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AN ANALYSIS OF CORN TILLAGE AND CULTIVATION ENERGY CONSUMPTION AND GHG EMISSIONS

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ABSTRACT: This article discusses various corn tillage technologies and analyses their energy consumption and GHG emissions. The experimental research and analytical calculations took place in Lithuania and were carried out using five different tillage technologies of varying intensities: deep ploughing, shallow ploughing, deep cultivation, shallow cultivation, and the no-tillage system (NT). The research has determined that lower intensity tillage technologies expend 12-58% less energy than deep ploughing. NT technology causes the least pollution: the agricultural machines involved only emit only an average of 107 kg ha^{-1} of CO_2. The most efficient technologies in terms of energy efficiency are the NT and the conventional deep ploughing.
Keywords: tillage, fuel consumption, CO_2 emissions, energy indicators, corn

1. INTRODUCTION

The most important objective of tillage is to create favourable soil conditions for plant growth. Annual deep ploughing has usually negative consequences: the values of good soil properties decrease and the subsurface soil layer condenses [1, 2, 3]. Crop type, meteorological conditions, terrain, soil fertility level, organic matter content, weed infestation, moisture conditions, soil structural level, available tillage techniques, know-how, etc. most influence the tillage technology choice. Without a doubt, every tillage system has advantages and disadvantages. A higher yield is more likely with traditional plough tilling, but due to the low performance of tillage operations and the need for high-power tractors, the tillage costs are usually the highest. In addition, the adverse effect of conventional tillage on the environment, soil, and biodiversity is also very high [2, 3]. Irrational selection of tillage machines and their working mode can also adversely affect the environment. More toxic gases may be emitted due to increased load on the machines in such cases, which damage the natural ecosystem environment [4].

Environmentally sustainable systems with minimum tillage and no-tillage are increasingly used searching for alternatives to reduce the intense tillage with the plough. Thus the tillage machinery effects on soil degradation and soil properties are reduced; the subsurface soil layer condenses less, which preserves more the natural water filtration and the plant root penetration into the various layers of the soil [5].

The main challenge of sustainable agriculture is to limit its intense impact (mechanical, chemical and biological) on soil and plants, to reduce its negative consequences to ensure a continuous renewal of soil productivity, protect the biosphere, and maintain cost-effective production. Sustainable agriculture has a number of objectives: a more rational use of materials, energy, and labour resources to meet stringent environmental requirements for the production of healthy and cheap agricultural products. But perhaps the most important objective of sustainable agriculture is soil conservation. The aim is to preserve soil, prevent the loss and degradation of humus, reduce the nutrient leaching and soil water pollution, protect soil from erosion and structure depletion, promote natural biological processes, better balance of field organic metabolism, and improve the topsoil layer aeration and irrigation [6].

One of the most important tasks of environmental sustainability is to reduce the human impact on climate change through economic activity. Over the past few decades, CO_2, methane (NH_4), nitrous oxide (N_2O), and other gas emissions have been increasing. The popular term for these is greenhouse gases or GHG [7]. CO_2 has the greatest impact among the greenhouse gases. Its level in the atmosphere, compared to pre-industrial revolution era level, has increased from 280 ppm to 366 ppm [8].

No less important than environmental aspects are the energetic and economic features of cultivation technology. For the purposes of no-plough minimum tillage or no-tillage systems plant the yield and the quality are likely to be lower, but the costs of land cultivation and sowing operations are also lower. In addition, recent technological impact on the environment and biodiversity is also more positive than conventional tillage.

Reducing the tillage and seeding operations and the number of machines driving over the soil can significantly reduce fuel consumption and thus greenhouse gas emissions from the tractor/machinery agricultural units. Research done in Germany demonstrated that burning 1.0 litre of diesel emits about 3.76 kg of gas into the atmosphere [9]. The energy costs of implementing these operations are an important variable for assessing the pollution of tillage operation in Lithuania.

The aim of the work is to evaluate energy and environmental aspects of deep and shallow ploughing, deep and shallow hoeing, and no-tillage systems to determine their technological energy efficiency.

