UP-TO-DATE TRENDS IN SOIL TILLAGE ENGINEERING

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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. The amount of CO_2 produced as a result of its combustion is approximately 3.3 times greater. At present it is an international task to avoid overheating of the earth, and therefore the lowering of harmful emissions by 5.2% is a very urgent matter (Kyoto agreement protocols). At the present technologies and existing machinery soil tillage costs make 45-58 USD/ha [1], which are comparatively high, therefore measures should be sought for their reduction. Ploughing accounts for the most considerable part (26-50%) of all the expenses. The machines destroy the structure of soil, compact subsoil, and contaminate soil with oil and other substances escaping from the hydraulic systems and machines. Therefore solutions should be found and measures taken to avoid or reduce these undesirable factors.

The purpose of this study is to offer a brief review of up-to-date trends in soil tillage and an estimate of soil tillage energy and fuel requirement, the factors affecting tillage quality and costs, as well as machine designs for efficient, environment-friendly soil tillage.

OBJECTS AND METHODS

The objects of research are the energy content (capacity) and costs of soil tillage, the good and bad influence of technologies and machines used on soil and environment. Theoretical and experimental studies are carried out to determine the energetic characteristics of tractors and machines and their effect on fuel consumption, soil properties, environment and tillage costs. The consumption of fuel, labour and expenditure were evaluated for intensive, ordinary, simplified and minimised technologies with and without ploughing, as well as technologies for the introduction of green manure in order to raise soil fertility.

RESULTS

ENERGY SAVING AND COST-EFFICIENT TILLAGE

The amount of energy consumed for soil tillage with machines having passive operating parts depends on their specific draft resistance [3]. The total specific draft resistance of a machine is determined by two components – the static resistance and the dynamic resistance [2]. The static resistance practically does not depend on speed. The dynamic resistance is functionally related to the working speed.

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, 3]. The formula 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 former is determined by the static and dynamic resistance of soil tillage, the latter by the efficiency of the tractor engine, draft efficiency, and the character of its variations. Than, the impact of these characteristics on the energy capacity of soil tillage is studied as well as possible ways of its minimisation, fuel economy and improvements in engineering.

APPLICATION OF UP-TO-DATE, MORE POWERFUL AND EFFICIENT TRACTORS, THEIR RATIONAL USAGE

The specific fuel consumption of the engines of CIS tractors MTZ-80/82, K-701, T-150K and others that are most widely spread on the farms today is approximately 250 g/kWh. The specific fuel consumption of the new perspective tractors, such as FENT Favorit is only 191-195 g/kWh (to 20% lower). An important factor in fuel consumption is engine loading. If it falls, the specific fuel consumption rises. The specific fuel consumption changes in a similar way also during soil tillage. From what was said above it follows that efficient tractors should be used in order to ensure efficient work, and they should be loaded in a proper way by running them at an optimum speed with machines of proper width [1].

The tractors with all the driving wheels have a higher draft coefficient (η_v = 0.60-0.72) than the ones with the rear ones (η_v = 0.52-0.60). It is increased by 4-12% through ballasting the wheeled tractors. It can be accomplished in the most rational way by transferring onto the tractor a part of the weight of the hang-up machine using the automatic control system or the hydraulic loader of the tractor hung-up equipment. This allows saving fuel in ploughing by 1.4-1.6 kg/ha, in cultivation 0.2-0.4 kg/ha. With caterpillar tractors the draft coefficient is considerably higher than with the wheeled tractors at low working speeds (3-5 km/h). Increasing speed, this coefficient falls because of rising energy consumption that is required to overcome the friction resistance in the caterpillar joints [1, 4, 6].

The draft coefficient can be increased by 8-12% by installing additional wheels, which is particularly important when working under extreme conditions (in too humid or loose soil). Installation of extra wheels on powerful tractors saves fuel in ploughing by 2 kg/ha, in cultivation by 1 kg/ha. Similar economy is gained when tractors with four driving wheels are used instead of tractors with two driving wheels.

INTRODUCTION OF MORE EFFICIENT MACHINES

The most significant factor that determines fuel consumption is the specific draft resistance of the machine that is characterised by its static resistance and dynamic resistance coefficient. Their value depends on the physical and mechanical properties of soil, the design of the machine and its working parts as well as their usability for work in a particular situation [1, 3]. The lower they are the less fuel is required, the work is more efficient and the costs are lower.

More suitable for work at higher speeds (9-12 km/h) are the machines with lesser values of the dynamic resistance coefficient: ploughs having gently sloping screw bodies (the angle between the share and the edge of the furrow is less than 40°), cultivators with S-shape spring teeth having a shallow (20-24°) share setting, rotary knife harrows and chisel cultivators for stubble breaking [1, 3]. Energy consumption in ploughing depends also on the working width of each body. Increasing it from 30-35 cm to 45-50 cm, the energy capacity and specific fuel consumption in ploughing decreases [1].

