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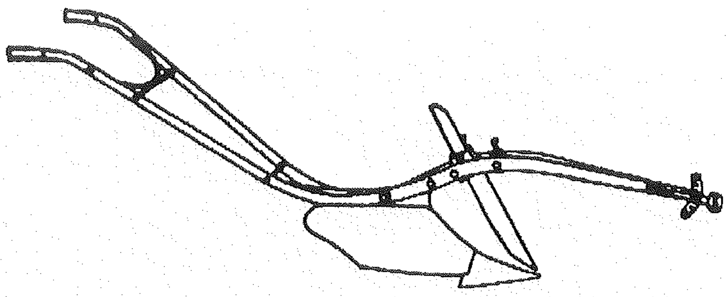

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Inge Håkansson, Editor

REPORTS OF PROJECT WORKS BY PARTICIPANTS IN THE COURSE "SOIL TILLAGE AND RELATED SOIL MANAGEMENT PRACTICES"

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PREFACE

From August 21 to October 27, 1995, an international course on "Soil Tillage and Related Soil Management Practices" was held at the Swedish University of Agricultural Sciences, Division of Soil Management. The course was held in English and was aimed for Ph.D.-students and advanced M.Sc.-students from any country. It had 10 participants from 5 countries.

During part of the course each participant carried out a project work in the form of a small literature review or experimental work. The reports of these project works are brought together in this bulletin. They cover a wide range of soil management problems.

Inge Håkansson
Professor emeritus
Course leader

CONTENT

EMERGENCE AND ROOTS GROWTH OF PEAS (*PISUM SATIVUM L.*) AND RAPE (*BRASSICA NAPUS L.*) IN THREE SOILS UNDER DIFFERENT MOISTURE AND COMPACTION LEVELS

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ABSTRACT

In a pot experiment, the development of roots and seedlings of peas and rape as influenced by different seedbed characteristics and different states of compaction in three soil types was studied. The best and most uniform emergence was in clay soil with an agregate size of 4-8 mm in the seedbed. When 100 kPa load was applied to compact the layer beneath, most pea roots were grown horizontally between top and bottom layers.

INTRODUCTION

The use of heavier machinery and reduced tillage techniques can lead to increased compaction, which may restrict root growth.

When soil is compacted the bulk density increases and this is accompanied by a reduction of mean pore diameter, which is often associated with greater resistance to root penetration. A dense soil is usually poorly aerated and may often contain excess water (Braunack and Freebairn, 1988). The greater strength of the soil beneath a seedbed, the less likely it is that roots can penetrate this soil. The proportion of roots penetrating a compacted soil below a seedbed, decreased exponentially with soil strength (Dexter, 1986 a). Roots which grow down through a seedbed and encounter a strong, untilled soil beneath may be unable to penetrate this soil and may be deflected horizontally. They will continue to grow horizontally along the top of the subsoil either until the seedbed dries out and the roots wilt and cease elongating, or until they find some path of low resistance down through the subsoil.(Dexter,1986 b).

The water content in soil has great influence on to the growth of plant roots. In compact clayey soils the mechanical resistance is closely related to the water content and increases sharply as the soil dries up. Espesially those with a high content of fine silt, have a tendency to harden so rapidly during an intence early drought that root development of spring-sown crops is impeded in the lower part of the plow layer or in the plow sole (Heinonen,1985).

The critical bulk density for root penetration is lower in clay than in sandy soils (Misra, 1994). Increased bulk density and penetration resistance resulted in reduction of all root growth parameters such a number of roots, mean and total root length, rate of root elongation, and fresh and dry root mass in an experiment by Panayiotopoulos et al.(1994). The critical penetrometer resistance for root growth is about 0.4 MPa for plants with a single seminal axis (dicotyledons) and 3 MPa for plants with four seminal axes (monocotyledons) (Dexter, 1986a). An important property is thickness of root, if the other factors are equal, the ability of root to penetrate a massive soil increases with increasing thickness (Heinonen, 1985). Diameters of root tips of plants grown in soil with a compacted layer are larger than those from uncompacted soil (Materechera et al., 1992).

Evaporation from a bare soil is two-stage phenomenon involving conversion of liquid water to vapour and its escape into the atmosphere. There are three requirements for such a process: a) the continual supply of energy to vapourize water; b) the existence of a vapour-pressure gradient between the evaporating surface and the surrounding atmosphere; and c) the continual supply of water to the evaporating surface (Jalota and Prihar, 1990).

MATERIALS AND METHODS

A pot experiment was caried out in plastic boxes with an area of 0.1 m^2 and depth 145 mm. Three soils were used in experiment : loamy sand, silty clay loam and clay.(table 1) From the loamy sand and silty clay loam sieved soil was used. From the clay soil sieved soil was used as bottom layer and 4-8 mm aggregates as top layer. A dry soils were gradually moistened to about field capacity during one week. In some boxes with silt clay loam and clay drier soil was used, and in few boxes moist soil was used for bottom layer and air-dry for top layer.

Table 1. Properties of the soils used in the experiment

Soil	Particle size distribution g kg^{-1}			Organic matter content g kg^{-1}	Water content(% w/w) at tension (MPa)			water content %
	Clay	silt	sand		0.01	0.1	1.5	
loamy sand	72	105	823	17	12.5	8.6	3.6	13.4
silty clay loam	295	568	137	58	40.2	32.3	14.9	35.6
clay	493	392	115	34	33.0	25.5	18.3	26.7
silt clay loam dryer							14.9	24.3
clay dryer							18.3	19.5

Weighed portions of soil were put into the boxes as bottom layer and compacted uniaxially by

hand 8 kPa or by a pressure apparatus 30 and 100 kPa. 48 seeds per box of peas or rape were placed on top of the compacted soil and covered by about 4 cm of loose soil. No irrigation was carried out. The boxes were placed in a green house, directly on the floor. The temperature was about 23+-2^{0}C, and the photoperiod around 12 h . No extra light was provided. After the first plants had emerged, number of plants were counted daily until the experiment was finished. The boxes were then investigated and the reasons for any lack of emergence examined.

Bulk density and degree of compactness of the bottom layer were determinated. Bulk density was calculated from the dry mass and volume of the soil in the boxes. Degree of compactness, D was defined as D=100 $\rho_d/\rho_{d'}$.(table 2) Where ρ_d is the dry bulk density of the soil and $\rho_{d.p'}$ is the dry bulk density of the same soil in the reference state, with in the densest state that was obtained by a static pressure of 200 kPa (Håkansson, 1990).

Table 2. Dry bulk density and degree of compactness below the seedbed

Soil	Dry bulk density Mg m^{-3}	Degree of compactness (%)
Loamy sand 100 kPa	1.47	85
Loamy sand 30 kPa	1.42	82
Lomy sand 8 kPa	1.32	76
Silty clay loam moist		
100 kPa	1.18	82
30 kPa	0.94	65
8 kPa	0.91	63
Silty clay loam dryer		
100 kPa	1.08	75
30 kPa	1.01	70
Clay moist 100 kPa	1.25	85
Clay moist 30 kPa	1.10	74
Clay moist 8 kPa	0.95	64

At the end of the experiment penetration resistance of top and bottom layers were measured with a hand penetrometer. Penetration resistance was calculated as the force exerted by the penetrometer, divided by cone surface area.
Potential evaporation during the experiment was determinated using an Andersson evaporimeter placed 15 cm above the floor. Water loss from the boxes was estimated by weighing the boxes. Amount of roots between the soil and the bottom was estimated by counting root intersections with a wire placed on the soil in five places after the soil had carefully removed from the boxes and turned upside down.

RESULTS AND DISCUSSION

Water evaporation

The evaporation rates were highest in moist silty clay loam, and lowest in soils with air-

air-dry surface layer (fig.1). 4-8 mm size aggregates were a good protection against water evaporation from the moist bottom layer

.

Seedling emergence

The best and most uniform emergence was in clay soil (fig. 2, 3). Big reduction in emergence of peas in silty clay loam with wet top layer seemed to be caused by root rot infestation and oxygen deficiency. Many seeds were not germinated only swollen and covered with mould. In loamy sand and clay most peas seeds were germinated, but some shoots could not penetrate the quite hard toplayer.(Table 3)

Table 3. Penetrometer resistance of the top layer and plants emergence

Soil type and AWC %	PR of top layer (MPa) in boxes with peas	Emergence % of peas	PR of top layer (MPa) in boxes with rape	Emergence % of rape
Loamy sand (9.8)	0.45	68	0.73	34
Silty Clay loam(20.7)	0.99	38	1.43	21
Clay (8.4)	0.42	93	0.42	44
Silty clay loam (9.4)	0.14	81	-	-
Clay (1.2)	0.21	87	-	-
Silt clay loam with air-dry top layer	0.13	73	0.11	46
Clay with air-dry top layer	0.13	92	0.16	35

Too deep sowing was one of the reasons of very low rape emergence precentage.When rape seedlings start growing, they place rather great demand on the soil structure.The small seeds need shallow sowing (1-3 cm) (Lööf, 1972).

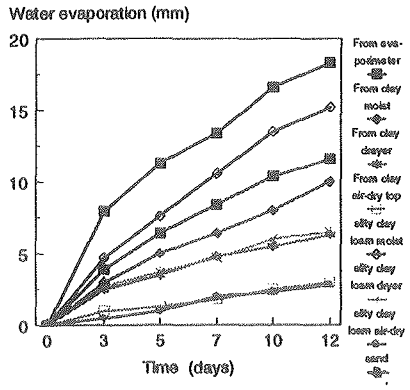

Fig. 1. Water evaporation from different soils

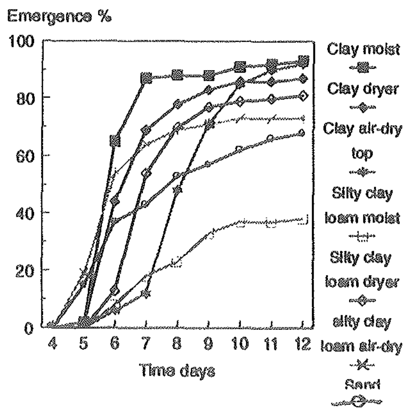

Fig.2. Emergence of peas in different soils

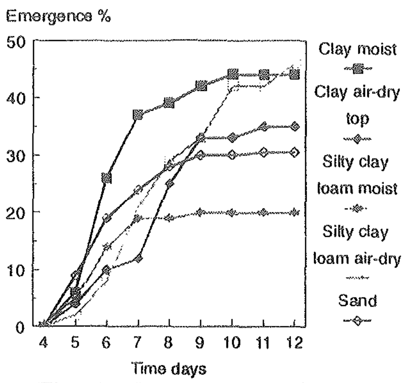

Fig. 3. Emergence of rape in different soils

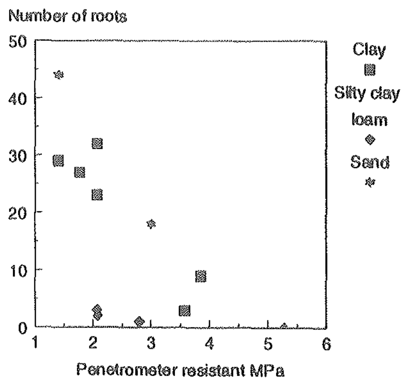

Fig. 4. Number of pea roots on the bottom

Root.. growth

No rape roots were found in the bottom of boxes The rooting depth of rape was about 3-4 cm below seedbed. It seemed to have been too short time for deeper development. For peas rooting and number of roots in the bottom depended on penetrometer resistance (fig. 4).In boxes where 100 kPa pressure was applied for subsoil compaction there were many roots between top and bottom layers. The same picture was in boxes with silt loam soil where 30 kPa pressure was aplied and soil on the top was drier or air-dry.

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BARLEY YIELD LOSSES SIMULATION UNDER LITHUANIAN CONDITIONS USING THE SWEDISH SOIL COMPACTION MODEL

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Abstract

Barley yield losses caused by soil compaction were simulated under Lithuanian conditions. Influence of traditional machinery systems with minimum and maximum traffic as well as improved wheel and tyre equipment were established.

Introduction

Soil compaction, due to strong influences to soil properties and processes, is one of the major factors affecting crop production (Lipiec and Simota, 1994). However, very few investigations of compaction effects are carried out in Lithuania (Tindziulis, 1979). Since these studies were undertaken, heavier machines have become more common. Therefore, the aim of the study was to analyze the situation concerning soil compaction under present Lithuanian conditions with respect to "soil compaction costs". For barley, as a widely spread crop in Lithuania, yield losses due to soil compaction were simulated. The economic calculations were made using a PC - based model for estimating crop yield losses caused by soil compaction witch was developed by Arvidsson and Håkansson (1991). It is based on results of field trials from an extensive Swedish field experimental program.

Matherials and methods

One part of the Swedish soil compaction model estimates the annual effects on the current year's crop of re-compaction of the plough layer after ploughing. Since ploughing usually overloosens the soil, moderate re-compaction increases crop yield, but overcompaction again decreases the yield. For characterization of the state of compactness of different soils the model uses the degree of compactness (Håkansson, 1990), which is defined as the ratio between the dry bulk density of the soil and a referense bulk density of the same soil determined in the laboratory using a 200 kPa static pressure. A distribution of the degree of compactness in the field is estimated from the wheel track distribution, the contact pressure, the weight and working width of the machines and the soil moisture content. The degree of compactness is then used to estimate the crop response.

Second part of the model estimates the long-term effects of topsoil compaction persisting after ploughing. The calculations are based on the traffic intensity in Mg km ha^{-1} (i. e. the product of the machine weight and the distance driven), the soil moisture content, the tyre inflation pressure and the clay content. The crop response disappeared within five years. The total yield losses during this period is expressed in percent of one year's yield.

Another part of the model estimates the long-term effects of subsoil compaction. The calculations are similar as in the second part of model. In the 25 - 40 cm layer it is assumed that damage persists for 10 years. Yield reductions over the 10 years period are estimated in percent of one year's yield. When calculating the traffic intensity, axle loads are reduced by 4 Mg, except for furrow wheels of tractors when ploughing. In the layer below 40 cm damage is assumed to be extremly persistent. The crop response is expressed as a permanent annual yield reduction in percent. When calculating traffic intensity, axle loads are reduced by 6 Mg, except for furrow wheels of tractors when ploughing, where it is reduced by 3 Mg.

The estimation was based on barley yield losses caused by compaction in a field with soil having a clay content of 20 %. Machines typical for Lithuanian conditions were employed. Calculations were made using the widely spread tractor MTZ-82, which weighs 3.8 Mg, and for some field operations - the heavy tractor T-150K, which weighs 7.5 Mg. The harvester SK - 5A weighs 9.1 Mg when half loaded. The following machinery systems were analysed:

Minimum traffic - two fertilizer spreadings, two separate harrowings followed by sowing, spraying, harvesting, one stubble cultivation, autumn ploughing.

Maximum traffic - as above, but separate fertilizer spreading, spraying and stubble cultivation operations were used once time more, plus separate rolling and separate harrowing after sowing as well as manure broadcasting.

Yield losses for both machinery systems were estimated with the following tractors, wheel equipment and inflation pressure:

I Heavy tractor combination. Heavy tractor T-150K (tyre inflation pressure 120 kPa) used only for two harrowings, stubble cultivation, manure broadcasting and ploughing. For other field operations MTZ-82 (tyre inflation pressure 250 kPa front and 140 kPa rear) was used.

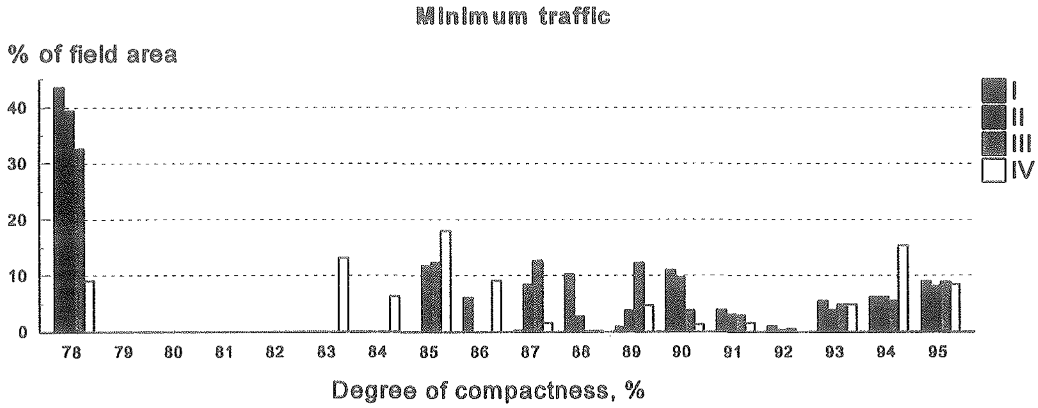
II Tractor MTZ-82 with single wheels, high inflation pressure (250 kPa front and 140 kPa rear).

III Tractor MTZ-82 with single wheels, low inflation pressure (140 kPa front and 90 kPa rear).

IV Tractor MTZ-82 with dual rear wheels till crop emergence, low inflation pressure (140 kPa front and 70 kPa dual rear or 90 kPa single rear).

Results and Discussion

The distribution of the degree of compactness in the field is not uniform. Calculations gave the following results (Fig. 1). The degree of compactness in the unwheeled area was lower than the optimum (about 87 %) that has been demonstrated to give the highest crop yield (Håkansson, 1990). The largest unwheeld field area was obtained where tractor with single wheels and high pressure (II) or heavy tractor combination (I) was used. Equipping the tractor with dual wheels with low pressure (IV) extremely decreased unwheeld area. In minimum traffic system more than half main area was too loose when tractor with single wheels and high inflation pressure (II) as well as with dual wheels and low pressure (IV) was used. For the maximum-traffic system more than 60 % of the field was overcompacted when the heavier tractor combination (I) or tractor with dual wheels (IV) was used. The largest area with optimal degree of compactness in all traffic systems were obtained where single wheels with low pressure (III) were used. In maximum-traffic system, tractors with dual wheels and low pressure (IV), compared with the other treatments, significantly increased the area where the degree of compactness reached a level intolerable for agricultural crops.



