Evaluation of Energy and Environmental Aspects of Reduced Tillage Systems Applied in Maize Cultivation

E. Sarauskis, L. Masilionyte, Z. Kriauciuniene, K. Romaneckas, S. Buragiene

***Abstract*—**In maize growing technologies, tillage technological operations are the most time-consuming and require the greatest fuel input. Substitution of conventional tillage, involving deep ploughing, by other reduced tillage methods can reduce technological production costs, diminish soil degradation and environmental pollution from greenhouse gas emissions, as well as improve economic competitiveness of agricultural produce.

Experiments designed to assess energy and environmental aspects associated with different reduced tillage systems, applied in maize cultivation were conducted at Aleksandras Stulginskis University taking into account Lithuania's economic and climate conditions. The study involved 5 tillage treatments: deep ploughing (DP, control), shallow ploughing (SP), deep cultivation (DC), shallow cultivation (SC) and no-tillage (NT).

Our experimental evidence suggests that with the application of reduced tillage systems it is feasible to reduce fuel consumption by 13-58% and working time input by 8.4% to nearly 3-fold, to reduce the cost price of maize cultivation technological operations, decrease environmental pollution with CO_2 gas by 30 to 146 kg ha^{-1}, compared with the deep ploughing.

***Keywords*—**Reduced tillage, energy and environmental assessment, fuel consumption, CO_2 emission, maize.

I. Introduction

INTENSIVE air circulation within the soil, promoted by intensive technological operations of tillage such as deep ploughing, accelerate organic matter decomposition rate in the soil, which results in elevated greenhouse gas (CO_2) emissions. These processes reduce organic carbon content in the soil and influence carbon cycle and soil physical and other characteristics. All these reasons and intention to conserve soil, environment and energy necessitate a search for more rational soil management methods. Currently a lot of farms are introducing advanced agricultural production technologies and are aiming at higher profitability; however, despite the efforts made, the engine fuel consumption of tractors and other agricultural machinery and exhaust emissions still often exceed the allowable limits [3], [5]. Irrational choice of agricultural machinery and operating regimes of engines, i.e. when permissible motor load is exceeded or is insufficient, has also an adverse effect on the environment. In such cases, noxious exhaust substances, oil products and their fumes are emitted into the atmosphere and all this severely disturbs the natural environmental ecosystems [5].

Tillage is a technological operation which requires considerable working time input and ample fuel consumption [8]. Conventional deep ploughing is the least efficient and most energy-intensive tillage method [7]. The use of reduced tillage technologies or no-tillage practically does not alter or ever so often even improves soil chemical and physical properties and crop yields are often similar to those obtained using conventional tillage technologies. Calculations of energy balance of the different technologies showed that reduced tillage technologies are often superior not only in terms of lower working time input and fuel consumption but also in terms of being more environmentally-sustainable, i.e. they produce lower greenhouse gas emissions [2]. With reduced energy input intensity one can cut down on crop production costs and contribute to sustainable agricultural development. A well-balanced management of energy input intensity is one of the top priorities of contemporary energy policy, since energy is a critical factor of socio-economic development of any country [10], [6], which enables safeguarding of energy security, economic competitiveness and environmental protection [1].

Over the past several decades, soil degradation processes have markedly intensified and this is resulting in the loss of the fertile soil layer. Climate change and separate extreme climatic events, which have been occurring increasingly more frequently recently, have adverse effects on the soil. However, man's farming activities, especially inappropriate technological operations of tillage, are probably the ones that accelerate the soil degradation processes the most. As a result, the use of conservation and no-tillage technologies has been rapidly increasing worldwide, including the Baltic countries where farmers gradually refine and upgrade their production processes and introduce various reduced tillage technological operations that are environment-friendly and energy-conserving. The objective of the current study was to

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evaluate energy and environmental aspects of different reduced tillage systems applied in maize cultivation.