APPLICATION OF COMBINED MACHINES AND AGGREGATES

Significant fuel economy can be achieved by combined machines simultaneously performing several technological operations. Under Latvian conditions it is purposeful to use combined machines and aggregates to combine the following operations: basic soil tillage (ploughing, stubble breaking) with additional soil tillage and simultaneous fertiliser introduction; complete soil pre-sowing preparation with the introduction of fertilisers and herbicides per pass of the aggregate; soil pre-sowing preparation with simultaneous grain and fertiliser sowing. It saves 15-36% of fuel [1, 4, 6]. Very useful for the formation of combined aggregates are tractors that have also a front hang-up device.

IMPROVEMENT OF THE WAYS OF AGGREGATION

Under Latvian conditions the best machines are mounted (hang-up) aggregates, also multisectional wide aggregates during the operation of which it is possible to transfer their extra weight (in order to perform technological operations) to the tractor using the automatic control system of the tractor hydraulic hitch-up device, hydraulic loaders or other analogous means (the support of the front part of the machine on the wheels of the tractor). A working width recognised as an optimum one is such that it ensures the maximum efficiency of an aggregate at a corresponding speed and the minimum fuel consumption in a given situation. The optimum speed of contemporary energy saturated high-speed wheeled tractors during soil tillage that ensures maximum labour efficiency with minimum consumption of fuel and means is 7-9 km/h [1, 3]. The economical working speed at which the costs of soil tillage are the lowest is a little greater (10-15%) than the optimum one. The more expensive is the machine and the cheaper the fuel, the greater is the speed.

OPTIMISATION OF SOIL TILLAGE TECHNOLOGIES

On many farms there is a stereotyped attitude to soil tillage: stubble breaking in one or two operations, ploughing at the depth of 22-24 cm, dragging of the ploughed field, pre-sowing cultivation in 2-3 operations, rolling down. The studies as well as practical experience have shown that it is not always useful. However, there may be cases when even more intensive soil tillage is necessary, for instance, in recovering untilled lands, soil preparation for very fastidious crops. Therefore, depending on particular conditions and requirements, variable soil preparation technologies should be used, yet always considering if they are economically justified.

A remarkable reserve for the reducing of energy consumption and costs is the minimisation of soil tillage: decreasing the depth of tillage, intensity and the number of tillage operations, as well as joining operations. It has become a routine on many farms to plough the arable land at its full depth. Yet investigations show that after the deep ploughing (22-25 cm) the next two ploughing operations may be carried out at lesser depth (15-18 cm) with no harm to the yields. Minimisation of the ploughing depth by 1 cm decreases fuel consumption by 0.4-0.6 kg/ha and costs by 0.43-0.52 USD/ha.

Currently The Baltic states more widely introduce tillage without ploughing: shallow loosening with chisel cultivators, disc or knife harrows for crops growing, direct seeding. In the dry summer of 2002 soil preparation for winter crops with this method gave better results than with ploughing. There were better germination of seeds and more uniform spacing of sprouts than on ploughed fields

After quality autumn plough on farms single soil cultivation with a combined cultivator is more useful than the widely practised double cultivation. In the first case even higher yields of summer crops are obtained, besides the labour and fuel consumption is by half less, which makes 3.5-4 kg/ha in the case of the second cultivation. There are instances in practice when after a quality ploughing of loose soil, preparing it for sowing winter or summer crops, it is not cultivated at all but prepared with a loosening drag in the way which economises time and saves 3.5-4 kg/ha of fuel that would be required for cultivation. The loosening drag disintegrates better clods and forms a more even surface of the field.

By intensive soil tillage the consumption of labour and fuel and the costs are 1.5 times greater than using the classic technology. Whereas simplification of soil tillage reduces all this expenditure by 30%, minimisation with ploughing two times and without ploughing – six times [5]. Ploughing is not necessary in weedless soils after the intertilled crops (e.g., beet and potatoes) have been harvested [1]. However shallow soil tillage is permitted if the density (volume mass) of the lower unprepared layer does not exceed 1.7 g/cm^3 for a soil with 20-22% humidity (1.4 g/cm^3 for dried soil).

Soil tillage can be minimised if herbicides are used to remove weeds because then there is no need in agrotechnical measures for their control.

SOIL-SAVING TILLAGE

INTRODUCTION OF ENERGY-SAVING TECHNOLOGIES AND MACHINES

The technologies and machines described above are, at the same time, also soil-saving ones [4].

PROBLEMS OF USING BIG POWERFUL TRACTORS AND MACHINES

Intensification of agricultural production and raising efficiency are connected with wide introduction of powerful machinery having remarkably greater total mass. Simultaneously with the introduction of powerful machines measures should be taken to avoid undesired soil compaction, which may lead to its lower fertility and yields: firstly, tires should be used with appropriate air pressure in them; secondly, tractors and machines should be introduced with wide-profile low-pressure tires that have greater contact surface with soil and, correspondingly, exert lower specific pressure on it; thirdly, it is necessaryto provide tractors with additional wheels. It should be noted that the use of heavy powerful machinery, at its correct aggregation, does not by principle increase soil compaction because the working width of the aggregates is proportional to the mass of the tractor. Therefore, the number of passes across the field is lower [4].