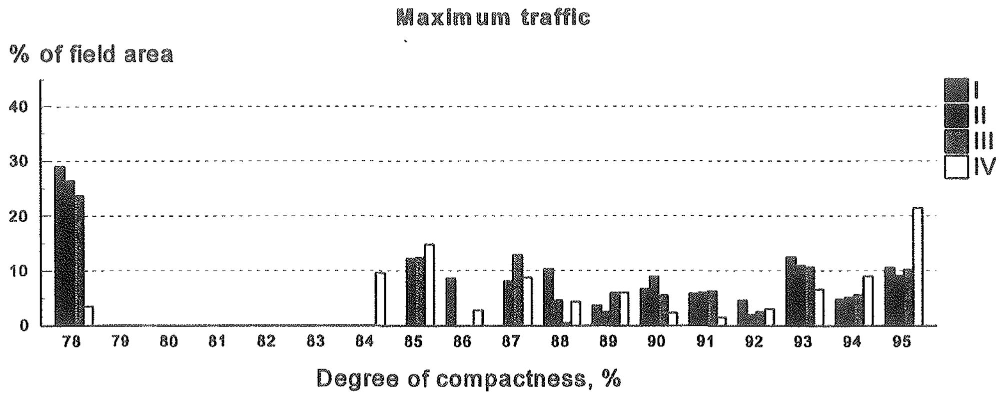


Figure 1. Degree of compactness within the main area of an autumn ploughed field with minimum and maximum traffic by (I) heavy tractor, (II) tractor with single wheels, high inflation pressure, (III) tractor with single wheels, low inflation pressure, (IV) tractor with dual rear wheels, low inflation pressure.

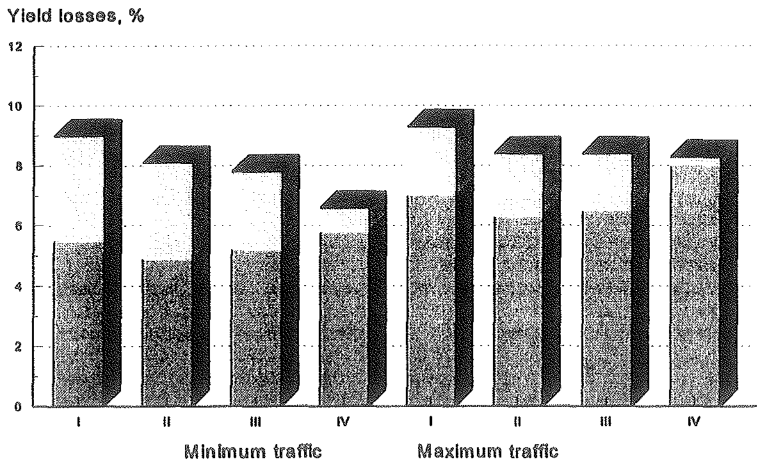


Figure 2. Barley yield losses in the same year's crop caused by machinery systems with minimum and maximum traffic by (I) heavy tractor, (II) tractor with single wheels, high inflation pressure, (III) tractor with single wheels, low inflation pressure and (IV) tractor with dual rear wheels, low inflation pressure.

The reason for yield losses may be either a too loose or an overcompacted soil. The estimated annual effects on the current year's crop (barley) are given in Figure 2. Yield losses are caused mainly because of overcompacted soil. The yield losses were higest and the situation most uniform in maximum-traffic system. Duble wheels and low-pressure tyres on the tractor has annual effect only in machinery system with minimal traffic. In this case barley yield losses were 6.6 %, as compared to 9.0 % for heavier tractor combination. Thus, operating double wheeled tractor with low-presurre tyres decreased the yield losses by 27 %.

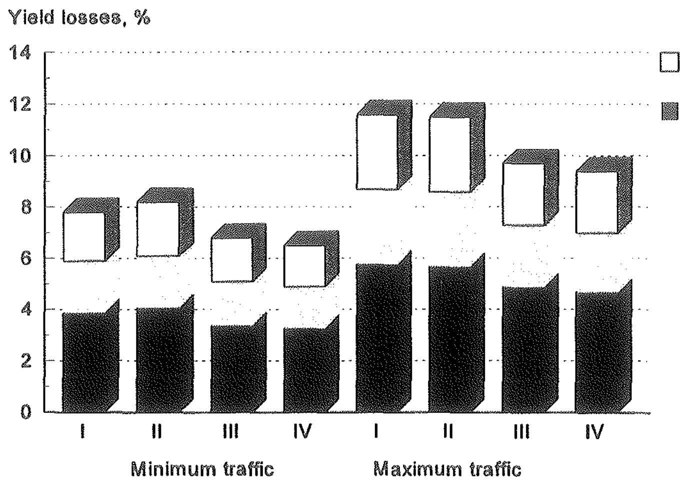


Figure 3. Yield losses in subsequient crops, in % of one year's yield, from structural damage in the topsoil. The losses are calculated for different clay contents, machinery systems with minimum and maximum traffic and by different tyre equipment.

Damage caused by compaction of the topsoil persists for a long time after this layer has been loosened by ploughing. Figure 3 shows estimated results on subsequient crops (in percent of one year's yield). The losses are calculated for different clay contents. The highest long-term damage of topsoil compaction were established for tractor and equipment systems I and II. Compared with these, single wheels and low-pressure tyres (IV) reduced damage to subsequent crops by 14-19 %. These effects were obtained at different clay contents and in both machinery systems with minimum and maximum traffic. Field operations in the case of maximum traffic, compared with the other machinery system increased estimated yield looses for subsequent crop by 44 %.

Table 1. Yield losses in subsequient crops, in % one year's yield, from topsoil and subsoil (25-40 cm) compaction by different tractors and field operations

Field operation	Minimum traffic				Maximum traffic			
	topsoil		subsoil		topsoil		subsoil	
	MTZ-82	T-150, MTZ-82	MTZ-82	T-150K, MTZ-82	MTZ-82	T150K, MTZ-82	MTZ-82	T-150K, MTZ-82
Fertilizer spreading (2 and 3 times)	0.5	0.5	-	-	0.7	0.7	-	-
Harrowing (2 and 3 times)	0.7	0.9*	-	-	1.0	1.1*	-	-
Sowing	0.5	0.5	-	-	0.5	0.5	-	-
Rolling	-	-	-	-	0.2	0.2	-	-
Spraying (1and 2 times)	0.1	0.1	-	-	0.2	0.2	-	-
Harvesting	0.6	0.6	0.1	0.1	0.6	0.6	0.10	0.1
Transpor-tation	0.6	0.6	-	-	0.6	0.6	-	-
Stubble cultivation (1 and 2 times)	0.2	0.2*	-	-	0.5	0.4*	-	-
Manure broadcasting	-	-	-	-	0.7	0.9*	-	0.1
Autumn ploughing	0.8	0.6*	0.4	0.3	0.8	0.6*	0.4	0.3
Totally	4.0	4.0	0.5	0.4	5.8	5.8	0.5	0.5

*Operated with heavier tractor T-150K

The long-term effects of both tractors with single wheels and high inflation pressure were estimated for various field operations. The effects of the size of the tractor, provided matching implement size, varied a bit with the type of work (Table 1). The heavier tractor used for two harrowings folloved by sowing increased, but ploughing with this tractor decreased yield looses in subsequient crops. The effect on subsoil compaction was established only in 25-40 cm layer. The yield losses were estimated to 0.4-0.5 % in all analysed treatments.

All analysed factors influenced yield losses. Traffic by tractor with single whels and high inflation pressure, as well as by heavier tractor T-150K should be avoided, particulary in spring-time seedbed preparation or in manure broadcasting, when soil moisture is not optimal. Operating with low-pressure tyres significantly decreased crop yield losses. Therefore, it is the cheapest way to reduce soil compaction. Equipping the tractor with duals is effective only in machinery system with minimum traffic.

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Impact of rolling on establishment and yield of crops with small seed

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Introduction

Rolling like any other farming operation has been applied by farmers since many years back. The farmers have to make a good seedbed preparation in order to get a good crop establishment and yield. Rolling is often considered to be one of the necessary operations during seedbed preparation or after sowing. In many countries, irrespective of climatic and soil condition, rolling is practised by farmers. The reason why rolling is practised may be different from place to place and some of the functions can be :-

- breaking up clods
- burying stones
- compacting the soil
- conserving the soil moisture

The purpose of this project work was to make a literature review on the impact that the rolling has on crop establishment and yield of small seed crops.

Seedbed preparation:- Rolling is desirable in preparing a firm seedbed for small seeds. For a seed to germinate, it must have adequate moisture, satisfactory temperature and a certain amount of oxygen. After a seed has germinated, the roots must be able to grow through the soil to secure nutrients and water and the seedling must be able to penetrate the overlying soil and break through a possible the crust to reach the soil surface. To provide moisture for germination, the seed must have a good contact with moist soil. The soil clods and aggregates must be fine enough so that the seed can be closely surrounded. The smaller the seed, the more important it is to have a fine seedbed. Small seeds must also be planted close to the surface to allow the seedlings to emerge. It is important to note in this connection that a shallow layer of soil above a seed dries quickly. Fine seeds must be able to germinate in time to push roots to greater depth where the moisture supply is more constant. Larger seeds make better contact because of their size. In addition, they are able to sprout through a thicker layer of soil and thus can be planted at greater depth, where the soil will dry out more slowly.(Knuti , Williams and Hide 1979)
Uptake of water by seeds from the soil:-The uptake of water by seeds is an essential, initial step toward germination. The total amount of water taken up during imbibition is generally quite small and may not exceed two or three times the dry weight of the seed. For subsequent seedling growth, which involves the establishment of the root and the shoot systems, a large and more sustained supply of water is required.(Bewley and Black , 1994)
Several factors govern the movement of water from the soil into the seed, but particularly important are the water relations of the seed and of the soil. Water

potential (Ψ) is an expression of the energy status of water, and net diffusion of water occurs down an energy gradient from high to low potential
(i.e., from pure water to water containing solutes). Pure water has the highest potential, and by convention, it is assigned a zero value. Other potentials, therefore, have positive (i.e.,> 0) or negative (i.e., < 0) values.
The water potential of the cells in a seed can be expressed as follows:

$$\Psi_{cell} = \Psi_{\pi} + \Psi_{c} + \Psi_{p}$$

This means that cell water potential is affected by three components:(1) Ψ_{π} the osmotic potential. The concentration of dissolved solutes in the cell determines the osmotic potential—the greater their concentration, the lower is the osmotic (water) potential and hence the greater the energy gradient along which water will flow. Thus, the concentration of solutes in the cell influences water uptake. (2) Ψ_c , the matrix component. This is contributed by the hydration of matrices(e.g., cell walls, starch, protein bodies) and their ability to bind water. (3) Ψ_p , the pressure potential, which occurs because, as water enters a cell, an internal pressure builds up which exerts a force on the cell wall. Values for Ψ_{π} and Ψ_c are negative since they have a lower potential than pure water, and Ψ_p is positive and hence opposite force. The sum of the three terms, the water potential, is a negative number, except in fully turgid cells where it approaches zero. Water potential can be expressed in terms of pressure or energy, and the bar was the unit most frequently used(1 bar = 10^3dynes.cm^{-2}, 10^2 J.kg-1, or 0.97 atm). The unit megapascal (Mpa) is now preferred, and -1 MPa = -10 bar.
The soil also has its own water potential (Ψ_{soil}), which is the sum of its Ψ_{π}, Ψ_{c}, and Ψ_p although of these only Ψ_c plays a significant role (except in saline soils where Ψ_{π} may be appreciable).(Bewley and Black, 1994)
The difference in water potential between seed and soil is one of the factors that determines availability and rate of flow of water to the seed. Initially, the difference in Ψ between the dry seed and moist soil is very large because of the high Ψ_c of the dry coats, cell walls, and storage reserves. But as the seed moisture content increases during imbibition and the matrices become hydrated, the water potential of the seed increases (i.e.,becomes less negative) and that of the surrounding soil decreases as water is drawn. Hence, the rate of water transfer from soil to seed declines with time, more quickly in soils of low water-holding capacity (e.g., sandy soils). Continued availability of water to the seed depends on the water potential of the zones of soil immediately surrounding the seed and on the rate at which water moves through the soil, i.e., the hydraulic conductivity of the soil.
Capillary and vapour movement of water near the seed is influenced considerably by soil compaction (bulk density), which may result in mechanical restraint of the swelling seed and decreased imbibition.
Other factors may play a role in determining the rate and extent of water uptake regardless of the difference in Ψ between the seed and soil, e.g., the impedance of the soil matrix (caused chiefly by surface and colloidal factors) and the degree of contact of the seed with soil moisture (i.e., seed-soil contact). The latter varies with seed size and shape and with the texture and compactness of the soil itself. Small seeds, seeds that produce mucilage, and seeds with relatively smooth coats tend to be the most efficient in absorbing water owing to their greater contact with soil and their larger surface area/volume ratio. The influence of hydraulic conductivity and seed-water

contact area on germination at a particular soil water potential varies between soitypes, and so the germination response to soil water potentials in sandy soil is markedly different from that in clay soils.(Bewley and Black, 1994)

An adequate water availability in the soil is very crucial for seed germination and healthy crop establishment. However, evaporation limits the availability of water to the seed and has a tremendous impact on the extent of water loss and drying of the soil. In addition to suitable aggregate size distribution the drying process can be influenced by rolling and soil compaction. A reduction of air-filled pore space naturally decreases evaporation whenever soil air exchange is more important than capillary rise for the evaporation flow-study done by Johnson and Buchele (1961) indicates that a slight compaction up to 0.35 bar clearly reduced the evaporation rates, especially from the coarser aggregates. Under field conditions the topmost layer of clay soils is nearly always so coarse that evaporation can be reduced by appropriate rolling.(Heinonen, 1985)

A study done by Lafond and Fowler (1989) in Canada, to determine the importance of soil temperature and moisture potential on kernel water uptake and germination in order to identify the minimum requirements for successful crop establishment, indicated that in a controlled environment, germination could occur at moisture contents as low as 512 g water kg^{-1} kernel dry weight. Therefore, differences in rate of water uptake observed for kernels placed in a Typic Haploboroll soil at – 0.2, – 1.0, and – 1.5 Mpa did not result in differences in speed of germination. Temperature differences in the 5 to 30^0C range had a large influence on rate of kernel water uptake and speed of germination. As temperature increased, rate of water uptake increased and median germination time decreased from 6.9 days at 5^0C to 0.9 days at 25 and 30^0C. This study demonstrated that the effects of temperature on speed of germination are much larger than those of moisture, indicating that seeding of stubbled-in (direct seeding) winter wheat should proceed at the optimum date regardless of seedbed moisture conditions. The study was an attempt to give an answer for the dilemma of producer either to seed at the optimum date into a dry seedbed or to delay seeding until after a rain.

Rolling impact on yield :-

In Sweden a combined spring tillage intensity and irrigation experiment was carried out on a medium heavy clay soil (45 % under 2 µm) at Uppsala, during the very dry summer of 1965. It was stated that increased intensity of harrowing and rolling (with tractor wheels outside the test plots) reduced evaporation and increased oat yields significantly in the non-irrigated part of the experiment. Rolling was clearly advantageous even after the most intensive harrowing. Irrigation levelled off the effects of different tillage treatments on crop yields. A large number of other tillage experiments in different parts of Sweden have confirmed the trends revealed. On a dry soil the effect of rolling comes from the pulverisation of surface clods as well as from compaction. Russian work on chernozem soils indicates that if soil water content is less than 80 to 85 % of field capacity, rolling is likely to conserve soil moisture. At higher moisture contents, rolling enhances hydraulic conductivity and may increase the rate of evaporation.(Heinonen, 1985)

Optimum compactive pressure varies greatly under different conditions. From the point of view of evaporation control under dry conditions, most plowed soils (particularly dry and cloddy clay soils) would require a rather heavy compaction, but in practical soil management the compaction must be adjusted with regard to the requirements of seedling emergence, infiltration capacity and root development.

Seedling emergence can easily be reduced by excessive compaction of newly sown fields. There is evidence that when rolling after sowing, the pressure should not exceed 0.30 to 0.35 bars.

Rolling immediately after sowing with a Cambridge roller, weighing about 200 kg/m, has increased the yields of spring sown cereals in Scandinavia by 100 to 200 kg/ha. Later treatments have been mostly without effect. Additional loading has sometimes improved the response slightly, but it increases the risk of impeded emergence if the surface layer is moist and then dries up rapidly.(Heinonen, 1985)

In Sweden, during the period of 1970-1981, a large number of field trials were carried out to study the effects of rolling after sowing on yields of spring-sown crops like barley, oats and wheat under various conditions. Trials were sited over the entire country and the soil type varied from light sandy soils to heavy clays.

The results of the experiment show that rolling immediately after sowing increased yields by on average 2 % when compared to unrolled plots, but delayed rolling did not have the same effect. The highest yield increase from rolling (+ 4 %) was brought about on soils with a clay content of less than 15 %. All the three crops responded positively to rolling and the effects of rolling increased in proportion to the amount of plant available moisture in the bottom layer at sowing. The effects of rolling were greater in sites where the soil surface was uneven before rolling, and the coarser the seedbed, the greater was the effect.(Von Polgar, 1984)

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MOVEMENTS OF SOIL BY TILLAGE IMPLEMENTS

-a literature studie

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Introduction

Every time an implement is moved through a soil, the soil is moving from one place to another.
This movement is found when a row-hoe is used in a row crop to control weeds, when a harrow is preparing the seedbed or when ploughing is made with a mouldboard plough in the autumn. These movements are important to know in order to achieve e.g. a good effect of weed harrowing or a good incorporation of straw in the soil. This short literature review of the topic : "soil movement" will mainly deal with soil movement when harrowing and hoeing are applied for mechanical weed control.

The terminology is somewhat diffuse; soil cover and soil covering are both expressions for the amount of soil that covers crop plants and weeds after harrowing and/or hoeing, but can also be an expression for the method itself.

Row crops are usually weeded with different types of hoes, i.e. "inter-row weed control": Those weeds that remains in the untreated strip between the crop plants, are controlled with e.g. band spraying or hand weeding. These latter methods can be called "intra-row" or "in-row" weed control.

