MINIMISATION OF SOIL TILLAGE

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INTRODUCTION

Soil tillage is one of the most power-consuming and expensive processes in agricultural production. It requires 180-320 kWh/ha, which corresponds to 50-80 kg of fuel per hectare of the land tilled and makes 20-25% of its total consumption in agriculture. At the present technologies and existing machinery soil tillage costs make 45-58 USD/ha. A considerable part (26-50%) of all the expenses are taken by ploughing [1, 3]. In order to produce cheaper agricultural products, it is necessary to reduce this expenditure.

The purpose of this study is to evaluate the possibilities and efficiency of soil tillage minimization.

OBJECTS AND METHODS

The objects of the research are technologies, machines and systems of soil tillage. The theoretical and experimental studies of soil tillage minimization are carried out in five main aspects:

– the agronomic aspect – possibilities for the reduction of the passes number and for tillage intensification, the quality of the prepared seedbed, weed, pest and plant diseases control, the obtained yields,

– the energetic aspect – soil tillage energy capacity and fuel consumption, ways of their reduction,

– the mechanical aspect – improvements in machine design and aggregation for energy, labour and environment saving soil tillage,

– the economical aspect – labour and fuel consumption and costs,

– the ecological aspect – decreasing undesirable influence of tillage on soil and environment.

RESULTS AND DISCUSSION

THE AGRONOMIC ASPECT

Depending on particular conditions and requirements variable soil preparation technologies should be used. After the deep ploughing (22-25 cm) the next two ploughings may be carried out at a lesser (15-18 cm) depth with no harm to the yields [3]. After quality autumn plough a single soil cultivation is more useful than a double one. Soil tillage can be minimized if herbicides are used to remove weeds. The successful experiments are carried out to prepare soil for growing cereals and vegetables without ploughing [5].

A considerable factor is soil density that should meet the needs of the grown crops. The optimum density of mineral soils for cereals and fodder grass is 1.2-1.4 g/cm^3 (dried soil), for tilled crops 1.0-1.1 g/cm^3. At higher densities deep loosening by means of a chisel cultivator is preferable to ploughing.

The most suitable machines for shallow tillage of soil are rotary knife harrows, especially for the cultivation of the stubble and tillage crop fields left unploughed in the previous autumn. The knife harrows mix the soil well up with the plant remnants and organic fertilisers, leaving an even field behind.

Minimised soil tillage without ploughing involves the problems of weed, pest and disease control, particularly of perennial weeds (dog-grass, thistle). Their control requires a greater amount of chemicals (herbicides, pesticides, fungicides).

THE ENERGETIC ASPECT

The amount of energy consumed for soil tillage with machines having passive operating parts depends on their specific draft resistance [2, 3, 6]:

$$E_m = K_1 = k_1^{\prime} + \varepsilon_1 v^2, \tag{1}$$

where:

E_m – is the specific energy capacity of soil tillage, Nm/m^2,
K_1 – is the specific draft resistance of the machine, N/m,
$k_1^{\prime}$ – is a generalised (total) specific static resistance related to a unit of the working width, N/m,
ε – is the dynamic resistance coefficient related to a unit of the working width, Ns^2/m^3,
v – is the working speed of the machine, m/s.

To carry out comparative energetic estimation of soil tillage machines, the values of their static and dynamic resistance coefficients are compared, as well as the character of their variations. From the energetic point of view, those machines are better for which the values of the resistance indices are lower. The characteristics of the specific draft resistance of some soil tillage machines are given in Table 1.