2. MATERIAL AND METHOD

The research was carried out at Aleksandras Stulginskis University Experimental Station with its mid Lithuanian meteorological conditions and loamy soil in 2009-2012. Five different technologies were researched in terms of the energy and environmental impacts of tillage:

1. Uncultivated soil – no-tillage system (NT)
2. Shallow cultivating with a disc harrow at a depth of 12-15 cm (SC)
3. Deep cultivating with a cultivator at a depth of 25-27 cm (DC)
4. Shallow ploughing at a depth of 12-15 cm (SP)
5. Deep ploughing at a depth of 23-25 cm (control)

The purpose of choosing the traditional tillage technology as the control was to be able to compare it with the four sustainable tillage technologies in terms of energy costs and CO_2 emission. The placement of research plots was random. The original size of the plot was 126 m^2 (14 × 9 m), the size for the observation plot was 84 m^2 (12 × 7 m). The researches were repeated four times.

The Väderstad Carrier 300 stubble cultivator was used at all the fields, except for the NT; after the winter wheat (*Triticum aestivum* L.) harvesting, NT technology was used to spray each ha with 4 litres of Roundup herbicide. Autumn tillage as described above was carried out at the end of September or October depending on the meteorological conditions.

Before corn (*Zea mays* L.) for sowing in all technologies, with the exception of NT, the shallow topsoil (6-8 cm) was tilled with a cultivator in spring. The corn Pioneer P8000(x027) was planted at the beginning of May. The seed rate was 100,000 per hectare with an inter-row width of 45 cm. The entire corn field during planting was fertilized with NPK 16:16:16 at a rate of 250 kg ha^{-1}. The Maister (150 g ha^{-1}) and Actirob (2 l ha^{-1}) herbicides were used for post-sowing weed control. In late June, the corn was fertilized with ammonium nitrate (NH_4NO_3), at a rate of 180 kg ha^{-1}. The corn biomass was harvested at the end of September or beginning of October (depending on meteorological conditions).

Energy indicators were calculated in accordance with the Lithuanian Institute of Agrarian Economics recommendations developed for agricultural and other companies, farmers, and other organizations providing services to farmers carrying out agricultural work [10]. Because the average farm in Lithuania is about 14-15 hectares, the calculations reflect exactly such operating scope for farm machinery under normal conditions, i.e. proper contour and not rocky land.

Energy values were chosen in MJ for agriculture assemblies, fuel, fertilizer, pesticides, and other inputs based on scientific works published by various researchers. Energy assessment assumes that the energy value of work is 1.96 MJ h^{-1} [11, 12], diesel fuel is 39.6 MJ l^{-1} [13, 14], agricultural machinery (including automotive) is 1.38 MJ kg^{-1} or 357.2 MJ h^{-1} [15], corn seed is 15.3 MJ kg^{-1} [12, 16], herbicides is 295.0 MJ kg^{-1} [11, 17], fungicides is 115.0 MJ kg^{-1} [11, 17], insecticides is 58.0 MJ kg^{-1} [11, 17], nitrogen fertilizer is 40.0 MJ kg^{-1} [17], phosphate fertilizers is 15.8 MJ kg^{-1} [14, 18], potassium fertilizers is 9.3 MJ kg^{-1} [14, 18], and the corn harvest is 14.7 MJ kg^{-1} [12, 16].

The EE energy efficiency ratio for different tillage and corn growing technologies is determined by this formula [19]:

$$EE = \frac{E_P Y}{E_T} \quad (1)$$

here E_P is the energy value of corn, MJ kg^{-1}; Y is corn harvest, kg ha^{-1}; E_T is the energy cost of one technology, MJ ha^{-1}.

Total energy consumption for a particular technology E_T is calculated thus [3, 19]:

$$E_T = E_F + E_{SFP} + \frac{E_H + E_{AM}}{FC} \quad (2)$$

here E_F is fuel energy costs, MJ ha^{-1}; E_{SFP} is seed energy costs, fertilizer and pesticides, MJ ha^{-1}; E_H is work energy costs, MJ h^{-1}; E_{AM} is agriculture assembly energy costs, MJ h^{-1}; FC is agriculture assemblies efficiency, ha h^{-1}.

An environmental assessment of the different tillage and corn cultivation technologies determines how much fuel is required for individual mechanized operations and the total fuel consumption for an entire technology to be implemented. Based on the research results published by other scientists [9, 20], burning 1.0 litre of diesel fuel emits 3.76 kg of CO_2, including all of the tillage and corn growing technologies researched.