Different methods to move soil

All kinds of implements can move soil more or less. The mouldboard plough makes the greatest and most visual movement; a soil layer of perhaps 20 cm is turned upside down. Harrows and hoes move the soil sideways, leaving a path or furrow after the tine. Brush weeding machines and rotary harrows are mixing the soil in the entire treated area, and can transport soil sideways. Most implements also move the soil in the direction of travelling.

The tine and its behaviour in soil.

Several studies of tines and tine-like tools were presented during the 1970s, and many of them came from the Netherlands where tillage research started in 1954 (Kuipers & Koolen, 1989). Studies have also been made in Germany (e.g. Feuerlein, 1962), Sweden (e.g. Henriksson, 1987) and the United Kingdom (e.g. Stafford, 1979).

Meyler & Rühling (1966) studied different types of tines, forward speeds, working depths and soils. They found that forward speed of a tool in a field always is accompanied by soil throwing. With a working depth of 2 cm, the soil could be thrown up to 25 cm from the tine if the driving speed was 12.4 km/h (Fig 1.). The conclusion was that the effect of all implements, within the range of 4-12 km/h, was essentially independent of the forward speed.

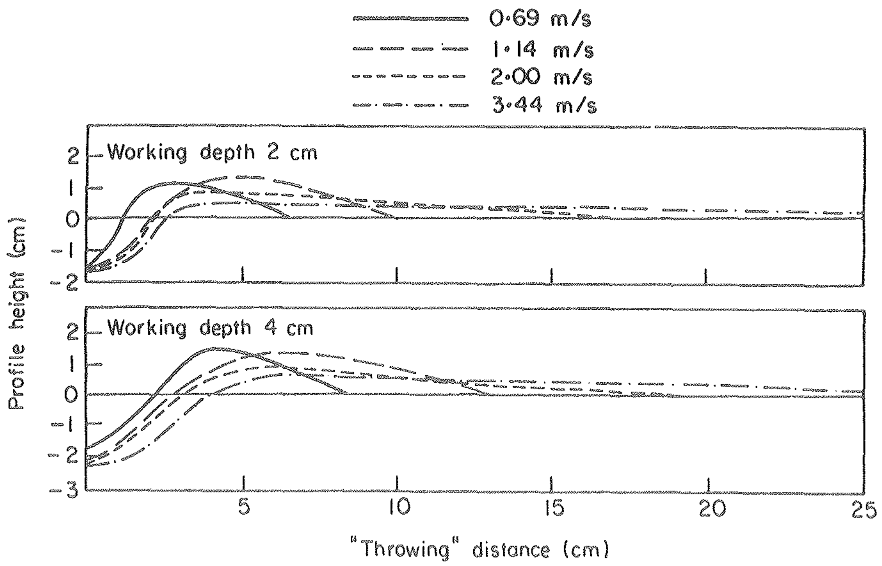

Fig. 1. Influence of travelling speed and working depth on throwing of soil aggregates and on the furrow depth (in Kouwenhoven & Terpstra, 1979, adapted from Meyler & Rühling, 1966)

In studies by Kouwenhoven & Terpstra (1973), the influence of travelling speed and tine inclination on the mixing of homogeneous media was quantified. In order to get a homogeneous media, glass spheres of three different sizes were used instead of natural soil. The experiments showed that a tine mixed a media by a downward displacement of spheres right behind the tine and by a small sideways and upward displacement of spheres alongside the tine.

Field experiments were conducted in a study by Kouwenhoven & Terpstra (1979) in order to investigate sorting and throwing action of particles by tines and tine-like tools. Generally, all tools have the same sorting action, and therefore, the segregation that occurs when a tool passes through a soil, will be determined by the properties and original distribution of soil particles. Moisture content, the size and shape of the tool in combination with inclination, travelling speed and number of cultivations will also influence the sorting result.(Fig. 2.). The width of a tool influences the transport of particles in the travel direction, the sideways transport and hence the size of the furrow left behind the tool.

Also the inclination of the tine influence the forward transport of particles. Forward facing of a tine could transport glass spheres (5 mm in diameter) 14 cm while backward facing transported them 10.8 cm. Table.1

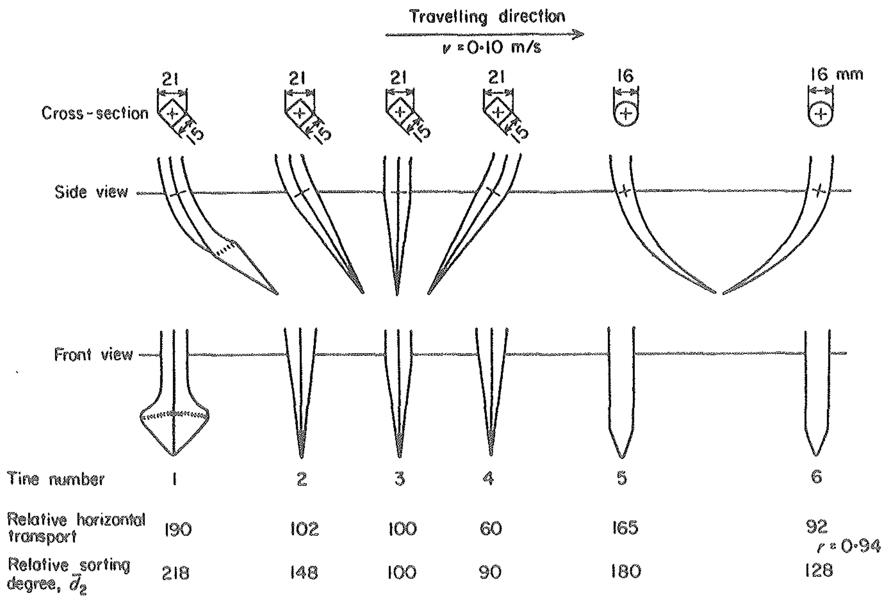

Fig.2 Influence of tine size, shape and inclination on the horizontal transport and sorting degree in a mixture of dry soil aggregates (Kouwenhoven & Terpstra, 1979).

Table 1. Influence of tine inclination on forward transport of component glass spheres in a mixture (Kouwenhoven & Terpstra, 1979)

Tine inclination	*Forward transport, cm*		
	Nominal sphere diameter, mm		
	5	*8*	*12*
Forward facing	14·0	12·9	12·3
Straight	13·3	12·3	10·1
Backward facing	10·8	8·9	8·2
Average	12·7	11·4	10·2

* In the tine zone; $v = 0{\cdot}10$ m/s; model tines

A hoe-ridger was studied by Terpstra & Kouwenhoven (1981) in laboratory to find out the sideways soil transport and degree of weed killing in and alongside the path of the hoe in relation to working depth, growing stage of the weeds and the weather after cultivation. Garden cress (Lepidium sativum L.) was grown in three different types of soil. The hoe share was then drawn through the soil at a steady speed.

The experiments showed that a soil cover of 1.5 cm was lethal for small weeds and 2 cm was lethal for longer ones in a band width 5-10 cm alongside the hoe path. The hoe loosened the soil were it passed, approx 40 cm wide path, and moved the soil sideways creating a soil cover of 2 - 5 cm from the centre of the hoe (Fig. 3). Also the movement of uprooted plants was measured showing that plants situated in the centre of the hoe path were deposited on the soil surface or mixed in the loosened soil (Fig. 4).

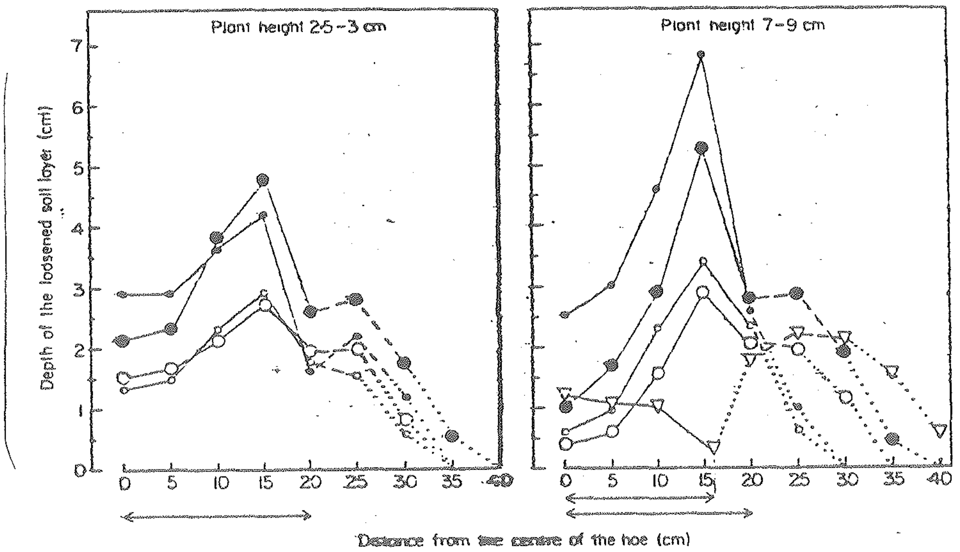

Fig. 3. Transverse movement of loosened soil related to plant height, type of soil, and distance from the centre of the hoe.
O loamy- and o sandy soil, working depth 2.5 cm; ● loamy- and ● sandy soil, working depth 4 cm. (Terpstra & Kouwenhoven, 1981).

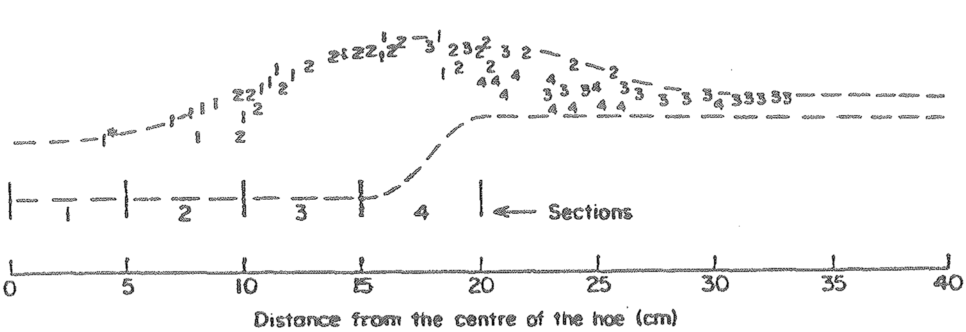

Fig. 4. Transverse movement of uprooted 7-9 cm plants on a sandy soil with working depth of the hoe 4 cm, in relation to the distance from the centre of the hoe path before hoeing.
* = Plant started in section 1, etc. (Terpstra & Kouwenhoven, 1981).

The mouldboard plough and its behaviour in soil.

In order to get a good mixing of soil and straw by ploughing, it is important to find out the transport of soil by the ploughbody. In studies by Feuerlein (1962) both the forward and transverse transport of soil by different plough types were measured. (Tab.2.)

Table 2. Transport of soil by ploughing. Adapted from results by Feuerlein (1962).

Ploughing speed *km/h*	Transverse trans. *cm*	Forward trans. *cm*
4.5	33.5	20.0
7.0	44.5	28.0
9.0	42.5	38.5
12.0	76.0	73.5

Feuerlein (1962) noticed that ploughing could create "field-hills" i.e. ridged soil in one end of the field if ploughing had been used for a long time. He pointed out that his results only could be used as a general estimation and that every soil had to be tested individually.
Works by Groth (1971) and Bosse & Herzog (1970) regarding the mixing of soil and straw showed that different types of ploughs were more or less efficent. Bosse & Herzog placed straw on a field and tilled it with different types of ploughs and cultivators. In the following spring, the amount of straw that remained in the field was measured and compared with the original amount. The experiments showed that a special type of rotating plough only left 22 % of the straw on the surface, while an ordinary type of disc cultivator left 52 % . The untreated plot had 82 % of its straw left.

The in-row brush weeding technique

A method for in-row weeding in row-grown crops has been developed in Japan (Naka, 1980) and is now used in commercial organic crop production in Sweden. The machine has one pair of nylon brushes, placed on vertical axis, for every row. The brushes can rotate in both directions putting soil in the row or taking soil out of the row.
Experiments by Fogelberg (unpublished) have shown that the soil cover in the row can vary between 0.6 and 1.9 cm. The amount of soil in the row probably depends on: a) the driving speed of the machine, and b) the rotation speed of the brushes. Further experiments regarding soil cover of weeds in the row, will be perfomed during the winter of 1995 and the beginning of 1996. The soil cover in the row affects both the number of surviving crop plants and the weed control effect. About 23% of the weed control effect in the row is due to soil covering.

Future research

Generally, the method for measuring the soil cover of weeds by harrowing, originates from studies by Habel (1954), Kees (1962) and Koch (1964). The method is based on visual estimation of the percentage of weeds covered by soil. The method is still used e.g. by Rydberg (1995), and is probably the most usable for determination of soil cover. It is generally believed that the weed control effect is due to soil covering and only a small proportion of the weeds (5-20 %) are uprooted. However, a visual estimation is not as exact as a counting of the weeds. Experiments by Fogelberg have shown that the main weed control effect of in-row brush weeding is upprooting (75 %) and not soil covering. This indicates that methods and results from weed harrowing, cannot be generally applied to other types of mechanical weed control. There is a need for developing new methods, both simple and precise, for determination of soil covering effects in field.

Practical applications

The knowledge of soil movements is important for making a good incorporation of straw by ploughing, and for mechanical weed control, both by harrowing in cereals and by hoeing in row crops. Even if the hoe leaves an untreated strip along the crop, the soil loosened by the hoe can cover the weeds in the row. Studies by Terpstra & Kouwenhoven (1981) have shown that a loose soil cover of 2 cm is lethal for almost all weed plants, provided they are 7-9 cm high as maximum. This knowledge is applied in weed harrowing and row hoeing as a mechanical weed control method. Works by Habel (1954) and Kees (1962) show that the primary weed control effect of a harrow is that the weeds are covered with soil and that only a small proportion are damaged by uprooting

Also the type of plough affects the mixing of straw and soil. In order to get a fast decomposition of crop residues, it is important to use a type of plough that mixes the soil thoroughly.

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Effect of irrigation on soil crusting and seedling emergence

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Introduction

Soil crusting has been recognized as one of the major problems that limits soil productivity and threaten sustainability of agriculture in many parts of the world. Soil crusting or sealing is common on most cultivated soils and is always associated with collapse of structure which occurs when the soil is subjected to wetting by irrigation or rainfall. In specific situations by capillary movement, formation of a thin crust layer due to rainshowers followed by rapid drying after sowing may result in a hard soil surface horizon. This impedes seed emergence and restricts root development.

The objective of this study was to ivestigate the influence of rainfall or irrigation after sowing on crust formation and seed emergence.

Materials and methods

A simple experiment was conducted in the greenhouse of the Department of Soil Sciences from September 22 to October 4, 1995. The soils used were sandy loam, silty clay loam and heavy clay, having 7 to 48% clay content. The choice of soils was based on the differences in the susceptibility to crusting problems under Swedish conditions.

Two crops, barley and oil-seed rape were used. The treatments were three levels of irrigation (0, 6 mm and 12 mm), and two intensities of irrigation or rainfall (low and high).

From the soils which were previously prepared, i.e., (one-week soil preparation to attain the desired moisture) about 13 kg for silty clay loam and heavy clay soils and 15 kg of sandy loam were placed in plastic boxes having a dimension of 36 x 26 x 14 cm^3, to form seedbed bottom. By a pressure plate the bottom layer was compacted by 30 kPa. Afterwards, 48 seeds of good quality were sown and covered by 5 kg which gives 5 cm sowing depth. Boxes were placed directly on the floor. Additional boxes for crust breaking and penetrometer resistance were prepared.

Irrigation was carried out immediately after sowing and boxes were kept in the greenhouse at 25 °C temperature. As soon as crust or hardening was observed crust breaking was on one occasion immediately introduced. Penetrometer resistance was recorded four days after sowing.

Initial moisture content was taken, i.e., water content before irrigation, and was determined by oven drying of about 1 kg wet soil.

Potential evaporation was recorded daily using an Andersson evaporemeter.

Observations and measurements

1. Count of the number of plants emerged daily.
2. Penetrometer resistance was measured three times, i.e., on the 4th day, 6th and 8th days after sowing.
3. Amount of water loss was estimated by weighting some of the boxes.
4. Daily evaporation.
5. At the end of the experiment the surface soil was removed to see what had happened why emergence had not occured. Subjected estimate of roots in the bottom of each box was also carried out.

Review of literature

Soil crusting or hardening has been widely researched, however an insight or background into the problem of its impact on seed emergence has to be reviewed and described fully.

Soil crust formation

A soil crust is a thin layer formed on the surface of the soil due to dispersive forces in raindrops or irrigation water followed by drying (Hellel, 1960). The physical mechanism of crust formation was described fully by Heinonen (1982). Five types of surface layer hardening are presented (Fig. 1). In a loose, fine seedbed a rain sometimes leads to slaking and to subsequent hardening of a thin surface layer, i.e. crusting (Fig. 1a). This is most frequent case on clay loam and clay soils. On silt loam, a rain or irrigation after sowing, results in slaking and subsequent hardening of the whole seedbed, i.e. harsetting, (Fig. 1b). When rain is gentle and does not cause slaking of the surface soil, as on soils with a stable structure, the bottom layer or the seedbed may be water saturated, its structure may collapse and it may subsequently harden, i.e. sub-subsurface hardsetting (Fig. 1c). This may also occur as a result of water saturation by capillary transport from below. In seedbeds with a coarse structure, soil particles from the surface may be detached, transported to deeper layers and cause cementation of aggregates, i.e. vertical micro-erosion (Fig 1d). Detached soil particles may be transported also horizontally and form a sedimentation crust (horisontal micro-erosion, Fig. 1e).

Physical characteristics of crusting or hardening

Soil crusts are characterized and distinguished by great mechanical strength and by low degree of aggregation and sometimes by low porosity, higher bulk density, , high amounts of silt and clay and higher values of cation exchange capacity (Hillel, 1959; Sharma and Agarwal, 1980).

A number of researchers have studied the hydraulic conductivity of the crust. In wet conditions the gaseous permeability of the soil was reduced leading to seedbed respiration problems (Roze, 1962; Evans and Buol, 1968). Norling (1980) noticed that when slaking or the whole seedbed occured, the capillary conductivity was restricted and the evaporation became equal to the potential (Stenberg et. al.,1992).