Table 1. The characteristics of specific draft resistances of soil tillage machines in the speed range of 1.5-3 m/s (5-11 km/h)

The type of operation and the machine used	Static resistance k1/, N/m	Coefficient of dynamic resistance ε1, Ns²/m³
Ploughing at the depth of 20-22 cm:		
with a hitch-up plough having digger bodies	7000-18000	400-700
with a mounted plough having digger bodies	6000-15000	400-700
with a mounted plough having helicoidal bodies	5000-12000	250-450
Dragging the autumn ploughing		
with a shallow loosening of the surface	1500-2300	l00-400
Pre-sowing cultivation of autumn ploughing at the depth of 8-12 cm:		
with an S-shaped spring tine cultivator	1300-3500	80-400
with a heavy disk harrow	2000-3600	60-400
with a rotary knife harrow	1300-1500	60-80
with combined high-speed machines	4000-5500	200-550
Repeated cultivation at the depth of 8-12 cm		
with an S-shaped spring tine cultivator	800-l000	50-l00
Deep (15-20 cm) loosening of autumn ploughing:		
with a peak-shaped chisel cultivator	2000-5300	150-500
with a combined chisel cultivator	5000-8500	300-600

The below data show that ploughing takes up considerably more energy in comparison with other soil tillage operations. Pre-sowing preparation (dragging, cultivation) of the ploughed soils require additional energy. Therefore, to save energy, it is important to replace ploughing with other ways of soil tillage.

The energy capacity can be characterised by the amount of the consumed fuel. The specific fuel consumption for soil tillage (ploughing, cultivation, harrowing, etc.) can be determined by the formula [1]:

$$Q_0 = 2.778 \cdot 10^{-6} g_e \eta_{v\,max}^{-1} (k_1^{/} + \varepsilon_1 v^2)\, e^{c(v_0 - v)^2} \text{ kg/ha,} \quad (2)$$

where:

Q_0 – specific fuel consumption for tillage, kg/ha,

g_e – specific fuel consumption of the engine, g/kWh,

$\eta_{v\,max}$ – maximum draft coefficient of the tractor,

e = 2.718 (basis of the natural logarithm),

v – working speed of the aggregate, m/s,

v_o – the speed corresponding to the maximum draft capacity, m/s,

c – a coefficient that depends on the physical and mechanical properties of soil and working capacity (gripping with soil, resistance to movement) of the tractor undercarriage (wheels, caterpillar track),

$c \approx 0.15 \pm 0.05$ in dense soils, $c \approx 0.30 \pm 0.05$ in loose soils [1].

Formula (2) shows that the fuel consumption required for soil tillage is mainly dependent on the energy capacity of the technological process and the energetic characteristics of the tractor. The first one is determined by the static and dynamic resistance of soil tillage, the second one by the efficiency of the tractor engine, draft efficiency, and the character of its variations [3].

THE MECHANICAL ASPECT

Energy and fuel economy as well as cost reduction can be expected from the introduction of more economical machines: ploughs with gently sloping bodies having helicoidal or semihelicoidal mouldboards (the angle between the share and the furrow edge is less than 40°) having a working width 45-50 cm, drag harrows, combined cultivators with S-shape spring teeth having a shallow (20-24°) share setting, rotary knife harrows, combined soil pre-sowing preparators. Under Latvian conditions the best machines are the mounted ones, also the multisectional wide aggregates during an operation of which it is possible to transfer their extra weight to the tractor using the automatic control system of the tractor hydraulic hitch-up device. The recognised optimum working width is the one that ensures a maximum efficiency of the aggregate at a corresponding speed (7-9 km/h) and a minimum fuel consumption [1, 5].

THE ECONOMICAL ASPECT

The efficiency of soil tillage methods, technologies and systems evaluated in terms of their labour, fuel consumption and costs is shown in Tables 2 and 3.

