirable. Compaction caused by traffic is one of the more serious problems of highly mechanized agriculture. Some aspects of this problem are examined in the following chapter.

The shape of the roller is important for efficient compaction of the soil. Rollers with small diameters and large surface areas compact the soil more shallowly than narrow wheels with large diameters. Spike rollers cause high pressures over small areas and are effective for compacting at greater depths, especially when moving at slow speeds.

Cutting often occurs during tillage and is part of operations such as ploughing, rotary tillage and weeding. The determinant factors are the speed (impact) and the cutting angle of the knife or tool. When the angle is too large ("blunt"), damaging side-effects, such as smearing and compaction, may result.

Transport. Soil is transported in some way during each tillage operation. This process is most evident during ploughing but some movement of the soil occurs during rolling, weeding, etc. Soil transport may be intentional and desirable to produce a specific surface configuration (e.g. levelling or the formation of ridges), mixing (e.g. harrowing causes selected downward transportation of smaller agregates) or inverting (e.g. mouldboard or disc ploughing). In some cases soil transport has damaging effects: when the soil is very hard, clods or aggregates will not be broken up under the pressure of an implement but will be moved forward or sideways, an unnecessary useless movement of the soil which reduces the efficiency of the implement (bulldozing effect).
The formation of "back" and "dead" furrows when using two-way ploughs is also harmful when a level field is required.

Shear plane formation. When the soil moisture content is favourable, pressure may cause the formation of cracks and the subsequent breaking-up of clods or aggregates. Soil will break up along natural planes of weakness. Depending upon the tillage intensity - the number of pressure points in the specific volume of soil at any particular moment - the result will be the formation of large clods (when ploughing dry soils, low intensity) or fine material (rotary tillage, high intensity).

Deformation of the soil should usually be avoided since it destroys the (micro)aggregate structure of the soil. The only exception is the complete destruction of the soil structure caused when puddling wet rice fields by applying intensive tillage under saturated conditions. In every other case deformation has detrimental consequences. The soil becomes denser and harder after drying, which causes serious problems with regard to its permeability for water and air and its resistance to root growth.
Deformation will occur when the soil is in the plastic consistency phase (see Fig. 4). As examples, we can cite the ruts formed by traffic in fields which are too wet and the "sausages" brought up by chisel ploughs when the (sub)soil is too wet.

The above clearly shows that the soil consistency, which depends upon its moisture content, is a major factor in determining the effect of tillage operations. The term "workability" is used in this connection to indicate two characteristics:

A. The soil's suitability for tillage or for facilitating tillage operations. The optimum workability range (expressed in moisture content) is given in Fig. 4. Workability is good when this range is wide but when it is narrow or commences at a level where the moisture content is much lower than the field capacity (the soil condition a few days after rain), the workability is poor because tillage cannot start until the soil has dried for a considerable period after the rains.

B. The condition of the soil at any given time, determining whether or not it can be tilled without serious damage. A decision for or against tillage depends not only upon the soil workability but also upon the "trafficability", that is to say the soil's capacity to carry the weight of a tractor (animal) and machine. When drying conditions are strong, the topsoil may be dry enough for seedbed preparation but the subsoil may still be too wet and unable to bear traffic. The optimum workability or trafficability depends very much upon the type of tillage and the machinery used. For ploughing, for example, the soil will have a much wider workability range than for seedbed preparation.

A very broad rule of thumb is that for optimum workability the moisture content should be around 60% of field capacity, where field capacity is the moisture content of an initially saturated soil, allowed to drain freely for 24 - 48 hours. The soil may not reach this level of moisture during the rainy period in humid or semi-arid regions, but certain types of tillage operations may still be required. In such cases, methods should be chosen which cause as little damage as possible to the soil.

The moisture content can be considered optimum when:
- the effort (power) required to perform a certain operation is least, or
- the desired effect is greatest.

In practice, these two points will not coincide and so a compromise must be sought with due allowance for the basic input: the minimum requirements for cultivation and for overcoming the rolling resistance of tractor and implement.

2.5 Compaction Of The Field By Traffic

A few general rules regarding the compaction process are given below:
- The greater the soil moisture content, the easier it is to compact the soil (lower pressures required). This rule is valid up to the point where soils start flowing under pressure, which implies that the greatest compaction can occur under high pressures with relatively low moisture contents. Saturated soils cannot be compacted.
- The pressure distribution in the soil under a tyre depends upon the size and shape of the tyre (Fig. 5).
- Pressures extend to greater depths in loose soils than in hard soils.
- The first pass of a wheel over a soil produces more compaction than later ones (in the order of 90% for the first pass and 10% for the following ones).