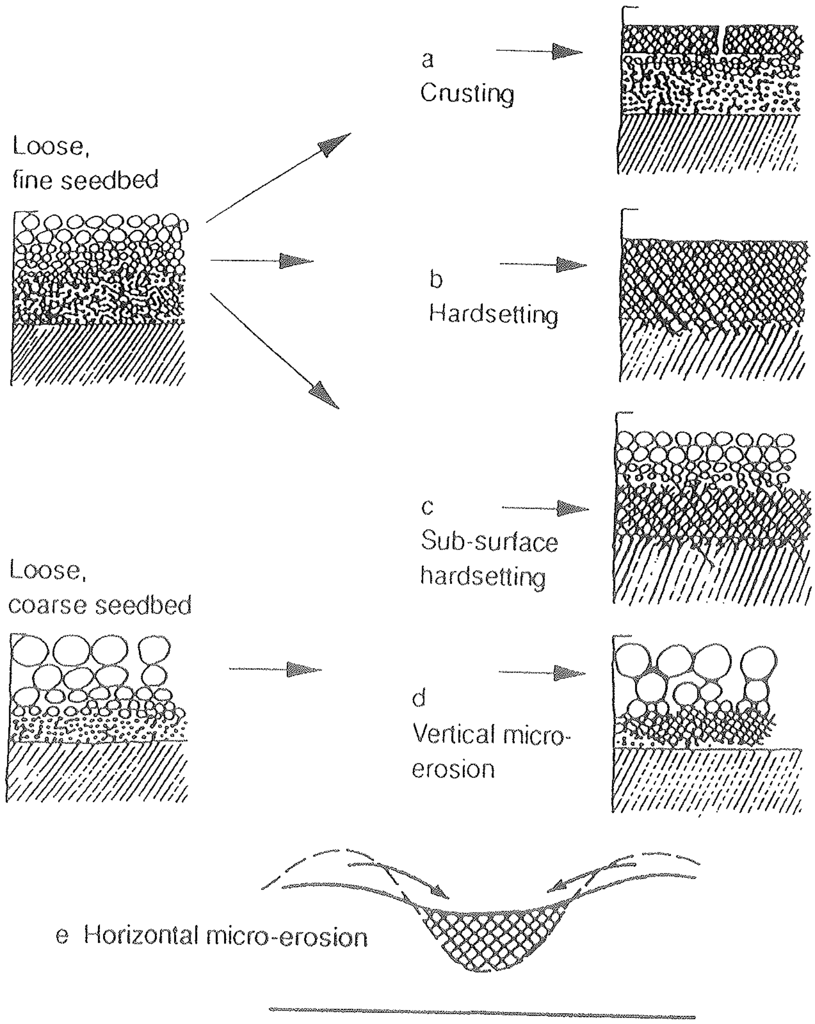

Fig. 1. Five types of surface layer hardening (Heinonen, 1982).

Impedance to seedling emergence

Crusting impedes crop emergence even when other factors like availability of moisture, oxygen, soil temperature, sowing depth are not limiting. It becomes also a problem to small seeded crops and inhibits emergence of even large seeds such as corn which normally have emergence forces.

Håkansson and von Polgar (1979) studied the effects of soil surface sealing on crop emergence and found out as the sealed surface layer dried out and hardened, crop emergence was very much affected. They concluded that oxygen deficiency that hampers crop emergence is rare. They also regarded that soil structure (fine and coarse) had no direct effect on the emergence, but a quick emergence, before the surface layer hardened is important. Thus, early irrigation with limited amount of water and deep seeding generally was most detrimental (Stenberg et. al., 1992).

Restrictions of seedling emergence takes place because due to mechanical resistance given by soil crust to the emerging seedling. If the force development of young seedling falls short of the resistance of crust penetration, the seedlings cannot push through the crust and bending of the seedlings take place just beneath the crust or hardening layer (Arnt 1965a). The emerging seedlings of cereal crops usually displace soil particles by compression and shear until the coleoptile tip is near the soil surface.

Emergence of small seeds decreased from 100 to 0 % as the crust strength increased from 0.10 to 0.27 MPa where as the emergence of grain sorghum seedlings decreased only when the soil strength exceeded 0.9 MPa (Rickard and Parkers, 1965). Emergence of large seedlings decreased sharply with the increase of soil crust resistance. The limiting crust values in a sandy loam for small seed and other cereals was 0.72 MPa. The limiting value of crust strength inhibiting emergence also depends upon soil moisture. At a given crust strength, seedling emergence was lowered when the moisture was lowest. Other factors that influence the ability of a seed to emerge are crop species, varieties, seed mass, soil temperature and depth of planting. Planting the seed at a greater depth reduced the chances at seedling emergence because by the time, the coleoptile reaches the soil crust, the latter becomes hardened (Heinonen, 1965).

These factors add to the problems in establishing critical crust strength, because of the variations encountered due to the variations to soil temperature, soil moisture, water content of the crust at the time of emergence.

Soil crust when dry does not affect aeration, because it develop cracks if clay is present and rare space is usually adequate if clay is not present. Domby and Kahnte (1956) reported that there was no significant differenece in the rate of diffusin only at low moisture tension. The wetter the soils the greater was the influence of crust on diffusin. A saturated soil crust could provide a very effective seal against diffusion.

Results and discussion

Table 1 shows the properties of the soils used in the experiment. All these soils, but particularly the silty clay loam, exhibit surface hardening or crusting that impedes seed emergence (Stenberg et. al., 1992). However, hardening or crusting is quite common, on sandy and loamy soils in many arid and semi-arid countries. (Awadwal, 1985)

Table 1. Physical properties of the soils used in the experiment

	Particle size distribution %			OM	MC	Water content %			BD	
Soil	Clay	Silt	Sand	g kg^{-1}	%	0.01	0.1	1.5	wet	dry
loamy sand	7.2	10.5	82.3	1.7	13.4	12.5	8.6	3.6	1.61	1.42
silty clay	29.5	56.8	13.7	5.8	35.6	40.2	32.3	14.9	0.94	1.28
clay	49.3	39.2	11.5	3.7	26.7	33.0	25.5	18.3	1.10	1.39

Figure 1 A-C shows the number of seeds emerged as a function of days after sowing of barley in sandy loam, silty clay and heavy clay soils.

Three soils were irrigated at different level (6 mm and 12 mm) at low and high intensities of rainfall. At 3 days after sowing, there was no signs of emergence for both barley and rape seed in all soils.

On the 4th day, barley started to emerge and crust breaking was introduced in clay and silty clay soils. It was on the 5th day that crust breaking was carried out in sandy soils.

There was marked increase of number of plant emerged in boxes were crust breaking was carried out on all soils, regardless of amount of irrigation, Fig. 1. There was a big difference on seed emergence between intensity of rainfall at 6 mm low and high intensity on silty clay and heavy clay soils.

For rape seed Figure 2A-C there was a delayed emergence from this small seed compared to barley. After crust breaking on sandy soil, there was a marked increased on seed emergence, but still lower compared of barley plants. There was no big difference on amount of irrigation (between 6 mm and 12 mm). But, with little difference on seed emergence at 6 mm irrigation, low and high intensity. On clay soils both barley and rape got high number of seed emerged at control treatment compared with treated boxes.

The evaporation rates were highest i silty clay soils and lowest in sandy loam soils.
The soil penetrometer resistance increased sharply as it dries up.

Conclusion

Crust breaking is an efficient way of reducing the problem of emergence, regardless of amount and intensity of rainfall, provided post sowing operation like soil crusting was done at the right time. Time of hardening is the most important factor consider crust establishment.

Acknowledgments

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And last but not least the Swedish Institute, for supporting this scholarship from August 1995 to October 1995.

Fig. JA. Number of the emerged plants as a function of days after sowing of barley in the sandy loam [illegible]

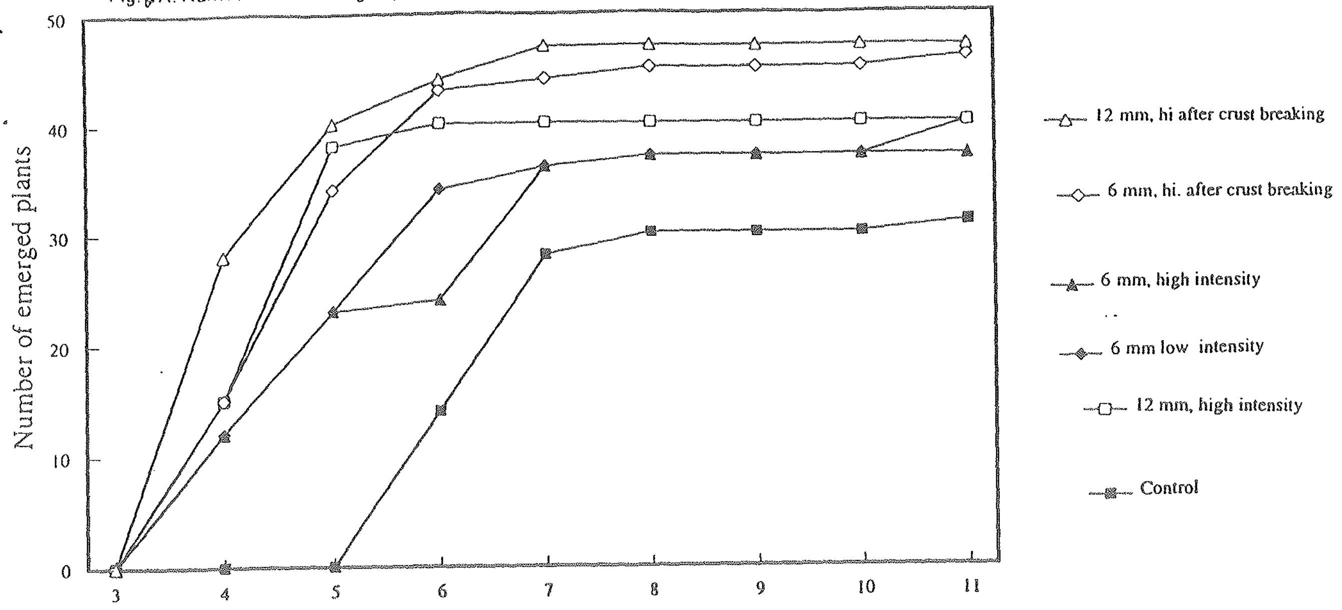


Fig. 1B. Number of the emerged plants as a function of days after sowing of barley in the silty clay (100% 48 seed)

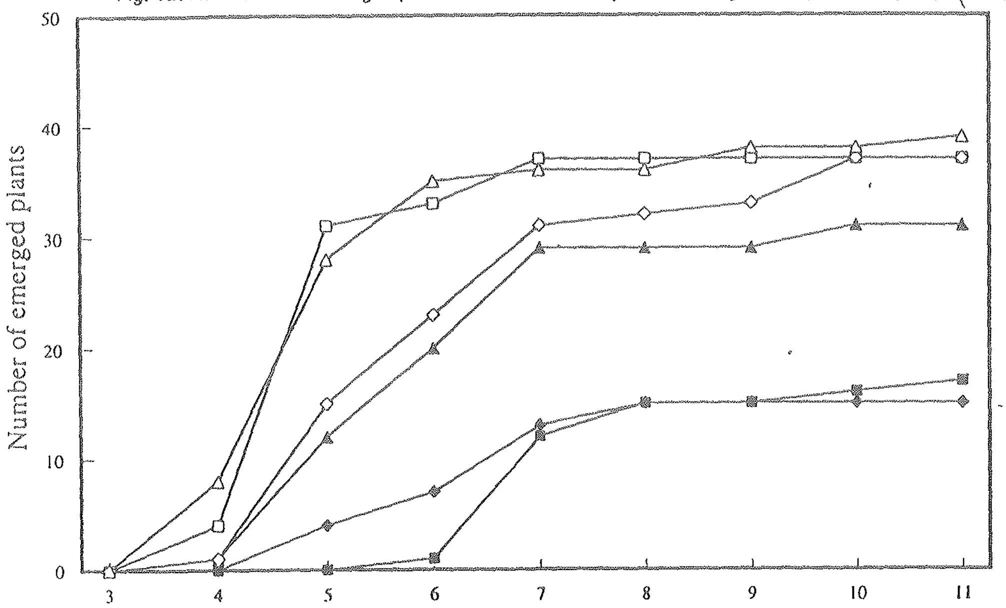


Fig. 1C. Number of the emerged plants as a function of days after sowing of barley in the heavy clay (100% 48 seeds)

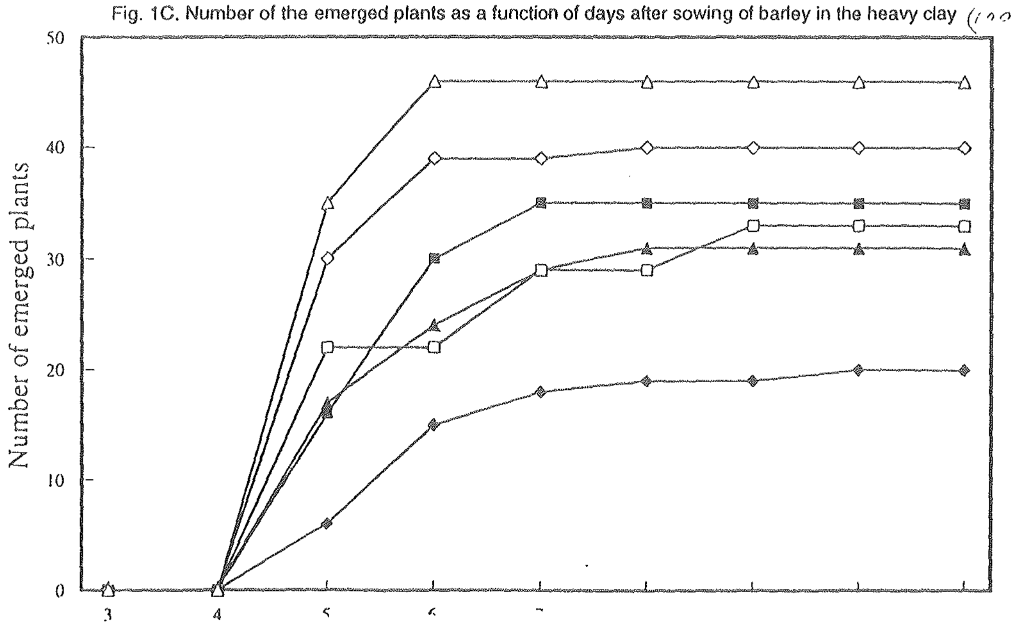


Figure 2A. Number of emerged plants as a function of days after sowing of rape in the sandy loam

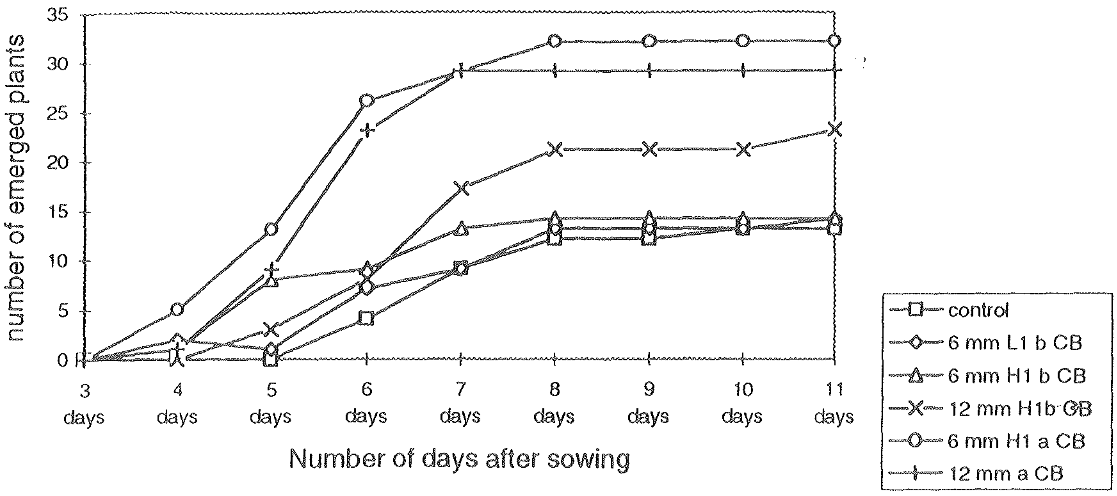


Figure 2B. Number of emerged plants as a function of days after sowing of rape in the silty clay loam