The results are 95% reliable according to standard statistical and mathematical methods for determining a least significant difference [21].

3. RESULTS

Energy, performance, and economic evaluation indicators for different tilling, sowing, spraying, fertilizing, and other mechanized operations of agricultural machinery are presented in Table 1.

Table 1. Energy and economic indicators of various agro-technological operations

Agro-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	0.71	10.7	30.1
Deep ploughing	67	1.05	0.52	1,92	24.5	53.1
Shallow ploughing	67	1.05	0.68	1.47	16.5	45.1
Chiselling	83	3.0	1.28	0.78	15.8	35.6
Discing	83	3.0	1.41	0.71	10.7	30.1
Pre-sowing cultivation	67	3.0	1.30	0.77	4.6	14.4
Fertilization	67	15.0	19.43	0.05	0.5	1.5
Conventional drilling	54	4.5	2.37	0.42	2.3	22.7
Direct drilling	83	3.0	2.24	0.45	6.9	25.4
Spraying	54	15.0	6.86	0.15	0.9	4.37
Fertilization	67	15.0	19.43	0.05	0.5	1.5
Harvesting	200	4.0	1.24	0.80	23.2	99.7

Diesel fuel consumption is one of the key factors that have a major impact on both individual operations, as well as the entire corn growing technology in terms of energy and economic costs. In assessing sustainable tillage technologies, we established that compared with the traditional technology (control) all other corn growing technologies reduce diesel fuel consumption. Fuel costs are similar when using sustainable SP, DC, and SC technologies (about 53.4–58.5 litres ha^{-1}); however, compared with the control technology fuel consumption was 12.9 to 20.5% less (Figure 1). NT technology has demonstrated the lowest fuel consumption (about 28.4 litres ha^{-1}).

In terms of individual technological operations, mostly diesel (about 24.5 litres ha^{-1}) is used in deep soil ploughing. Diesel fuel consumed in tillage and sowing is about 63% (about 42 litres ha^{-1}) of all control technology fuel. Researchers in other countries have obtained very similar results. Long-term German research has shown that traditional tillage consumes about 35 litres ha^{-1}, various environmentally friendly sustainable tilling methods from 14 to 25 litres ha^{-1} and no-tillage systems about 6 litres ha^{-1} of diesel fuel [22]. Researchers in Croatia analysed three different tilling and sowing technologies: conventional, sustainable, and no-tillage systems. They established that the conventional technique consumes 48 to 61 litres ha-1 of fuel for soil preparation and sowing. By using a sustainable cultivation technology, not ploughing, fuel consumption is reduced 1.5 to 2.0 times compared with a conventional technology. And using no-tillage direct drilling the fuel consumption is 5 to 8 times lower than conventional technology [23]. Dicle University researchers have came to similar conclusions, stating that in no-tillage system the fuel consumption was 6.6 litres ha-1, while fuel consumption seeding by conventional means is 5 times higher [24].

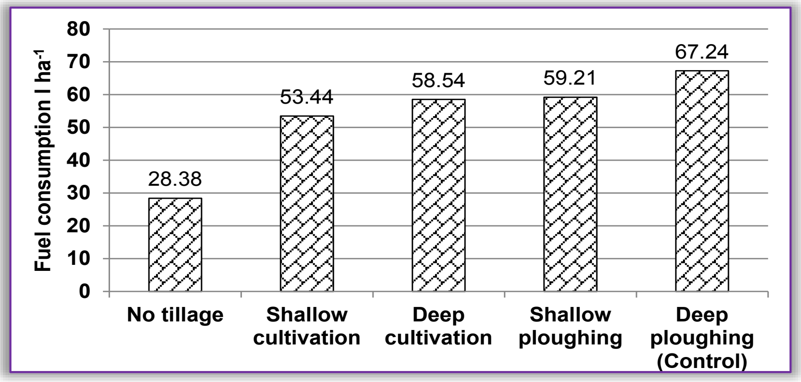

Figure 1 – Influence of tillage technology for corn cultivation on fuel consumption