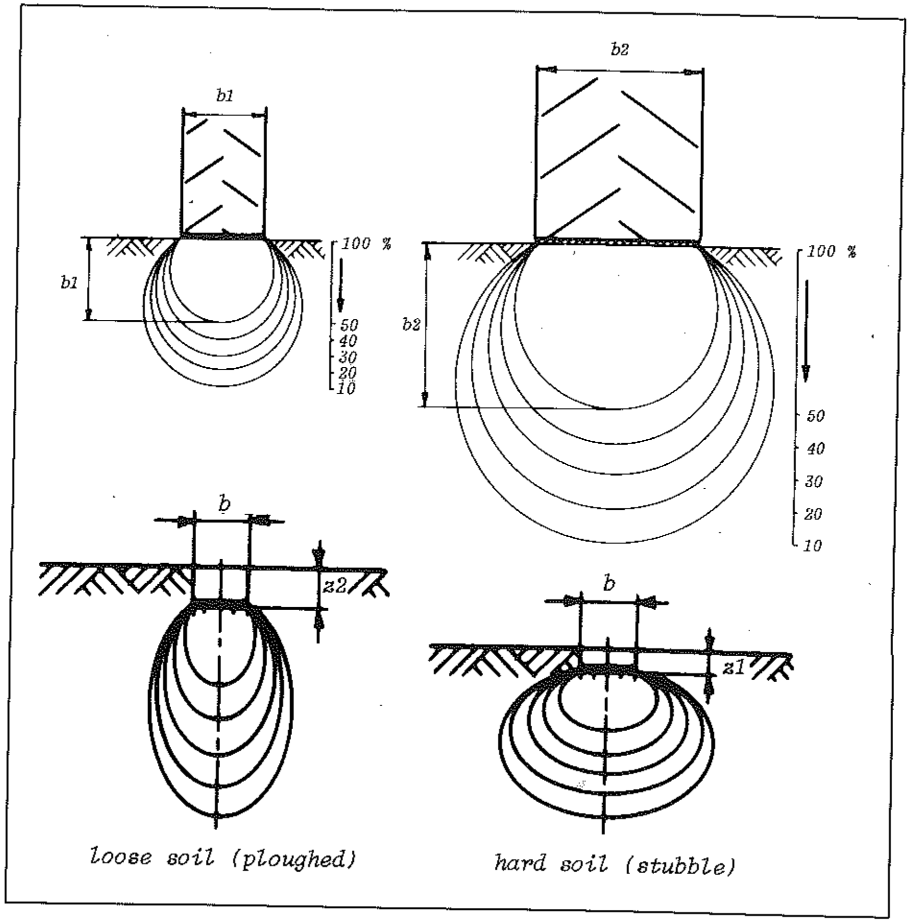

Fig. 5. Pressure distribution under agricultural tyres. - Source: Perdok and Terpstra.

Consequently, it is mainly during secondary tillage operations that compaction will produce the greatest effect. Particularly in cases where several passes are needed to achieve the required tilth of the seedbed, the bulk density of the soil may be reduced again to its level before primary tillage.

The most obvious harmful effects caused by traffic compaction are:

1. Irregular sowing depths and emergence of seedlings when plant rows are located both in and between wheeltracks.
2. An increased risk of erosion due to markedly reduced infiltration rates in the wheeltracks. Runoff followed by erosion often starts in wheel-tracks.
3. Waterlogging in the surface layers (aeration problems).

These problems can be avoided by:

- Reducing the number of passes over a primary-tilled field to a minimum and by avoiding turns on tilled land during the primary tillage operations;
- Lowering the air-pressures in the tyres of the tractors and implements and using dual or cage wheels;
- Tilling and sowing, as far as possible, along the contour in sloping fields;
- Loosening the tracks after each pass, using chisel or tine-type tools behind the tractorwheels.

Fixed traffic lanes (wide permanent beds or cropping strips) do not yet offer a practical or economic solution, but a system of permanent beds separated by furrows with a slight gradient (controlled runoff) has produced promising results with animal draught operations on difficult black cotton soils in India.

Needless to say, no standard system or equipment can be suggested as the ideal solution to any particular tillage problem over a broad range of geographical conditions. The technologies and tools available for the operations depend very much upon local factors. Continuous testing and, where necessary, adaptation of the commonly-used equipment and system are required.

2.6 A Note On Energy

Crop production is one of the few processes whereby solar energy is collected and conserved in the form of organic material for use as food or fuel.
There are many reasons why actual crop yields are lower than the yields which could be obtained from solar radiation. The main constraints are limited supplies of water, a deficiency of plant nutrients, competition from weeds, in some cases low temperatures, the detrimental effects of pests and unfavourable timing (sychronizing the vegetation period with the season).

This implies that any attempts to improve crop yields must be based on an increase in, or modification, of the farmer's (energy) input. The agricultural energy balance is a complex subject and lies outside the scope of this book. Some data and literature will, however, be given at this point to indicate the position of soil tillage within the general energy pattern.