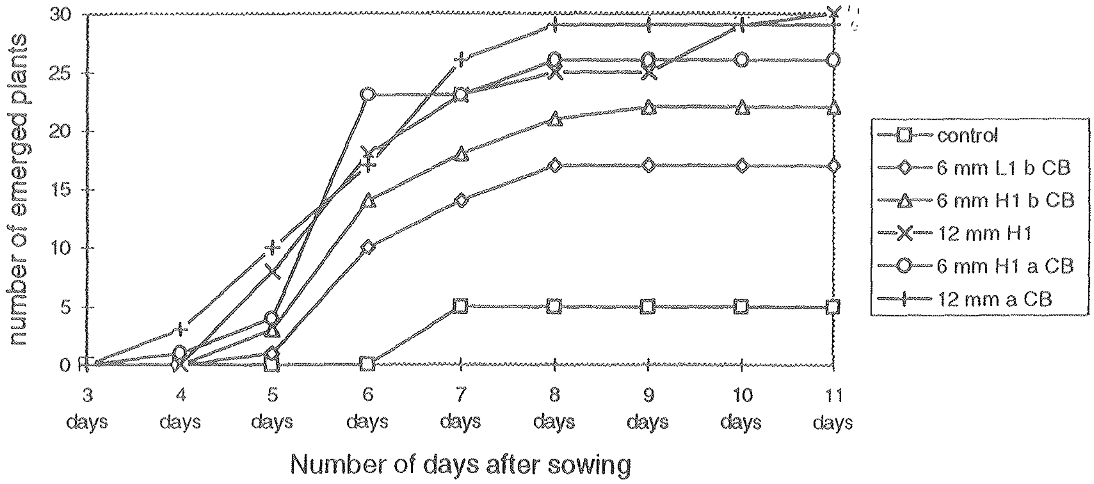
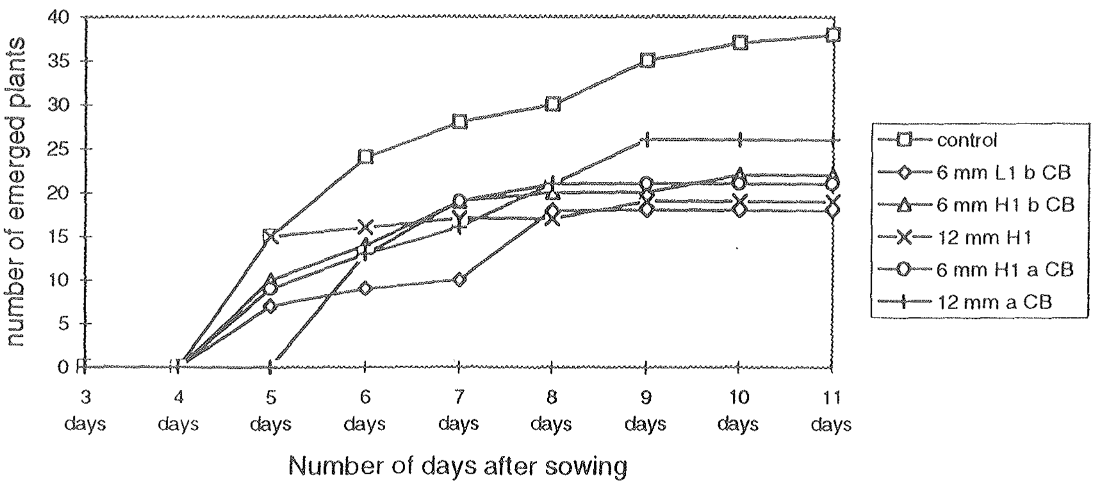
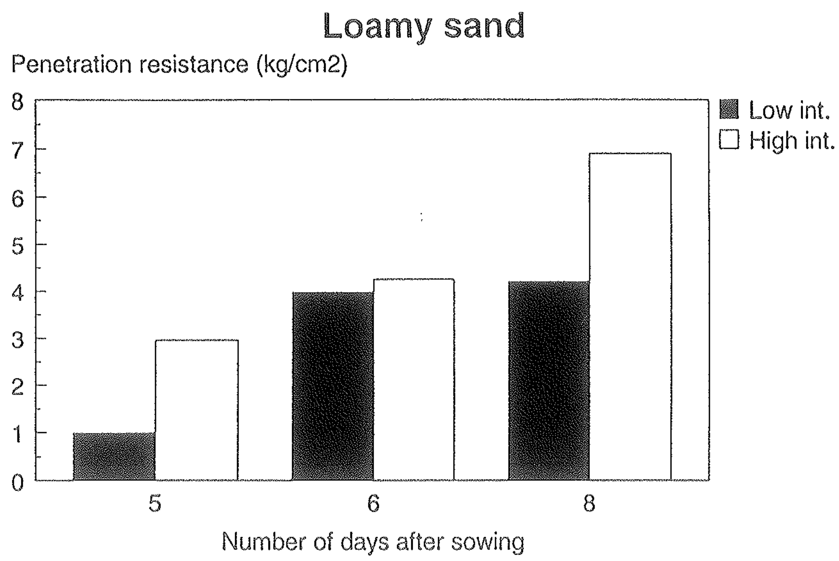
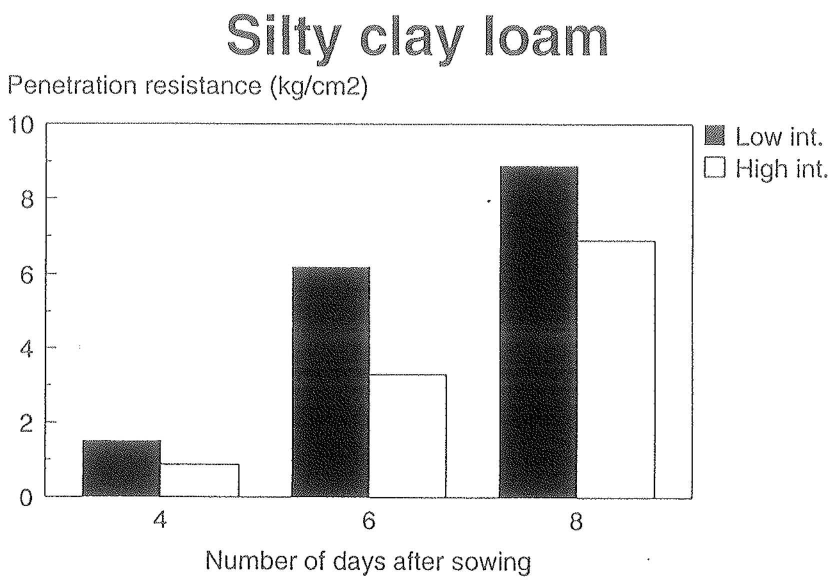
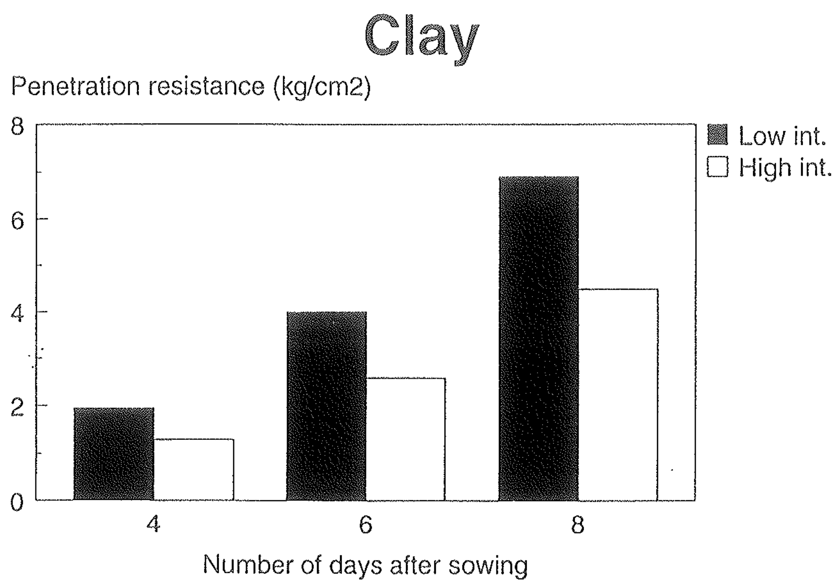


Figure 2C. Number of emerged plants as a function of days after sowing of rape in the heavy clay




Loamy sand
Penetration resistance (kg/cm2)
0
1
2
3
4
5
6
7
8
Low int.
High int.
5
6
8
Number of days after sowing


Silty clay loam
Penetration resistance (kg/cm2)
0
2
4
6
8
10
Low int.
High int.
4
6
8
Number of days after sowing


Clay
Penetration resistance (kg/cm2)
0
2
4
6
8
Low int.
High int.
4
6
8
Number of days after sowing

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WEED MANAGEMENT STRATEGIES: A REVIEW

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Introduction

In worldwide agricultural production, a 10% loss can be attributed to the competitive effects of weeds in spite of intensive weed control in most agricultural systems (Zimdahl, 1980). Without weed control, losses in yield range from 10-100% depending on the competitive ability of the crop (van Heemst, 1985). Therefore, weed management is one of the key elements of most agricultural systems. The use and application of herbicides enabled intensification of agriculture in the past. However, increasing herbicide resistance in weeds, the necessity to reduce cost of inputs, and the widespread concern about environmental side effects of herbicides have resulted in great pressure on farmers to reduce the use of herbicides. This led to the development of strategies for integrated weed management based on the use of methods alternative to herbicides and rationalization of herbicide use. In addition to direct weed control measures, emphasis is given recently on the management of the weed populations. Lotz et al. (1990) showed that weed control in some crops (like winter wheat) is generally not needed to reduce yield loss in the current crop, but only to avoid problems in future crops.

The development of weed management systems requires thorough quantitative insight in the behavior of weeds in agroecosystems, weed effects on crop yield and capability of farmers to adopt the system. This involves (a) insight in crop-weed interactions within the growing season and the dynamics of weed population over growing seasons (Kropff, 1993), (b) knowledge of the existing weed control techniques (c) economic assessment of the available control methods not only in terms of economic return to investment but also to effects in the environment.

Predicting crop losses by weed competition

Kropff and Spitters (1991) developed a new and simple descriptive regression model for early prediction of crop losses by weed competition. This model was derived from the well-tested hyperbolic yield density model and relates yield loss (YL) to relative weed leaf area (Lw expressed as weed leaf area/(crop + weed leaf area) shortly after crop emergence, using the "relative damage coefficient" q. This descriptive model fitted the data accurately and the estimated value for "q" based on simulated data was close to the observed value for *C. album* (Fig 1).

To implement the approach in practical decision-making a methodology has to be developed to enable simple determination of the relative leaf area in the field, e.g. by estimating the relative leaf cover with infra-red reflection techniques (Lotz et al., 1993) or the cross wired sighting service used by Ghersa and Martinez-Ghersa (1991).

Factors that affect the densities and frequencies of weeds

- Type of soils
- Moisture content of the soil
- Type of tillage
- Season temperature
- Crop rotation
- Fertility level of the soil
- Competitive property of the crop

If by some methods crop losses have been estimated and weed control necessary, what are the weed control technologies available?

I. Chemical

Chemical control of weeds include the use of the following;

1. Glyphosate
2. Diuron
3. Atrazine
4. Metribuzin
5. Oxadiazon
6. Imazamethabenz
7. Paraquat
8. Fluchloralin
9. Napropamide
10. Clomazone
11. Others

II. Biological

Biological control of weeds is the deliberate use of natural enemies and pathogens to reduce the population density of a target weed below its economic injury level. Recently, fungal pathogens have been developed, registered and marketed as inundative control agents, i.e. mycoherbicides. They can be used in combination with other pesticides and mainly have been developed to control weeds in crops.

In the U.S., Canada, Australia and Southern Africa, the use of biological measures to control weeds achieved some big successes. Living organisms are mainly used as biological control agents in classical or augmentative biological control.

Classical method consists of an introduction of preferably host-specific, self-reproducing, density dependent, host-seeking exotic natural enemies adapted to an exotic introduced pest, resulting in permanent control (Batra, 1982).

Augmentative method is characterized by a mass propagation and periodic release of exotic or native natural enemies that may multiply during the growing season but are not expected to become a permanent part of the ecosystem. Recent findings showed that about 32% of the final aim - a substantial damage of weeds - was achieved.

In Croatia, they have introduced an insect enemy of the common ragweed-*Ambrosia artemisiifolia* (IGRC, 1987), which they reared, investigated and released on three sites. The insect enemy is the beetle *Zygogramma saturalis F.* After several releases, the number of established insects is low and no effects on ragweed was registered. It remains to wait some more years, as it is known that an acclimatisation of some newly introduced insects and first successes in some cases occured ten years after introduction.

In Europe, only one current research programme using the classical approach is at an advance stage, that is, a biological control project on bracken (*Pteridium aquilinum*) in the U.K., (Muller-Schärer, 1993). Recently, an application has been made to the U.K. Department of the Environment for the release of the noctuid moth *Conservula cinisigna*, and a further application is planned for a second moth species.

With regard to the inundative approach, work has been mainly concentrated on the use of endemic fungi due to regulatory problems for introducing foreign agents. In the Netherlands, registration of a mycoherbicide (*Chondrostereum purpureum*) for the control of Prunus spp. in forests was applied for in 1991 (Muller-Schärer, 1993).

III. Mechanical

A. Tillage

Tillage can be considered a preventive type of weed control. Tillage action will cover the weed seeds, but on the other hand, early tillage may allow for a good condition for early weed growth.

During a 7-yr experimental period in New Zealand, deeply cultivated (250 mm) previously cropped with vegetables recorded 28 000 weed seedlings m^{-2}, whereas shallow cultivated (10 mm) had 11 000 and in uncultivated plots just over 4 000 (Popay et al., 1994). In a separate study, Vencill et al. (1994) found seed densities of common cocklebur and large crab grass greater in conventional tillage whereas smooth pigweed seed densities were not affected by tillage. Similarly, Gill & Arshad (1995) found increasing tillage intensity increased the broadleaf population whereas decreasing tillage intensity increased perennials.

In Northern Canadian Prairies, studies on the effects of conventional, reduced, and zero tillage systems on the growth of dryland spring barley (*Hordeum vulgare* L.), canola (*Brassica campestris* L.) and weeds showed that there was an inverse weed population response to tillage such that there was a greater weed population under zero tillage and a shift in species composition. This finding could relate to a study of Vencill et al, (1994) wherein with no-tillage there was greater seed densities of common ragweed, common lambsquarters, horseweed and sicklepod.

When tillage alone was compared to no-till it resulted in 88%, 78%, 64% and 31% control of quack grass with fall moldboard plough, spring moldboard plough, fall soil-saver and spring soil-saver tillage, respectively (Berti & Zanin, 1994).

Summing up, tillage effects on soil properties and weed seed placement influence number and diversity of the weed population (Roberts and Feast, 1973). Weed seed depth in the soil influences germination and seedling development. Seed at or just below the soil surface often germinate more than seed buried deeper in the soil. Seed placed deep by ploughing may remain dormant until further tillage places them where germination may occur. Weed species with long dormancy are favored by ploughing. Seed buried deep in the soil also take longer to emerge and develop seedlings than seed placed shallow (Mester & Buhler, 1990). Depth for optimum germination and development varies among species. For example, velvetleaf (*Abutilon theophrasti medicus*) seed germinate and establish optimally at 2.5 cm (Mester & Buhler, 1990) while dandelion (*Taraxacum officinale* weber in Wiggers) germinates best on the soil surface.

B. Hoeing

Hoeing implements usually consist of duckfoot blades of about 10 cm width. A hoe with inclined sharp blades is used to cut weeds. It is less dependent on the growth stage of the weed population than harrowing, so it can be applied to the crop over a longer period (Terpstra & Kowenhoven, 1981). When crop plants are small, hoeing is done with L-shaped hoes or A-shape of hoes with discs to protect the plants against covering with loose soil. Later, when crop plants have grown hoeing may be slightly deeper to throw up soil and cover weeds in the plant row. The 'ducksfoot' type of tyne especially, causes considerable movement of soil near the soil surface, and transport of soil alongside the path of the tool. Hoeing, however, is not so effective in intra-row weed control. To improve the performance of a hoe, Steketee (Terpstra & Kowenhoven, 1981) designed a ridger-like hoe, which turns the soil and moves it partly sideways. Intra-row weeds are covered with a layer of soil, while inter-row weeds are uprooted and overturned by soil, or brought to the surface of the loosened soil and exposed to dessication. Today, the Steketee hoe is mainly used in sugar beet in a later stage of crop development.

In Croatia, in a vineyard with 90% weed cover before first hoeing in spring was reduced to only 20% with only one hoeing which was already tolerable. With several hoeings thermophilar weeds were suppressed (Topic, 1993). Similarly, using the hoeing machine on the heavy alluvial soil and at 16 cm row space (sowing with the no-tillage system) very high weed reductions of about 90% were obtained (Böhrnsen, 1993). The big weeds were better controlled by the hoe than by the weeder-tines and chain harrow links. However, it has to be considered that the hoeing machines mostly affect the space between the rows, so that the weeds in the row continue to grow undisturbed or only slightly affected. Besides, hoeing of cereals demands time and great care to adjust the interblade distances (Böhrnsen, 1993).

Studies of Rasmussen (1993) showed that although hoeing reduced the density of natural weeds and *S. alba* to approximately 50%, the reduction in weed dry matter were very small due to strong intra-specific competition. Because hoeing is insufficient to control high competetive weeds in the inter-row spacings it has to be supplemented with other control methods to make efficient suppression of highly competitive weeds. The use of hoes in cereals is limited by the small capacity of the hoes, that is, it is only possible to hoe in the sowing width. A breakthrough may be possible in the mechanical field when sectioned auto steering implements are available in the market.

C. Brush Hoeing

Brush hoe weeders are specially designed to eliminate weeds at the plant inter-row. Basic requirements for successful inter-row weed control are:

- to have a good weeding effect
- to have a high working capacity
- to maintain or improve soil conditions
- to minimize the uncultivated strip along the crop row

The weeding effect of the rotary brush is combined with a soil transport to the back of the brush. This means that a complete layer down to the working depth of soil is disturbed. The weeds are digged out, buried or left on the soil surface for desiccation. Deeper and firmly rooted weeds will be damaged by stripping leaves and breaking stems (Weber & Meyer, 1993). The working depth proved to be a decisive factor for the success of the weed control. If the level of the average depth of the weed roots is reached, the weed reduction is increased to 100%.

Under constant soil conditions and constant adjustments of the supporting wheels and the spring tension, the driving velocity and the absolute brush velocity which means the velocity of the bristles striking the soil are decisive for the working depth. An increase of the driving velocity at a constant absolute brush velocity lead to a decrease of the working depth. Constant driving velocity and an increasing absolute brush velocity lead to an increase of the working depth. These two factors always have to be regarded together. This means that with an increase of the driving velocity the absolute brush velocity has to be increased in a specific ratio to get the same depth.

For some types of row brush hoe this fact will cause a limit to the possibility of driving faster to get a higher working capacity. The first limit is a technical limit caused by the tractor and the transmission. The second limit is an ecological limit- the decrease of the soil structure quality.

High absolute brush velocity leads to an increase of the fraction of the fine earth and to a decrease of the coarse and stabilizing fraction. The consequence is erosion after heavy rainfall. The soil with higher fraction of fine aggregates are more susceptible to silting up or compaction. This shows that the absolute brush velocity must not be raised too much.

During wet conditions, the row brush hoe had no apparent detrimental effect to the soil structure and throughout the experimental period there were good results of the weed control (Weber & Meyer, 1993).