Table 2. Economical indices of soil tillage methods(average data when working with tractor MTZ-82)

Operation	Labour consumption, man h/ha	Fuel consumption, kg/ha	Costs, Ls/ha (1 Ls ≈ 1.7 USD)
Ploughing	1.8-2.2	16-20	12-16
Dragging	0.4-0.6	4-6	2.50-3.20
Cultivation	0.4-0.6	4-6	2.70-3.40
Tillage with a power harrow	0.7-0.9	9-12	10-12
Chiselling (at the depth of 15-20 cm)	0.8-1.0	9-12	5.20-6.00

Following from the data of Tables 2 and 3, in contrast to ploughing, the alternative ways of soil tillage save its labour, fuel and costs approximately 2-4 times. Minimised soil tillage technologies without ploughing, in contrast to the ordinary ones, sharply (up to 6 times) decrease these expenses. However, in spite of the remarkable economic effect of the soil tillage technology without ploughing, it cannot be applied everywhere. For instance, ploughing is more efficient for the cultivation of perennial grasslands, particularly in heavy clay soils. In the same manner catch-crops and a great amount of after-harvest remnants should be introduced [6].

Table 3.Energetic and economic characteristics of soil tillage technologies (average data).

Technology	Fuel consumption		Labour consumption		Expenditure	
	kg/h	%	h/ha	%	USD/ha	%
Intensive	78	159	8.2	158	76.25	160
Ordinary	49	100	5.2	100	47.62	100
Simplified	36	73	3.7	71	33.73	71
Minimised with ploughing	24	49	2.4	46	22.52	47
Minimised without ploughing	8	16	0.8	15	6.63	14

To ensure the credibility of the results, systematic and multi-year experiments should be carried out.

THE ECOLOGICAL ASPECT

We have conducted our studies for 9 years applying shallow soil tillage without ploughing and herbicide application in growing vegetables (potatoes, red beet, carrots, cabbage, tomatoes, cucumbers, pumpkins, vegetable marrow, lettuce, onions, garlic, beans, peas, and many others). In this period no soil compaction was observed. The vegetable yields have gone up, the weed control was successful and the number of weeds, especially the perennial ones (dog-grass, thistle), has decreased. There are few problems with the weeds that usually come from other fields, for example, dandelion and bent grass.

A witness of the healthy condition of the soil is an increased amount of earthworms in this period.

There are a few trials of grain drilling without any previous soil tillage using special machines, such as, combined seed drills for direct sowing and fertilising (seed drills Wäderstad Rapid Super). This is one way to preserve and develop natural downward soil structure.

A decrease in energy requirement and fuel consumption for soil tillage lower harmful emissions of tractor engines.

CONCLUSIONS

1. Minimization of soil tillage is an agronomically acceptable, energy, labour and cost saving action. Improvements in the machine design and use of the traditional soil tillage technologies allow to save 24-36% of energy (46-110 kWh/ha, which corresponds 12-27 kg/ha of fuel), to reduce labour consumption by 16-22%, as well as to cut tillage costs by 14-26% (10-20 USD/ha). Soil tillage minimisation with ploughing reduces these indices up to two times, without ploughing – up to six times. These actions are soil and environment saving too.

2. The tillage technologies without ploughing require more attention to the perennial weed, pest and disease control, preferably by applying adequate chemicals, but no more than in traditional tillage systems with ploughing.

3. In favourable cases direct grain drilling may be used. This method may be useful to preserve and develop natural downward soil structure.

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SUMMARY

The work sums up and briefly discusses solutions of soil tillage minimisation technologies and machinery, their agronomic, energetic, mechanic, economical and ecological aspects. Tillage minimisation is performed in the following directions: reducing number of passes, as well as tillage depth and intensity, joining operations, improving machine design and aggregation, using advanced more suitable technologies and machines, conducting tillage in optimal terms. Minimization of soil tillage is an agronomically acceptable, energy, labour and cost saving action. Improvements in the machine design and use for the traditional soil tillage technologies allow to save 24-36 % of energy (46-110 kWh/ha, which corresponds to 12-27 kg/ha of fuel), to reduce labour consumption by 16-22 %, as well as to cut tillage costs by 14-26 % (10-20 USD/ha). Soil tillage minimisation with ploughing reduces these indices up to two times, without ploughing – up to six times. Furthermore, these actions help to protect soils and environment.