Studies show that, in the industrialized nations, agricultural production usually accounts for less than 5% of the total energy consumption. Unfortunately, very little information is available concerning the developing countries. A different situation obtains in those countries with regard to their total consumption: subsistence farming usually represents a much larger proportion of their total output while the on-farm energy input is not much lower than in the industrialized nations. In particular, the amount of energy required to feed the draught animals is very high and the input may actually be greater than with the highly mechanized methods employed in developed nations.
By comparing the energy balances of the agricultural systems applied in various countries, it becomes obvious that the developed countries' input consists mainly of fuel, fertilizer, irrigation, machinery, drying and on-farm processing. The energy input of subsistence farming or

small-holders in developing countries is mainly associated with human and animal labour and only a very small proportion is expended on fertilizers, machinery and fuel.

The output (in terms of energy of the agricultural product) from the high-input system is much greater but the output:input ratio is generally much lower than for low-input systems. Calculations show output:input rations ranging from 1.5 to 6 for high-input systems and from 15 to 60 for low-input systems (care should be taken when comparing figures from various sources because of the different calculation methods).

Soil tillage accounts for a proportion of the total input side of the energy balance, a proportion which depends upon a number of factors. The overall production system determines the magnitude of the inputs for irrigation, fertilizers, pesticides, harvesting, crop drying, transport, etc. and for the type of tillage or cultivation system employed. In high-input systems using conventional tillage methods tillage accounts for approximately 5% for irrigated and up to 15% for dryland systems (all factors are expressed in energy units). Fertilizers, mechanization and irrigation are the greatest energy consumers. Reduced tillage or direct drilling systems may reduce the proportion used for tillage but, generally speaking (and certainly in the tropics), reduced-tillage systems are not applied only because of energy savings (see Chapter II.10).

Machinery and fuel are usually available for tillage in high input systems but their cost and the labour are the prime concern while in low-energy systems the available energy and machinery are usually restrictive factors. When only a certain number of animal-hours or man-hours are available for each hectare, the area which can be used for crop production is limited to the number of hectares which can be coped with during peak labour periods. The bottlenecks are tillage, weed control and, to a lesser extent, harvesting. In many cases it may even be physically impossible to carry out some farming operations; for example, human or animal labour cannot till the dry hard soil in semi-arid regions.

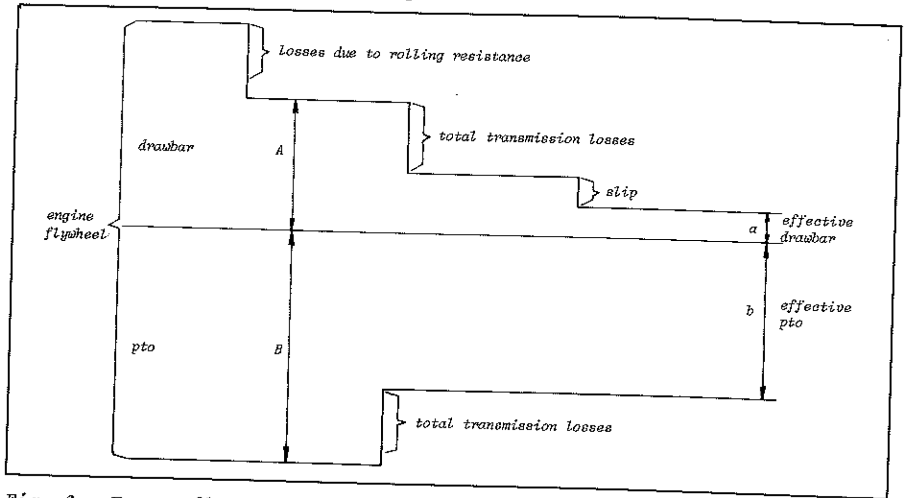

Fig. 6. Energy flow of a tractor as a power unit. Source: Meiborg and Perdok.

Only approximate figures can be given for the actual energy requirements for various tillage operations. The figures for each operation or implement depend on many factors, such as:
- soil type;
- condition of the soil (moisture content, bulk density, structure);
- shape, working depth and speed of the tool;
- climatic conditions;
- the extent to which the power source and implement or tool match;
- correct adjustment or use of the implement.
- plant cover

The relationship between draught and pto drive requirement and the required tractor power is shown in the energy flow chart in Fig. 6.

Figs. 7 and 8 provide rough guidelines for the required tractor power and draught for various tillage implements on a range of soils. The values are only for one speed and working depth; any increase in speed or in depth results in a disproportionate increase in the required draught.