MEASURES FOR BETTER UTILISATION OF SOIL AND RAISING ITS FERTILITY

The soils in Latvia have a low humus content (1.3-1.8%). In order to raise soil fertility, it is necessary to give great portions of organic fertilisers (20 t/ha a year). Still this fertiliser is not available in sufficient quantities, therefore a greater amount of green fertiliser (catch crop) must be applied. An energy-saving technology has been applied for the introduction of unshredded long-stalked crops into soil [7].

MORE FRIENDLY MACHINES FOR SOIL TILLAGE

Previously it was made clear what requirements are set for tractors and machines in soil-saving tillage: lower undercarriage pressure, lower draft resistance, optimum parameters of units, machines as well as their working parts. In addition to this, it is important to protect the soil from materials used in machines, such as oil, fuel, coolant and various chemicals, for instance by replacement of hydropneumatic protection systems of the machine working parts with spring protection systems, avoiding the possibility for oil to come into soil in case these systems are damaged. The machines for spreading fertilisers, pesticides and other chemicals should meet high requirements of quality work.

CONCLUSIONS

1. Advanced engineering in soil tillage is performed in the directions of energy saving, costs reduction, soil and environment saving as well as by designing more friendly tillage machines and technologies. It comprises a complex of technical and technological improvements: an application of more powerful and efficient tractors and machines as well as better ways of their aggregation and an optimisation of soil tillage technologies.

2. More considerable effect on the energy and fuel economy at a higher output of the tillage aggregates as well as cost reduction is achieved by introducing up-to-date tractors and economical machines: ploughs with gently sloping bodies having a working width of 45-50 cm and helicoidal or semi-helicoidal mouldboards (the angle between the share and the furrow edge is less than 40°), drag harrows, combined cultivators with S-shape spring teeth having a shallow (20-24°) lug setting, combined rotary knife harrows, soil pre-sowing preparator with simultaneous grain and fertiliser seeder.

3. Under relatively similar conditions energy capacity in soil tillage, characterised in terms of fuel consumption, is about 78 kg/ha (159%) at intensive technologies, 49 kg/ha (100%) – at ordinary technologies, 36 kg/ha – at simplified, 24 kg/ha (49%) – at minimised technologies with ploughing, and 8-12 kg/ha (16-24%) at minimised technologies without ploughing. Labour consumption, costs and the amount of undesirable emissions change in a similar way.

4. Improvements in the machine design and use for the traditional soil tillage technology allow to save 24-36% of energy (46-110 kWh/ha, which corresponds to 12-27 kg/ha of fuel) and, consequently, serves to lower the amount of carbon dioxide and other harmful emissions, 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.

5. Introduction of more efficient tractors and machines, better means of aggregation, as well as improved undercarriage (using low-pressure tires, double wheels) reduces their adverse effect on soil.

6. The technology and technical means worked out by us provide rational introduction of unshredded green manure into soil and raise its humus content and fertility.

REFERENCES

1. **Vilde A.**: Cost-Efficient Soil Tillage. Ulbroka, Latvia, 49, 1997.
2. **Vilde A.**: Dynamics of the soil tillage machine operating parts and their elements. In: Proceedings of the Latvia University of Agriculture, Vol. 1 (295). Jelgava, Latvia, 1999, 36-44.
3. **Vilde A.**: Energetic and economic estimation of soil tillage systems. In: Wydawnictwo Akademii Rolniczej Szczecin (eds.), Folia Universitatis Agriculturae Stetinensis 195, Agricultura 74. 1999, 213-222.
4. **Vilde A.**: More environment-friendly cost-efficient soil tillage. In: MILGA (eds.), Proceedings of the International Conference "Field Technologies & Environment". Raudondvaris, Lithuania, 9-15, 1998.
5. **Vilde A.**: Soil tillage without ploughing. In: Proceedings of Baltic States Branch of ISTRO Conference. Tartu, August 21-24, 2001, 92-96.
6. **Vilde A., Rucins A., Pinnis U., Cesnieks S.**: Technical, economical and ecological estimation of up-to-date combined soil tillage, fertilising and sowing machines. In "Progressive Eco-friendly Technological Processes in Agricultural Engineering". Proceedings of the International Conference EurAgEng, 19-20 September, 2002. Raudondvaris, Lithuania, 2002. 31-36.
7. **Cēsnieks A., Vilde A. Liepiņš J. a.o.**: Introduction of green manure without previous shredding – environment-friendly raising of soil fertility. In: MILGA (eds.), Proceedings of the International Conference "Field Technologies & Environment". Raudondvaris, Lithuania, 1998, 109-114.

SUMMARY

Up-to-date trends in soil tillage engineering are of mainly three directions: energy saving and cost-efficient soil tillage, environment and soil-saving tillage, as well as more friendly machines for it. Analyses have been made of soil tillage energy capacity, their determining factors, as well as the causes and consequences of their harmful effects: a great amount of carbon dioxide emitted from the burned fuel, deterioration of soil structure, subsoil compaction, penetration of oil and other substances from the machines into soil. Several ways are found out and proposed how to reduce the adverse influence of these factors on soil and environment including more efficient and appropriate tractors and machines, improved means of aggregation, as well as better quality of undercarriage. The values of these indices and tillage costs have been estimated.