In weed-free onions, findings of Fogelberg and Johansson (1993) showed that there was a weak tendency for a lower yield when the brushes rotated forward whereas the onions were earthed up when the brushes were rotating backwards. A more thorough investigation on the use of brush weeders seems necessary particularly on cropped fields. On the other hand, from the same study on a crop-free soil a normal intensity of 2.6 for the row brush reduced weed significantly by 73%. The very high intensity of 7.9 resulted to significant weed reduction of 89% until two weeks after brushing.

D. Harrowing

Rasmussen (1993) introduced the use of the term "selectivity" for assessing the effectivity of harrowing. Selectivity is defined as the ratio between weed control and crop covering by the soil and is used as a function of the level of weed control.

The factors to consider in order to attain high selectivity:

1. Time of harrowing
2. The composition of weed flora
3. Differences in the growth stage
4. Plant height of crop and weeds

The harrows used to control annual weeds are provided with tines, which are either stiff or vibrating. The tines are hardly managed with respect to the rows and hence the entire soil surface is superficially cultivated. However, this method of weed harrowing pulls up none or only a few percent of the crop plants. Harrowing at the earliest stages of the development of the weeds mainly functions by covering the weeds with soil.

Finger weeders are the ones used for selective harrowing that is carried out when the rows of cereal have become so vigorous (at late tillering stage) that the tines of the harrows are forced sideways into the space between the rows.

Studies of Rydberg (1995) showed that good weed control by harrowing was obtained during the 0-4 leaf stage. However, weed harrowing damaged cereal plants as indicated by the weight of cereal shoots two weeks after final harrowing. There was a lower weed control effects of harrowing in winter wheat than in spring cereals because weeds are bigger in winter wheat as they are established in autumn. Another problem with harrowing in winter wheat seems to be that not enough loose soil aggregates are available or created by the harrow to bring about sufficient soil covering of the weeds.

Rydberg (1995) also indicated similar observations as Rasmussen that the effect of harrowing on the weeds and also on the grain yield was best correlated with the soil coverage on the crop plants. The degree of soil covering is an important parameter for measuring weed harrowing intensity. Additionally, harrowing direction did not significantly affect weeds but increasing driving speed caused more soil to cover the oat plants, thereby significantly reducing grain yield. Harrowing when weeds had 4-6 true leaves and crop had 6 leaves with a depth of 4 cm involves high selectivity ratio and was supported by higher yield of oats compared to harrowing in the 0-4 leaf stage.

Constraints to mechanical weed control:

1. Economy= Herbicides could be cheaper than mechanical weed control. But according to Rasmussen (1993) it is important to intensify research in mechanical weed control in an international context - both regarding research that has its starting point in basic biological problems and research that comprises new technologies as for instance development of sensors which may be used for steering of implements and identification of weeds to minimize negative environmental and other effects.

2. New methods of control demand extra management. A shift from pure chemical weed control to a combined (mechanical and chemical) weed control as well as preventive methods requires further knowledge and education.

IV. New Methods

A. Photocontrol

This method is based on scientific principle: The daylight usually only penetrates a few millimeters into the soil, but seeds deeper down in the soil may get a short light exposure during soil disturbance (Tester and Morris, 1987). In full sunlight, with a photon flux of about 2000 mol $m^{-2}s^{-1}$, exposures of a few milliseconds are enough to promote germination in the most light-sensitive seeds (Scopel et al., 1991).

Works on photocontrol of weeds by Hartman and Nezadal (1990) showed a reduction of weed population when all soil-disturbing work was carried out one hour after sunset and one hour before sunrise. A valuable feature of photocontrol of weeds is that the weed emergence is not only reduced but also delayed (Freiburghaus & Häni, 1993; Jensen, 1992). A delayed weed emergence increases the competitive ability of the crop and thereby gives opportunities for further reduction by direct control methods.

When colored equipment such as sowing machine or tillage equipment with far-red lamps with very strong emission under a light-proof cover is used, it may further decrease or delay germination. Far-red light has ability to inhibit germination of light sensitive weed seeds (Frankland and Taylorson, 1983). The varying effects of photocontrol and the -at the moment- rather unpredictable interactions of different environmental factors are major drawbacks of the method. It may be possible to use the method as part of an integrated weed management system. Tillage in darkness may then become a valuable contribution to the environmentally friendly control methods (Ascard, 1993).

B. Flaming

It involves the use of liquified petroleum gas (LPG) or propane gas. The technique is to expose weeds to high temperature for a short period of time (about 100 °C for 0.1 s). Most annuals are sensitive to flaming at the cotyledon or 1-2 leaf stage. The effect of the flame is to coagulate the protein and burst the cell membranes, damaging the plant beyond recovery. The aim is not to burn or char the plant. The plant withers after 2 or 3 days. The way to test the effect of flaming is by pressing a leaf lightly between finger and thumb and a lasting impression indicates extensive cell damage

Findings in Italy (Ferrero et al., 1993) on a 10-year old orchard showed that weed management carried out with flaming did not differ remarkably from those achieved with mowing. Flaming kept the infestation of the same cover degree given by glyphosate at 150 g/ha but clearly induced a selectivity pressure in favor of *Taraxacum officinale*. In young plantation where the treatments started on a clean soil after cultivation, flaming maintained the weed growth at a cover degree of about 25% which was one-third of that obtained with mowing. However, flaming cost approximately 80% more than the chemical weed control at 600g/ha of glyphosate (Fergedal, 1993).

Plants have varying resistances to flaming (Rahkonen & Vanhala, 1993). *M. inodora* was less injured by flaming than *C. album* and *P. pratense*. In the vegetation flamed with low doses at the cotyledon-2 leaf stage, the fresh weight of *M. inodora* rose even higher than if untreated.

C. Freezing

The principle involves that when there is a very rapid fall in temperature, ice forms inside the plant cells and the entire cells immediately turned dark in color destroying normal functions.

The media that could be used for freezing includes liquid nitrogen and carbon dioxide. Freezing consumed more energy than flaming to reach the same weed control effect in dicot weeds. Compared with flaming, freezing with liquid nitrogen consumed three times as much energy and freezing with carbon dioxide snow consumed six times as much energy in order to reduce the number of weeds by 90%. Weed control by freezing seems to be an expensive method because of the large quantities of freezing media required to obtain good results. However, under certain conditions, freezing might be a useful method for example in places where there is a great risk of fire (Fergedal, 1993).

V. General crop management practices

A. Increasing crop density

Since plant density is one of the factors that determine the crop-weed competition, increasing crop density is one way of suppressing the growth of weeds.

Research in Nicaragua showed that higher planting density of pineapple decreased the weed infestation (Pohlan, 1993) whereas a study in Cameroon (Ambe, 1995) showed that a density of 20 000 plants ha^{-1} of improved sweet potato (*Ipomoea batatas* (L) Lam) gave higher mean tuber yield as compared to 10 000 plants ha^{-1}.

B. Intercropping

Intercrop species like rye or ryegrass and red clover were more effective in reducing weed infestation in broccoli as compared to cultivation alone. Establishment of an intercrop species 25 days after transplanting of the broccoli, combined with two cultivations is an effective strategy for controlling weeds without adversely affecting quality and yield of broccoli (Tessier & Leroux, 1993).

Since intercropping increased the plant population within a specific area it would require higher input of nutrients. Over the corresponding sole cassava intercropping cassava and maize with N-fertilizer application gave the highest leaf area index and light interception and hence the best weed control, highest N, P, and K uptake and total yields. Intercropping with no N application made only slight improvement in leaf area index, light interception and weed control (Olasantan et al., 1994).

Use of an oat companion crop has both agronomic and economic merit for producers establishing alfalfa on irrigation areas in the semi-arid region of Saskatchewan (Jefferson & Zentner, 1994). Economic returns were generally higher for direct-seeded alfalfa or for alfalfa seeded with an oat companion crop that was harvested for hay when the ratios of alfalfa hay and oat hay to oat grain price were greater than 1.2 and 0.9, respectively.

C. Crop rotation

In Guinea savanna in Africa, weed communities were differentiated using five factors to describe soil fertility and field history conditions through discriminate model. The analysis showed that maize-based cropping systems with a high frequency of cereal cropping and a low frequency of non-cereal cropping tended to be dominated by weeds sush as *Commelina* spp and *Kyllinga squamulata*. Increased frequency of non-cereal crops in mixed cropping with cereals was associated with reduced incidence of weeds such as *Leucas martinicensis, Oldenlandia corymbosa, Spermacoce verticillata, Ludwigia hyssopifolia, Celosia laxa* and *Ipomoea* spp.

D. Mulching

Various type of mulch are used to control growth of weeds. Harowitz (1993) used plastic fabrics (woven polypropylene, PP), solid films of polyethylene (PE) of various colors, and chips of okoume wood, to control weeds in soil infested with annual weeds and nutsedge (*Cyperus rotundus*) during summer. Results showed that white and green plastic (PE) had little effect on the weeds. Beneath brown and black PE, and black, blue and white-black (double color) PP fabrics, no annuals emerged and development of nutsedge was markedly reduced; however, weeds regrew after lifting the cover. Shoots of nutsedge are capable of piercing stretched plastic covers. A 15 cm-layer of wood chips effectively reduced the development of annuals and nutsedge (Harowitz, 1993).

Printz (1993) also suggested the use of plastic films for preventing the growth of weeds thereby avoiding or reducing the use of herbicides. The mechanical laying in place and removal at the end of the cropping season together with the possibility of reprocessing after use make plastic films one of the materials compatible with high performance modern cultural techniques which are environmentally acceptable. However, performance of plastic mulch was improved if combined with paraquat outyielding pre-plant application of aproamide followed by paraquat (Orengosantiago & Liu, 1994).

E. Integrated weed management

There are a lot to mention about integrated weed management strategies and most of them include anyone or more combinations of tillage, use of herbicides, mulching, timing of weeding, crop rotation and all other weed control measures mentioned earlier. But any control measure will depend on specific requirements for a particular location.

Improvement of decision making

Since weed problems obviously can not be solved by adaptation of only one of the control measures available or of general crop management practices mentioned, insight into the decision-making process of farmers is needed. This is to determine what knowledge should be at hand and in what form. The decision-making process in weed management based on post-emergence observations is illustrated in figure 2.

To allow rational decision-making the severity of weed infestation shortly after emergence should be quantified using a simple practical method. Recent studies allowed predictions of weed effects on crop yield on the basis of the observed severity of infestation. These observations should be repeated until newly emerging weeds no longer affect crop yield. The efficacy and cost of different possible weed control measures (mechanical, chemical, biological and others) also have to be quantified on the basis of observations of the weed infestation. Criteria must be defined (ie. the cost effectiveness of weed control) to enable economic decision making.

For a specific location a thorough knowledge should be available of the existing weed control measures both during the cropping period and when the land is not in use. And since occurence of the weeds depends on climate, tillage, amount of seeds in the soil and many other factors a farmer may have to use several weed control measures but of course the choice will depend on the profitability of the system.

At present, limited work on economic aspect of weed control is available. However, a suggested reference for this was that of Auld et al. (1987). Additionally, future research should be system-based. Emphasis should be given to weed control methods that minimize environmental side effects as well as those that improve the structure of the soil.

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EFFECT OF SOIL TILLAGE ON THE POPULATION OF EARTHWORMS

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INTRODUCTION

Soil tillage influences almost all physical, chemical and biological soil properties and processes (Håkansson, 1994). Thus, it may essentially influence the activity of soil fauna.

The earthworms have been subject of research by many scientists since 1881, when C. Darwin published his study on "The Formation of Vegetable Mould through the Action of Worms". The earthworms (*Lumbricidae*) form a major part of the biomass of soil fauna. So far, the effects of soil tillage on the populations of earthworms are, compared to other important problems, relatively poorly studied.

Three major ecological groups of earthworms have been recognized: epigeic species (*Lumbricus castaneus*), that live and feed above the surface of the mineral soil and do not make burrows; aneic species (*Alolobophora longa*), that feed at the surface and live in permanent burrows that open at the soil surface and endogeic species (*Alolobophora caliginosa*), that live and feed below the soil surface, making extensive burrow systems and ingesting and casting much soil as they seek soil organic matter for food (Lee & Foster, 1991). According to Lavelle (1981) one more group can be determined, i.e. epianeic group. *Lumbricus terrestris* is considered to be epianeic because it is not able to resist unfavourable conditions by either quiescence or diapause (Bouche & Gardiner, 1984). Therefore *L. terrestris* cannot belong among the aneic species.

The size and composition of the earthworm population stays almost stable in natural biocenosis. Due to the meteorological conditions some changes take place after all. The situation is completely different in arable land, where the number and composition of species depend upon the agrotechnology used (Pöder, 1995a).

There are usually smaller populations in arable soils than in grasslands and this has been attributed to mechanical damage during cultivation (Zicsi, 1958). However, according to Edwards & Lofty (1975), some forms of cultivation can increase the number of earthworms for a short time. Most likely a lack of organic matter in continuous arable systems is responsible for the decreased earthworm populations (Edwards & Lofty, 1982).

The effects of some soil tillage methods on the earthworm populations published in literature, will be discussed in this course project. The aim of the project is to summarize relevant results of research, thereby answering the following questions:

1. How does soil tillage influence the population of earthworms?
2. Which factors may influence the effect of soil tillage upon the earthworms?

WHY DO WE CONSIDER WELFARE OF EARTHWORMS SO IMPORTANT? CAN WE USE THEM FOR EVALUATING THE EFFECT OF SOIL TILLAGE AT ALL?

Most of the earthworms spend nearly all their life in the soil, thus, they are directly dependent on the quality of the soil environment.

As bioindicators, earthworms are of particular importance because they are sensitive (Edwards & Lofty, 1977) and widely spread. They are capable of changing many of the soil characteristics such as: structure, infiltration rate and exchange of gas with the atmosphere. However, the indirect effects on soil properties (humification and mineralization of organic matter, soil mixing and turnover, macroporosity) are those that make them so important for the maintenance of soil productivity and thus ecosystem stability (Pankhurst, 1994). It is also noticed, that earthworms have a positive influence on emergence, height and root weight of barley (Edwards & Lofty, 1980). By influencing soil chemical and physical properties earthworms indirectly affect the environment for bacteria, fungi and other organisms (Boström, 1988).

The presence of earthworms in large numbers is usually regarded as a sign of soil health and productivity. According to Lee (1985) the size of populations ranges from 10 to locally 2000 earthworms m^{-2}.

Before we start a discussion about the various effects of soil tillage on earthworms it is vitally important to know what is going on in soil when we cultivate it.

FUNDAMENTALS OF SOIL RESPONSE TO TILLAGE: A BIOLOGICAL POINT OF VIEW

Various changes take place in the soil when it is tilled:

1) Soil tillage increases microbial activity thus accelerating the decomposition of organic matter in the soil (Blevins et al., 1984), and decreases the activity of soil fauna (House & Parmelee, 1985). The decomposition and mineralization of organic matter in the soil

under conventional tillage takes place more rapidly, with a fewer steps and fewer number of organisms (microflora) and at deeper soil layers. Soil tillage takes part in the reduction in the number of soil organisms and their biomass (Dindal, 1989).

2) The absence of soil cultivation (no till) leaves the soil surface covered with plant residues of previous crop and improves the environmental conditions of soil fauna (House & Stinner, 1983). The loss of soil moisture and the temperature extremes become smaller, and heterotrophic organisms are supplied with continuous substrate (Crossley et al., 1984).

3) An increase in amount of organic matter and concentration of organic matter and nutrients closer to the soil surface takes place under a no till or shallow cultivation (Crossley et al.,1984).

In addition, if we minimize soil tillage we increase soil bulk density (Francis et al., 1987) and strength, and reduce both total and macro-porosity especially in top soil. Nevertheless, the population of earthworms is usually more numerous under reduced tillage. As a result of that, the system of soil pores is more continuous than under conventional tillage.

DISCUSSION

It is appropriate to start a discussion with a description of how the earthworms make their burrows in the soil. Earthworms use two basic mechanisms to make burrows. These are: 1. exerting axial pressure to insert the anterior portion of the body between soil aggregates, then compressing the soil radially using cyclic contraction and relexation of the muscles to generate peristaltic waves of pressure along the body; 2. everting the pharynx and using suction to engulf and swallow soil, which is passed through the gut and excreted as molded casts. A combination of these two mechanisms is probably used most often (Lee & Smettem, 1995).

The extent to which earthworms burrow by eating the soil and by penetration depends on many factors. It depends on the physical properties of the soil (texture, strength, macro-porosity), purpose of burrowing (feeding, looking for more suitable conditions) and earthworm species (aneic, epianeic, endogeic). Earthworms of the genus *Lumbricus* are not very extensive burrowers and earthworms of the genus *Aporrectodea* are far more active. If the earthworms burrow for the purpose of feeding they probably use more eating than penetration. In that case the speed of burrowing is rather low e. g. when *A. rosea* burrowed only for the purpose of feeding, rates of 40 mm per day were observed for adults and 10 - 25 mm per day for small immature worms (Bolton &

Phillipson, 1976). If they are looking for more suitable conditions to live their burrowing activity is very high, then the penetration is more important than eating. When the earthworms are not able to insert the anterior portion of the body between soil aggregates (high bulk density, low macro-porosity) in order to penetrate, they have to use eating. The same occurs to some extent if the soil strength is too high.

Soil tillage influences earthworms in several direct and indirect ways. Traffic and tillage implements, through which we can cause various compaction effects are of great importance. The bulk density range 1.38 - 1.66 Mg m^{-3} has negative effect on the length of earthworm burrows and ability to penetrate through the soil (Rushton, 1986; Kemper et al., 1988; Joschko et al., 1989). That is a value of bulk density we very often find in topsoil.

Even more important than the soil bulk density is the soil strength. If we use soil bulk density as a parameter we know how dense this soil is, but we do not know how much force the earthworm has to use in order to penetrate through the soil. The effect of soil strength on the earthworms depends to a great extent upon the earthworm species. According to McKenzie & Dexter (1988a), the ability to penetrate through the soil is more important to the endogeic species, such as *Aporrectodea caliginosa* and *A. rosea,* than to epianeic *Lumbricus terrectris*. It has been proved that *A. caliginosa* does not have permanent burrows (Edwards & Lofty, 1975) as is the case of *L terrestris*. In the case of aneic and epianeic species, the soil strength turns out to be important if their system of burrows is destroyed by soil tillage or compaction.