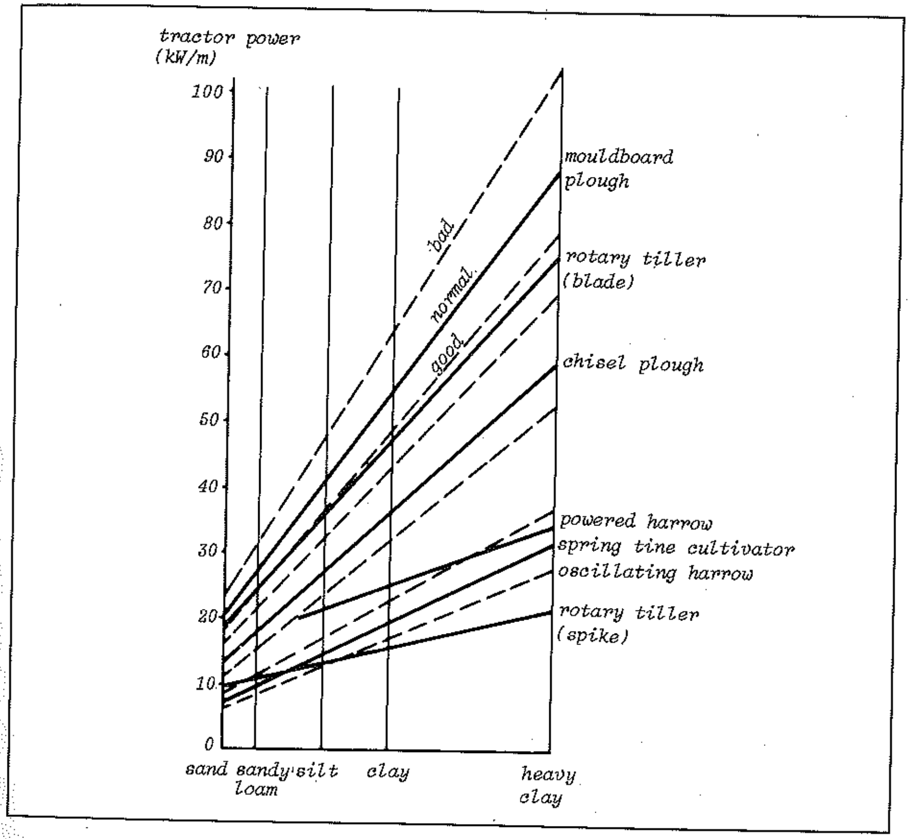

Fig. 7. Tractor power requirement per metre of working width for various tillage implements related to soil type. - Source: Perdok and van de Werken.

These data are approximate and attempt to provide information on the range of draught- or tractor power required for each implement type described in part II. It should be noted that considerable variations may occur even within one field.

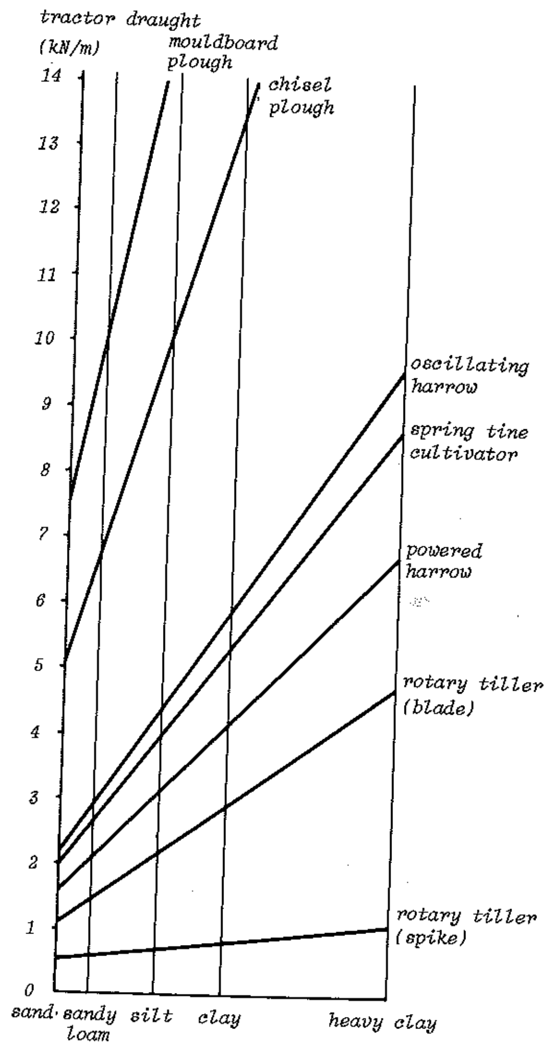

Fig. 8. Tractor draught requirement per metre and working width for various tillage implements related to soil type. - Source: Perdok and van de Werken.

2.7 Literature

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3.0 CLIMATE AND SOIL TILLAGE