II. Materials and Methods

Experiments were conducted at Aleksandras Stulginskis University's Experimental Station during the period 2010-2012. They involved 5 different maize growing technologies in 4 of which reduced tillage systems were employed and conventional tillage system was used in the control:

- Deep ploughing (DP) at 23-25cm (control treatment). The following technological operations were used in this maize growing technology: stubble cultivation, deep ploughing, pre-sowing cultivation, fertilization, conventional drilling, spraying, fertilization, harvesting.
- Shallow ploughing (SP) at 12-15cm. Stubble cultivation, shallow ploughing, pre-sowing cultivation, fertilization, conventional drilling, spraying, fertilization, harvesting.
- Deep cultivation (DC) at 25-27cm. Stubble cultivation, chiselling, pre-sowing cultivation, fertilization, conventional drilling, spraying, fertilization, harvesting.
- Shallow cultivation (SC) 12-15cm. Stubble cultivation, discing, pre-sowing cultivation, fertilization, conventional drilling, spraying, fertilization, harvesting.
- No-tillage (NT). Spraying, fertilization, direct drilling, spraying, fertilization, harvesting.

Energy and operating parameters were calculated according to the methodology elaborated by the Lithuanian Institute of Agrarian Economics for fields 10-20 ha in size, regular in shape and free from stones for normal operation conditions of agricultural machinery [4]. Diesel fuel costs were calculated according to current reduced complex price of fuel and lubricants (0.96 EUR l^{-1}) specially fixed for farmers. Direct costs include the costs for machinery upgrading, repair and technical maintenance, fuel and lubricants and wages. When calculating cost price of the technological operations we considered indirect expenditure on activities associated with management of agricultural enterprise or its branches, maintenance of premises and equipment. Five to ten percent of the direct costs are allocated for this. The value added tax is not included in the costs [4].

Assessment of maize growing technologies in terms of environmental aspect indicated how much fuel was needed for individual operations as well as the total fuel consumption required for the implementation of a complete technology. Based on other researchers' published evidence that burning 100 litres of fuel produces a CO_2 emission of 376kg [9], we estimated all technologies studied.

The data of the experiments was analyzed by statistical-mathematical methods assessing the least significant difference LSD_{05} at 95% probability level [11].

III. Results and Discussion

Table I presents machinery capacities, working widths, labour productivity, fuel consumption and other operational, energy and economic indicators of the operations of maize growing technologies.

All reduced tillage technologies applied in maize cultivation were found to require lower working time input and fuel consumption, compared with conventional (DP) technology. Fuel consumption in SP, DC and SC technologies was similar (ranging from 53.4 to 58.5 l ha^{-1}); however, compared with the control technology, they consumed by 12.9 to 20.5 % less fuel (Fig. 1). The lowest fuel consumption was recorded for the NT technology (about 28.4 l ha^{-1}).

TABLE I
MAINTENANCE, ENERGY AND ECONOMIC INDICATORS OF VARIOUS TECHNOLOGICAL OPERATIONS

Technological operation	Machinery power, kW	Working width, m	Field capacity, ha h^{-1}	Working time, h ha^{-1}	Fuel consumption, l ha^{-1}	Operations costs, EUR ha^{-1}
Stubble cultivation	83	3.0	1.41 ± 0.16	0.71 ± 0.08	10.7 ± 1.0	30.1±3.4
Deep ploughing	67	1.05	0.52 ± 0.08	1,92 ± 0.30	24.5 ± 2.1	53.1±8.2
Shallow ploughing	67	1.05	0.68 ± 0.05	1.47 ± 0.18	16.5 ± 1.3	45.1±7.0
Chiselling	83	3.0	1.28 ± 0.31	0.78 ± 0.20	15.8 ± 0.1	35.6±0.4
Discing	83	3.0	1.41 ± 0.16	0.71 ± 0.08	10.7 ± 1.0	30.1±3.4
Pre-sowing cultivation	67	3.0	1.30 ± 0.10	0.77 ± 0.06	4.6 ± 1.4	14.4±1.2
Conventional drilling	54	4.5	2.37 ± 0.21	0.42 ± 0.04	2.3 ± 0.3	22.7±2.3
Direct drilling	83	3.0	2.24 ± 0.41	0.45 ± 0.09	6.9 ± 0.9	25.4±3.9
Fertilization	67	15	19.43 ± 6.10	0.05 ± 0.01	0.5 ± 0.1	1.5±0.1
Spraying	54	15	6.86 ± 0.41	0.15 ± 0.01	0.9 ± 0.2	4.3±0.7
Harvesting	200	4.0	1.24 ± 0.21	0.80 ± 0.11	23.2 ± 4.4	99.7±20.0