Soil strength over the range of micropenetrometer resistance from 0.3 - 3 MPa did not influence the tunneling of *A. caliginosa* (Dexter, 1978). *A. rosea* (very similar species to *A. caliginosa*) can exert mean maximum axial pressures of 73 kPa and mean maximum radial pressures of 230 kPa (McKenzie & Dexter, 1988a,b). In the studies of Kemper et al. (1988) under simulated field conditions the critical values of soil strength for the earthworms appeared to be between 300 and 600 kPa.

Boström (1986) stated in her paper, that traffic and resulting soil compaction had both a direct and indirect impact on the abundance and biomass of earthworms. She also gave several reasons to that statement such as: the lower food supply due to the lower yield in trafficked plots, the lower number of juveniles (especially small and medium-sized juveniles) per adult and so on.

The effect of soil tillage implements is also important. In this case we can point out at least two factors which may influence the effect. These are the feed habit and the depth of location in the soil profile. *L. terrestris* and *Aporrectodea longa* are deep burrowers but both of them feed on plant residues which are on the soil surface. *A. caliginosa*, *A.*

rosea, *Aporrectodea castaneus* and *Lumbricus castaneus* are considered to be shallow burrowers and they all feed on the organic matter which is in the soil, exept *L. castaneus* that feeds also on plant residues on the soil surface. *L. rubellus* is considered to be a medium-depth burrower and it feeds on plant residues on the soil surface.

Usually the number of earthworms increases and the composition of their population changes after the transition from mouldboard ploughing to no tillage (Barnes & Ellis, 1979). In most cases the population of earthworms is smaller in arable land and this has been attributed to mechanical damage during cultivation.

How great is the mechanical damage of earthworms through the soil cultivation? Boström (1988) found the weight and number of *L. rubellus* and *L. terrestris* to be higher under in an undisturbed lucern field than in tilled soil. After conventional tillage (one rotary cultivation 7 cm + one ploughing 27 cm) almost all worms found had been cut to pieces during cultivation. As a sum of these tillage operations, 70 - 75% of earthworms were killed, from that 25% were killed by the ploughing. One year later, the number of *A. caliginosa* was higher in tilled plots than in those without tillage. In the case of *A. longa*, there were no differences in number.

Scientists from New Zealand got rather similar results as U. Boström. Repeated cultivation with ploughing reduced the population of earthworms by 74% in their studies (McLennon & Pottinger, 1976). The mortality of earthworms due to ploughing is according to Cuendet (1983) 25% from the earthworms which are found on soil surface.

Thus, the direct damage of earthworms through soil tillage is quite remarkable, but there are differences between species. In some cases, soil tillage has a certain favourable residual effect on some species.

The whole population of earthworms decreased during the 5 year growing of cereals under all forms of cultivation in the studies by Edwards & Lofty (1982). Associated with this decline, however, there were differences in the effects of direct drilling and ploughing on the different species of earthworms. In the case of direct drilling, the number of *L. terrestris* and *A. longa* was considerably higher. The number of deep burrowing species decreased dramatically in ploughed plots, whereas the effect of chisel plough was somewhere between that of direct drilling and ploughing. By contrast, the number of shallow burrowing species differed little between tillage treatments.

The domination of endogeic species decreased from ploughing to spring cultivated soils (ploughing > autumn cultivation > spring cultivation), whereas it was equal in ploughed and chisel tilled soils in studies of Nuutinen (1992). The population of epigeic and aneic earthworms always increased in ploughless tillage, especially when straw was left on the field.

Thompson (1992) concluded that the number of *Aporrectodea trapezoides* was higher in zero-till and stubble retained treatment than in tilled and stubble burnt treatment. The number and weight of earthworms increased in following direction: mouldboard plough < chisel plough < zero-till.

House & Parmelee (1985) found that the number of *Aporrectodea turgida* and *L. rubellus* was, depending on crop rotation, 211 - 549% higher under no till than under conventional tillage (mouldboard ploughing once, disc ploughed 3 times, rotary tilled twice). Ehlers (1975) counted 2 times more earthworms under no till than in soil with shallow tillage. In addition to the higher number of earthworms, reduced tillage increases the activity of earthworms (Riley et al., 1994).

In some cases, there are no significant differences in number and weight of earthworms between zero-tillage and autumn ploughing. Remy & Daynard (1982) found that spring tillage diminished the number of earthworms more than autumn tillage.

The moisture content and soil temperature can very much influence the effect of soil tillage on earthworms. Often there are 80 - 95% of the whole population of earthworms at the depth of 0 - 10 cm during the spring tillage operations, but hardly 40 - 50% during the ploughing of fallow land in autumn and sometimes there are no worms at this depth at all (Pöder, 1994). Consequently, when there are less earthworms at the tillage depth there will be less damage to them.

We can also conclude, that the deeper and the more intensively we cultivate and more we turn the soil the higher is the possibility of mechanical damage for earthworms.

One possible explanation for different effect of soil tillage on earthworm species could be the ecological peculiarities of earthworms, particularly their different feed habits. According to El Titi & Upach (1989), the most important factor, which influences the population of earthworms, is the amount of available organic matter, i.e. the food supply.

Endogeic species feed on organic matter in the soil and organic matter on the soil surface does not increase their activity very much. We mix the organic residues from the soil surface into the soil during the cultivation (especially ploughing). By doing that we improve the food supply for endogeic species whereby their activity increases. According to Edwards & Lofty (1982) the mechanical damage due to tilling is balanced by the greater availability of organic matter in the soil. In the case of aneic and epianeic species the situation is totally different. These species are favoured when we do not destroy their burrows and litter or plant residues are available on the soil surface not in the soil.

In different soil types the effect of soil tillage has been found being different. The biomass of earthworms was highest in clay soil and ploughing decreased the biomass in all sites except in a sandy soil in the studies of Haukka (1988). The reduced tillage increased the percentage of endogeic species in a heavy clay soil, but anecique group increased the most in a clay loam.

In ploughless tillage, there was the highest number of earthworms in clay soils, but in the case of ploughing the number of earthworms was higher in sandy loam (Nuutinen, 1992). Most likely the different composition of populations, soil physical properties, stability of earthworm burrows and regimes of soil temperature and soil water are responsible for that.

Cropping system is responsible for a supply of organic matter and intensiveness of soil tillage and compaction. Thus it may influence the formation of earthworm populations.

The earthworm population decreased markedly under 2 years of arable cropping when compared to the population at the start of the trial under the grass/clover pasture (Francis & Knight, 1993). But there were no dramatic changes in earthworm populations during 2 years in the part of the experiment where arable cropping had been carried on for 10 years.

It is possible to cause serious changes in an earthworm population formed under favourable conditions for earthworms within 2 years when we change the conditions. A relatively young population is extremely sensitive. For example, we succeeded to increase the number and weight of earthworms per area nearly 6 times by growing high-yielded clover grass for 2 years in experiments on crop rotations (Pöder, 1995b). But we were back at the original level when we grew barley and oats and used conventional tillage for 2 years. Thus, it is very easy to negatively affect a population of earthworms with a high percentage of juveniles by changing their living conditions abruptly.

CONCLUSIONS

It is evident that relationships between components of agro-ecosystem are extremely close. If we know these relationships we can make the soil work for us.

On the basis of what was previously discussed the following conclusions can be drawn:

A. Soil tillage and traffic influence population of earthworms by following ways:

(1) direct mechanical damage;

(2) changes of the strength and structure of the soil;

(3) changes of the content and distribution of organic matter in the soil and of the amount of plant residues on soil surface;

(4) changes of the regimes of soil temperature and water;

(5) destruction of the burrow system of earthworms.

B. The effect of soil tillage upon the earthworms is influenced by following factors:

(1) earthworm species;

(2) stage of development of earthworms;

(3) amount of plant residues on the soil surface;

(4) cropping system, crop yield;

(5) soil type (clay - sand);

(6) content and distribution of organic matter in the soil;

(7) physical properties of the soil (degree of compaction);

(8) moisture and temperature regime of the soil;

(9) tillage time, implement and depth.

A lot of work has been done and a considerable amount of information has been collected by the researchers all around the world. So, if we consider the welfare of earthworms important we should put this knowledge into practice. Unfortunately the methods for managing soil organisms are still at an early stage of development.

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THE FILTER PAPER METHOD TO DETERMINE WATER POTENTIAL IN TWO SWEDISH SOILS

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Introduction

For determination of soil water content and soil water potential we usually use gravimetric methods, time-domain reflectometry technique (TDR) and tensiometers. In some cases, for example in soils with low water contents and very loose soils, the TDR technique and tensiometers are not suitable to use. Equipment for some of the methods are also very expensive to buy. The filter paper method is used and described in the literature as a cheap and fast way to determine the soil water potential (McQueen & Miller, 1968; Al-Khafaf & Hanks, 1974; Hamblin, 1981; Campbell & Gee, 1986; Pasuquin, 1987; Bohne & Savage, 1991; Savage et al., 1992; Druege, 1995). The method is based on using filter papers with known water retention properties to determine water tension in soil within a wide range of soil water tensions. This is done by equilibrating the papers with the soil.

The aim with this study was to investigate the need of time for equilibration and of number of filter papers during equilibration in two Swedish soils with different structure and at different water content.

Materials and methods

Calibration of filter paper

Filter paper Munktell 00H with 55 mm diameter was equilibrated at water tensions 0.01, 0.02, 0.04 and 0.06 MPa, and then air dried. Nine replicates were used. The results were compared with the filter paper calibrations presented by Savage et al. (1992) (Fig. 1).

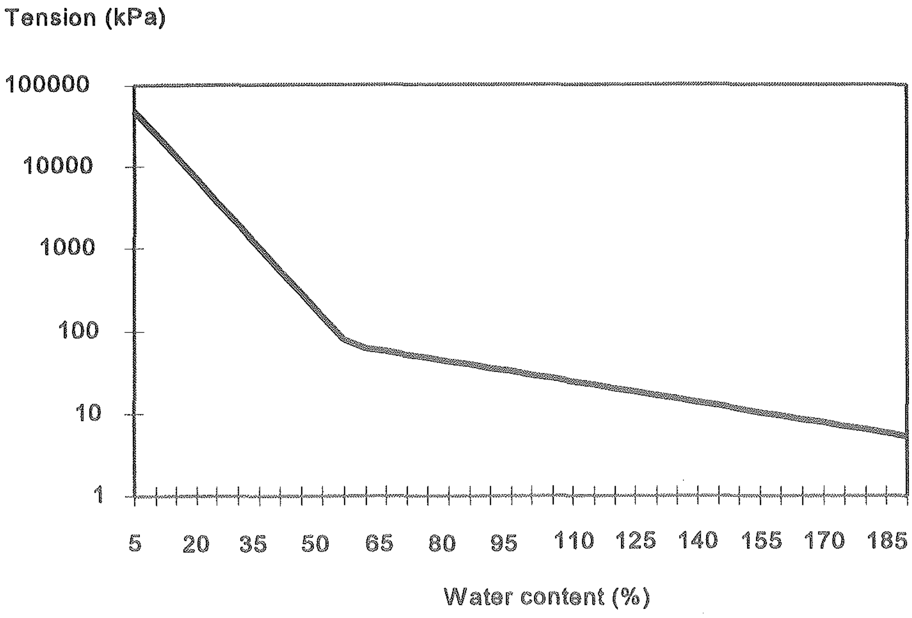

Figure 1. Filter paper water content (%, w/w) at different water tensions (kPa) according to Savage et al. (1992).

In the study by Savage et al. (1992), Whatman no. 42 filter papers were used, but the quality of the Munktell filter paper is almost the same as the Whatman quality.

The calibration equations in Savage et al. (1992) was:
for wf (%) <= 56.2 ψ_m (kPa) = exp (-0.128wf + 11.424)
for wf (%) > 56.2 ψ_m (kPa) = exp (-0.019wf + 5.282)
where wf is the gravimetric water content of the filter paper in per cent and ψ_m is the water tension in kPa.

Determination of water tension in the soil

Two soils were used in the study, a clay and a loamy sand (Tab. 1).

Table 1. Properties of the soils used in the experiment

Soil	Particle size distribution (g kg^{-1})			Organic matter content (g kg^{-1})	Water content (%, w/w) at tension (MPa)		
	Clay	Silt	Sand		0.01	0.1	1.5
Clay	494	392	115	35	33.0	25.5	18.3
Loamy sand	72	106	823	17	12.5	8.6	3.6

From the clay soil, both air dry and moist aggregates with diameter 4-8 mm and moist, slightly compacted unsieved soil were used. From the loamy sand, only unsieved, slightly compacted, moist and air dry soil were used. All five soils were replicated with two different times for equilibration; 24 and 48 hours. Each soil and time for equilibration was tested with both one and two filter papers.

Cylinders for soil core sampling (70 mm diameter and 50 mm high) were filled with soil according to the different treatments. One or two air dry filter papers were placed in the bottom of the cylinder and the cylinder was then sealed with lids in both ends to minimize evaporation from the cylinders during equilibration. The cylinders were then left for equilibration at 20°C. All treatments were replicated three times. A total of 60 cylinders were used.

After removing the filter paper after 24 and 48 hours, the gravimetric water content was determined in the filter paper and in the soil. The gravimetric water content of the filter papers were then recalculated into a water tension using the formulas presented by Savage et al. (1992).

Results and discussion

Calibration of filter paper

There were problems with equilibrating the filter paper at the different tensions on the pressure plates. I repeated the calibration procedure four times. There was a difference between using one filter paper placed directly on the pressure plate and using two or more filter papers as a sandwich (data not shown). When repeating the calibration the last time, weights were placed on top of the papers to increase the contact between paper and pressure plate. Four papers placed as sandwiches were used and water content was determined in the paper on top.

Table 2. The water content (%, w/w) of the Munktell 00H filter paper at different water tensions (mean from 9 replicates) and calculated water tension by Savage et al. (1992)

	Water tension (MPa)			
	0.01	0.02	0.04	0.06
Filter paper water content (%, w/w)	130	143	62	54
Calc. tension (MPa)	0.014	0.013	0.031	0.091

Water content of the filter papers after equilibration at different water tensions are presented in Table 2. The difference between the actual water tension and the calculated tension was big. The variation between the nine papers was big. The water content was higher at 0.02 MPa tension compared with 0.01 MPa, even in the case with four filter papers and weights on top. The pressure plate probably released water to the papers very fast after the tension was removed and released more water at higher tensions. There was a tendency that some of the papers weighed more at 0.04 MPa tension than at 0.01 MPa. Our laboratory routine did not suit the equilibration of the filter papers and the procedure at calibration has to be changed to avoid the problems. I changed the procedure slightly when weighing the papers after the 0.06 MPa equilibration, but without better adjustment to the equation. I can not say if the Whatman filter paper can be replaced by Munktell papers when using the calibration equation by Savage et al. (1992).

Table 3. Soil water tension (MPa) determined with the filter paper method and gravimetric water content (%,w/w) of the five soils

Soil	Water tension (MPa)					Grav. water content (%,w/w)
	1 paper, 24 hours	1 paper, 48 hours	2 papers, 24 hours	2 papers, 48 hours	Mean	
Clay, air dry 4-8 mm aggregates	31.2	34.8	43.0	37.1	36.5	5.5
Clay, moist 4-8 mm aggregates	0.127	0.085	0.171	0.090	0.118	24.5
Clay, moist, slightly comp.	0.061	0.051	0.067	0.058	0.059	26.0
Sand, air dry	58.0	43.0	62.0	47.5	52.6	0.85
Sand, moist	0.020	0.019	0.020	0.017	0.019	12.0

Determination of water tension in the soil

Weighing of the cylinders before and after equilibration showed that no water was lost during the equilibration time (data not shown).

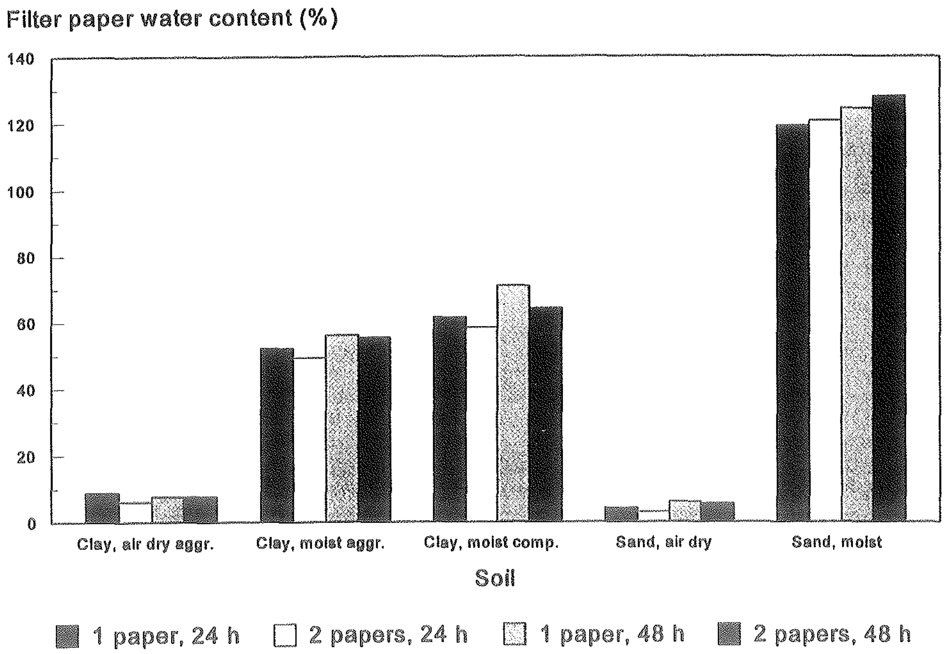

Figure 2. Water content (%, w/w) in the filter papers after equilibration in the soils.

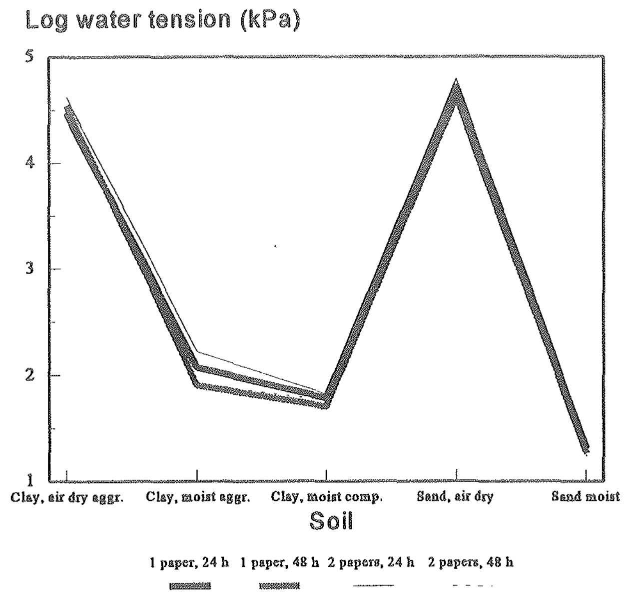

Figure 3. Logaritmized calculated water tension (kPa) in the soils according to Savage et al. (1992).

Water content of the filter paper after equilibration in the soils are presented in Fig . 2 and calculated soil water tension and gravimetric soil water content are presented in Tab. 3 and Fig. 3. The difference between all the five in water content of the filter papers and in calculated soil water tension after equilibration soils was significant. The difference in water content between the 24 and 48 hour equilibration time was also significant. The water content after the two different time periods for equilibration differed in all five soils.

The results from the experiments showed that 24 hour for equilibration in soil was not enough even in the moist soils or with one or two filter papers. Based on the results, I can not say if 48 hours are enough for equilibration. To be able to determine if 48 hours equilibration is enough, I need to compare with longer time periods. Especially in the filter papers in the loose, moist aggregated clay soil, the water content increased clearly after 48 hours compared with 24 hours both with one and two papers. In that case, a longer time for equilibration was probably needed because of the poor contact between soil and filter paper.

There was no significant difference between using one or two filter papers in any case but when looking at the data, there was a tendency that the calculated water tension in the soil always was higher using two papers. Two papers seem to require longer time for equilibration. One problem with using longer time for equilibration can be microbial growth on the filter paper (Hamblin, 1981). This is one of the reasons to use only one filter paper to shorten the time for equilibration despite the risk of soil sticking to the paper and disturbing the filter paper water content determination.

Conclusions

It was hard to find good procedures for calibrating the filter papers. When equilibrating the filter papers with soil, 24 hours was not enough for equilibration and two papers seemed to require longer time for equilibration. The method needs further testing at our laboratory conditions to suit our purposes with soil water tension determination.

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WEED CONTROL BY SOIL TILLAGE

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Introduction

Soil tillage is one of the oldest ways of weed management. With the use of chemical weed control the role of soil tillage in weed control fell into backround. The problem has become a live issue again in connection with ecological production.

When speaking of weed control we have to take into consideration the specific features of various weeds, and the conditions required for their growth and reproduction. The effectiveness of weed control also depends on the way of soil tillage, on time and quality and on several other factors.

Considering this the present paper has two parts:

- weeds, their quantity and conditions of reproduction;
- different ways of soil tillage and their capabilities of weed control.

The paper deals only with ordinary soil tillage in grain growing.

Weeds

The nature of weeds

Weeds have been defined in a number of different ways, the most common being the following form: "A weed is any non-crop (unsown) species" or "a weed is any plant growing where it isn't wanted". A plant becomes a weed, however, only in relation to human activities, and especially when it interferes with agricultural or horticultural processes. A better definition of a weed is: "A weed is any plant which is adapted to manmade habitats and interferes with human activities".

Weeds can be divided into two grups: annual weeds, that reproduce themselves mainly by means of seeds, and perennial weeds. The latter reproduce themselves both by seeds and by vegetative units: roots, rhizomes and runners.

Weeds take growth space from culture plants: shade them from light, use nutritients from soil and consume a great deal of water. Often weeds promote the spread of plant diseases and vermins. Weeds also make soil tillage and harvesting works harder, reduce the yield of culture plants and increase the production costs.

Soil seed bank

Size of seed bank

There can be millions of weed seeds in the ploug layer (20 cm) of a hectar. During investigations carried out in South-Estonia (Karmin, 1963) it was discovered that there were 260-1 644 millions of weed seeds per hectar in the ploug layer, and there were 48 species of weed seeds represented.

According to Wilson (1985) the density of weeds in soil can be between 4 100-137 700 per square meter. Although there is a large variety of seeds (up to 80 species), the majority (70-90%) of the seed bank is formed by only 10 basic species.

The seed bank of soil is of changing size. The supply of new seeds and its composition depends on the field's intensity of use, culture grown, years of tillage and other factors.

Kelly and Burns (1975) investigated the change of the seed bank before and after a five-year period with grassland grown after several years of annual crops.

The results were as follows:

- the seed bank grew four times;
- the importance of the predominating weeds (90%) degreased by up to 8% (annual bursage, slimleaf lambquartes);
- in the grassland period non-existent weeds (barniard grass, common lambquarters, pigweed) formed 90% of the seed bank.

Seed bank supplementation

The main way of weed spread is reproduction by seeds. For example, corn thistle can produce 35 000, corn mayweed 54 000, and white goosefoot up to 100 000 seeds. The majority of these seeds fall down close to their growing locality and this can be regarded as the main way of seed bank supplementation (Maltsev, 1959).

Weed seeds spreading by human activity, wind, water, animals or some other method can be regarded as of secondary importance in terms of seed bank supplementation (Lampkin, 1987).

Distribution of seeds in soil

Distribution of seeds in soil depends on the method and depth of cultivation.

In grasslands the basic part of seed bank is in the depth of 2 cm and doesn't reach deeper than 10 cm. In cultivated lands the major part of weed seeds is in the depth of 10-20 cm, but can range from the surface level up to the cultivation depth (Wilson, 1992).

Wicks and Samerbalder (1971) compared the affect of various kinds of soil tillage on distribution of seeds in various soil layers. With the use of stubble cultivation-ploughing-sowing the seeds were distributed within the whole range of tillaged layer. With minimized soil tillage where the field was not ploughed, about 50% of weed seeds were in sowing layer.

Germination of weeds seeds

Viability of seeds

Although some of the seeds in the seed bank will remain viable for many years, the year following the production usually accounts for the majority of total germination. Chickweed, for example, germinates rapidly in the surface soil (up to 95 % in the first year) but can remain viable for up to 60 years if buried under grass. The longevity of seeds in the soil is affected by the frequency of tillage and by the depth of seeds in the soil, but if no further seeds are added to seed bank, the reserves in the soil will decline.

Conditions of germination

Germination requires the presence of oxygen, moisture and suitable temperatures, usually in conjunction with light and nutrient sources such as nitrate ions. The mechanism which allows seeds to survive for long periods of time until conditions are suitable for germination is known as dormancy. Normally some factors such as farther ripening, ventilation, daylight, suitable temperatures or the correct degree of alternation between daytime and nighttime temperatures is needed to trigger on germination. Some seeds, such as coltsfoot, can germinate immediately and have no dormancy, while other annual grasses can enter enforced dormancy if conditions, such as soil moisture or enforced shading by burial, are not favourable to plant growth (Lampkin, 1987).

Germination and light

Although many weed seeds require light for germination, infra-red light, which passes through leaves, often inhibits germination, preventing seeds from germinating in conditions where the seedling is likely to be shaded out by other plants. Seeds which require light for germination are likely to germinate only in the surface layers of soil (Lampkin, 1987).

Taylorson (1970) examined the effect of light on germination of reedroot pigweed, barnyardgrass and yellow foxtail seeds. Seeds were buried in the soil and exhumed at various intervals. Reedroot pigweed seeds initially depended upon light for germination, but after 12 months of burial, seeds from all depths germinated after recovering. In contrast, barnyardgrass seeds, which were initially dormant and showed no response to light, became dependent on light for germination. Yellow foxtail seed germination did not respond to light.

Wesson and Wareing (1969) observed that fresh seeds of common chickweed indicated a low level of inhibition if exposed to light, but after burial for 14 days, seed germination was stimulated when seeds were exposed to light. Results from these experiments demonstrate the ability of seed burial to induce a light requirement that keeps the seeds of some species dormant.

Depth and germination

The depth of germination is also related to the size of the seed and its ability to supply nutrients to the seedling until it becomes properly established.

Figure 1 shows the relationship between seed size and the maximum depth of germination from which seeding emergence can occur.

The optimal germination depth is 1-5 cm, maximum 20 cm, but the seed will not germinate on the surface (Roberts, 1982).

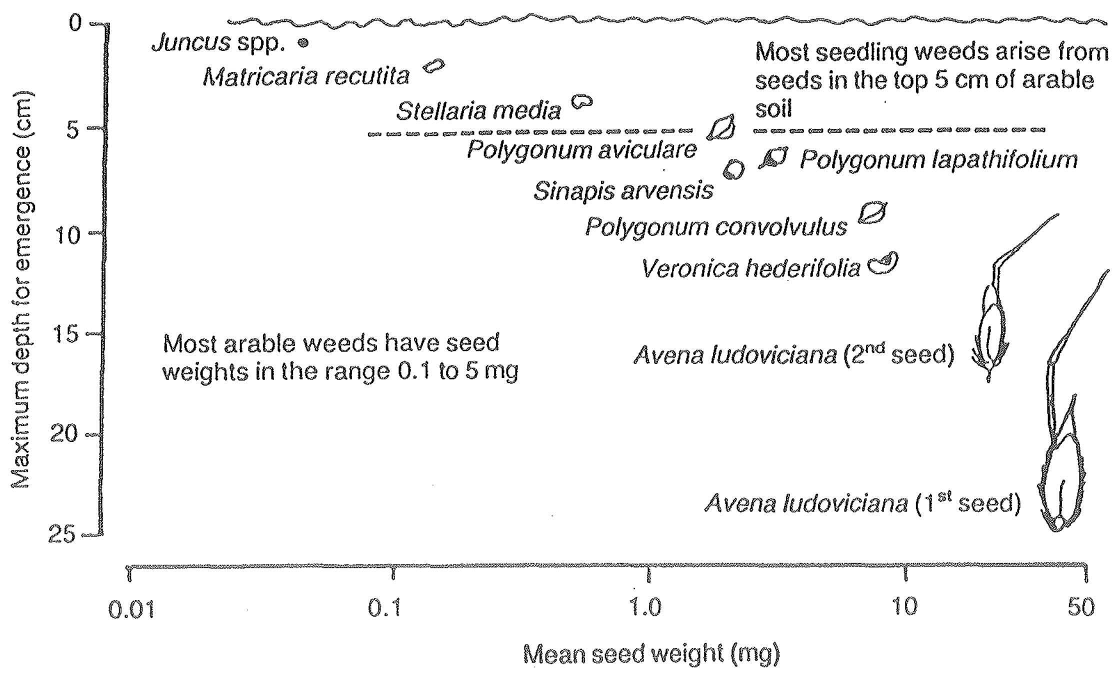

Figure 1. Relationship between seed size and the maximum depth of emergence (Roberts, 1982).

Seasonal germination

Many seeds germinate in particular seasons, some over very short periods. The time of germination is usually determined by day length, detected either by the penetration of light or by diurnal fluctuations in temperature. For this mechanism to be effective, the seeds need to be relatively close to the soil surface. For example, common hemp-nettle has its main germination period in the calendar spring, even with low temperatures, and will germinate from a depth of 1 to 4 cm, followed by rapid, strong root development. Other spring-germinating weeds including knotgrass and fool's parley, as well as fat hen and small nettle, which peak in the spring but continue germinating into the summer (Gwynne and Murray, 1985).

Weeds that germinate mainly in autumn include cleavers, winter wild oats, and ivy-leawed speedwell. Cleavers, however, are capable of germinating throughout the year, even in winter, but not in hot summer months.

Soil tillage

Stubble cultivation and disking

After grain harvesting, a surface layer of 7-12 cm in the fields is often cultivated. In this process soil is mellowed, loosened, mixed and partially turned over.

In ordinary technology of soil tillage the aim of stubble cultivation is to destroy weeds. By cutting the roots, growing plants are directly destroyed, and by soil mixing good conditions for germination and growing are created for weed seeds on the soil surface.

For stubble cultivation mainly harrows or cultivators with various tines, knives or disks are used. To combine various working characteristics of tines and disks, such combined machinery has been made that has both tines and disks-knives.

A positive effect of stubble cultivation on weed seed germination is achieved only when carried out during the optimal period for germination seed development. In Estonian conditions the latest term would be the second week of September. In later period germination of seeds has slowed down or totally stopped because of cool weather (Vipper, 1979).

Destroying perennial weeds by stubble cultivation is a practice of questionable value if it is immediately followed by sowing.

Ploughing

Excellent ploughing is an effective means of weed control. By giving up ploughing it is very difficult to achieve the same effect with some kind of other soil tillage implements.

With ploughing soil is turned over. During this process soil mellows and splits, and also mixes to a smaller extent.

With ploughing, smaller weeds are brought into conditions unsuitable for their growth and ungerminated seeds into conditions were they will not germinate.

If subble cultivation promotes the development of weeds by improving the germination conditions, then ploughing has to affect the growth of weeds only in a negative way.

Ploughing is the more effective, the more perfect the turning of a furrow is. In practice it is almost impossible to achieve a condition where the plough layer would be turned 180°, and the actual turning of the furrow has always been less than 180°.

Table 1. The effect of different ways of soil tillage on couch grass (Talpsep, 1967).

Ways of cultivation	Occurrence of couch grass, %
1. Spring ploughing	100
2. Autumn disking, spring ploughing	35,6
3. Autumn disking, harrowing, spring ploughing	21,2
4. Autumn ploughing	85,6
5. Autumn disking, autumn ploughing	37,9
6. Autumn disking, harrowing, autumn ploughing	21,2

Ploughing in autumn is generally more effective for weed management than ploughing in spring. Germinated weeds on soil tilled in autumn are either destroyed by winter frosts or by spring soil tillage. For of perennial weeds, then the Estonian experiments have indicated no real difference between spring and autumn ploughing.

Weed seeds have a marvellous ability to preserve the germination capacity for many years. There is a danger that with soil turning the seeds brought into depth, again will be brought up to the surface layer where the conditions for germination are good, with the next ploughing. To prevent this, some effect can be attained by varying the depth of ploughing in different years (Vipper, 1979).

Seed-bed preparation

With pre-sowing soil tillage, potentially favourable conditions for seed germination and growth are provided for the culture sown, but also the germination of weed seeds existing in the soil are promoted.

Naturally, with pre-sowing soil tillage, weeds germinated in early spring are destroyed, but this cannot be considered of any real importance in control of annual weeds. But pre-sowing soil tillage with S-tine harrow is effective in destroying root weeds (Vipper, 1979).

False seed-bed techique

The false seed-bed, or stole seed-bed technique means preparing the seed-bed some 10-14 days before drilling. When soil moisture is at the level to allow germination, subsequent flaming, harrowing or drilling will eliminate the major part of germinating weed seeding. This strategy has been known for decades and is often recommended in organic farming. However, without irrigation, it is difficult to obtain consistent results as low soil moisture or temperature often limit germination. Therefore the false seed-bed technique is likely to play a minor role in weed management. Delaying sowing might then even increase weed density or involve a risk of yield losses attributed to delayed planting time and to dry seed-bed conditions (Wookey, 1985).

Soil tillage in darkness

Soil cultivation and planting in the absence of daylight has been proposed recently as a method to reduce germination of weed seeds. This "photocontrol" of weeds prevents the germination of weed seeds due to lack of exposure to light. Jensen (1992) and Ascard (1993) found out that soil cultivation in darkness could reduce weed emergence by 15...60 %. Ascard (1993) also demonstrated that harrowing in daylight with a light-proof cover over the harrow reduced weed emergence.

Weed harrowing and hoeing

For weed control in grain production with mechanical devices after sowing and during growth, several light harrows and turning brushes are used for distribouce of the surface layer of soil.

Weed control with mechanical devices always means some damage to the culture plants or covering them with soil. Because of this mechanical weed control is not really required in cases where weeds cover less than 10% of the total area of a field (Geier and Vogtman, 1988).

Pre-emergence harrowing

Harrowing a field with a light harrow before the emergence of culture plants affects them in the least negative way.

For carrying out such harrowing the ideal time is 24 hours before crop emergence, but the development of the weeds should be the main basis for the considevation. If the first tiny roots have emerged, the operation can proceed. If not, then harrowing may well cause germination at a time when the emergence of the cultivated crop prevents further passes (Rasmussen and Ascard, 1995).

Early post-emergence harrowing

Early post-emergence harrowing is carried out soon after crop emergence in cereals and grain legumes. Harrowing mainly works by covering the weed seedling with soil, and by uprooting only to a minor extent. This method cannot control weeds without affecting the crop, as it covers the crop plants with soil.

Once crop is established and has past the three-leaf stage, harrowing can be effective. Before this stage, crop may be seriously damaged. Passes can be made across and along cereal rows. It is a quick operation and provided the ground is not too wet, little damage will be done, although the crop does look sorry for itself immediately afterwards.

Although the traditional chain harrow can be effective, the ideal implement is a harrow with long, thin, spring-loaded tines which are kinder to the growing crop.

This technique is effective against immature weeds that can be ripped out by the tines. If, however, the weeds themselves are well established, then harrowing has little effect on them. This approach is most successful on lighter soils and is not so suitable on heavy soils (Rasmussen, 1993).

Inter-row harrowing (hoeing)

This method consists of eliminating weeds only between rows. For this several machines with turning brushes and/or springtines are used.

As to not damage the growing plants, this method requires the use of large row spacing than commonly used. The recommended is 20-22 cm. In this method recommended also slow traveling speed (low capacity) and need a "extra operator" to working equipment.

Conclusions

It is possible to limit as well as promote the development and spread of weeds by soil billage. By knowing which are the dominating weeds in the field, we can choose suitable ways and implements of soil tillage for effective weed management. By eliminating growing weeds we can reduce the direct negative effect of weeds, but to decrease the weeding, control over the seed bank of soil is required. If we promote germination of different weed seeds by various soil lillage works, and afterwards eliminate sprouted weeds, we will lessen the seed bank of soil, which, in turn, helps to reduce the weed management in the growing cultures and the negative affect on plants competing with it.

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