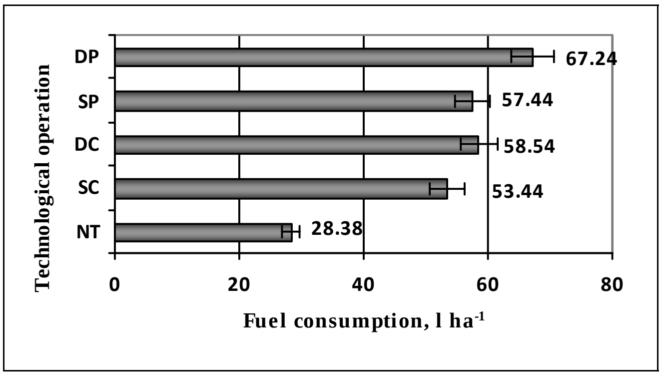

Fig. 1 Fuel consumption in different maize growing technologies

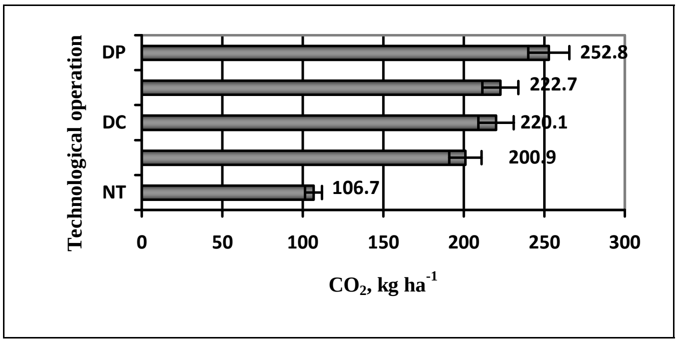

Fig. 2 CO_2 emission from agricultural machinery in different maize growing technologies

Assessment of the different maize growing technologies in terms of environmental aspect indicated that the NT technology resulted in the least CO_2 emission and consequently in the least environmental pollution. Calculations showed that in the NT technology the total CO_2 emission per hectare from the mechanized technological operations included in this technology was about 107kg (Fig. 2), while the rest of the reduced tillage technologies tested (SP, DC and SC) produced roughly twice as high CO_2 emission. The highest CO_2 emission (about 253kg ha^{-1}) occurred with the application of the conventional DP technology.

Working time input per ha for tillage, crop management and harvesting in the control DP maize cultivation technology was about 4.8 hours. In the SP technology working time input was 4.4, in DC – 3.7, in SC – 3.7h ha^{-1}. The least working time input (1.65h ha^{-1}) was required by the NT technology.

Economic estimation suggested that in the NT technology the cost price of mechanized operations was around 137 EUR ha^{-1}, in the SC technology – 204 EUR ha^{-1}, in the DC technology – 210 EUR ha^{-1}, in the SP technology – 219 EUR ha^{-1}, in the DP technology (control) – 227 EUR ha^{-1}. Crop yield is a very important indicator showing whether the right technology has been chosen. In the trials conducted during the period 2010-2012 it was established that the highest maize dry biomass yield was produced in the DP and NT technologies (about 15.3t ha^{-1}), in the other technologies tested the yield was 8.5 to 12.4 % lower.

IV. Conclusions

1. Conventional tillage involving deep ploughing is costly and of little efficiency. It is a time-consuming and fuel-intensive operation. With reduced tillage systems in maize cultivation technologies it is feasible to reduce fuel consumption by 13 to 58 % and working time input by 8.4 % to nearly 3-fold.
2. Economic calculations revealed that reduced tillage methods enable reduction of cost price of technological operations in maize production. In no-tillage technology, having achieved a similar yield to that produced in conventional deep ploughing technology, the cost price of technological operations declines by roughly 90 EUR ha^{-1}.
3. Reduced tillage systems enable a decrease in environmental pollution by CO_2 from 30 to 146kg ha^{-1}, compared with the conventional tillage technology.

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