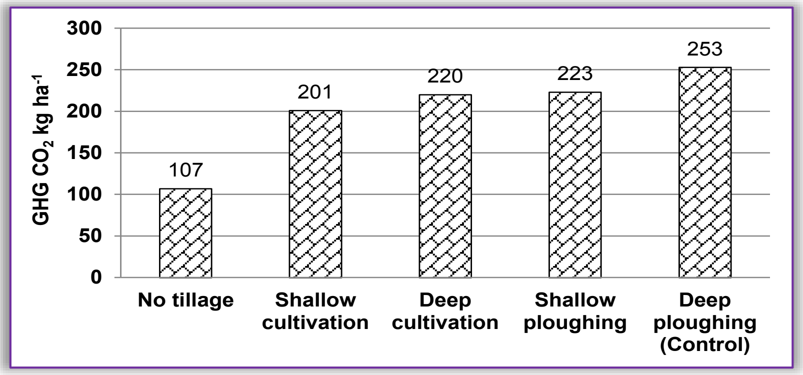

Figure 2 – Greenhouse gas CO_2 emissions from agricultural machineries under different tillage technologies for corn cultivation

Tillage is not only difficult work, but at the same time very energy-susceptible, requiring high power machines. Fuel consumption and hence greenhouse gas emissions depend on tilling process parameters: the depth of tillage, working width, speed, soil properties, etc. Evaluating the different corn-growing operations in terms of environmental aspects, CO_2 pollution is the lowest using NT technology. Analytical calculations show the following for all the mechanized operations provided for by NT technology for one hectare: agricultural machinery (tractors, combine harvester) emit about 107 kg ha^{-1} of CO_2 (Figure 2) into the environment, while all other simplified sustainable tilling technologies (SP, DC, and SC) pollute twice as much. The control technology produced the most CO_2 (about 253 kg ha^{-1}).

Analysing mechanized corn production operations separately we can see that the cleanest technology is NT, because requires only one operation, which emits about 26 kg ha^{-1} CO_2. For the other tillage and sowing technologies the pollution is between 4 (SC – 106.4 kg ha^{-1}) and 6 (control – 158 kg ha^{-1}) times more than NT. Sørensen and Nielsen [25] states that NT reduces energy consumption with 75-83%. CO_2 is similarly reduced as an output of agricultural machinery compared with the control technology. The fewer agricultural operations there are, the lower CO_2 emission is. Greenhouse gas emissions are strongly influenced by appropriate selection of agricultural machinery and the optimal engine load [4].

During the agricultural technology energy assessment, it is important to know not only the total energy costs incurred, but also the amount of energy generated by farmed production. Each technology's energy recovery was estimated based on the corn crop. Assessing three survey years of corn averages yield, the highest levels of energy were achieved by the NT and control technologies (Table 2).

Table 2. Yield and energy indicators for various tillage and corn cultivation technologies in 2010–2012 (average data)

Tillage technologies	Dry mass yield of corn Mg ha^{-1}	Energy output of corn yield MJ ha^{-1}	Energy inputs in corn cultivation MJ ha^{-1}	Energy efficiency ratio EE
NT	15.39	226233	16153.5	14.0
SC	14.00	205800	17146.8	12.0
DC	13.40	196980	17373.9	11.3
SP	13.99	205653	17478.2	11.7
Control	15.25	224175	18127.9	12.4

The calculation of values for each corn-growing technology's energy consumption revealed that under Lithuanian conditions different technologies' energy consumption ranged from 16.15 to 18.13 GJ ha^{-1}. By comparison calculations of sugar beet technology energy efficiency in Germany showed that total energy consumption was from 11.1 to 35.8 GJ ha^{-1} [14].

In all the corn growing technologies, the fertilizer and the diesel fuel accounted the majority of energy consumption. In the traditional control technology it is about 70% fertilizers and 15% fuel, while for NT it is 78% and 7%.

Energy efficiency balance calculations show that the best energy efficiency ratio (14.0) is achieved using the NT technology. The energy efficiency ratio was 12.4 in the control technology when deep tillage ploughing was performed.

4. CONCLUSIONS

Fuel consumption research have determined that sustainable tillage technologies expend 12-58% less energy than deep ploughing.

In the control technology (deep ploughing) agricultural machines emit an average of 253 kg ha^{-1} CO_2. The sustainable technologies (SC, DC, and SP), emit 2 to 22 % less CO_2. NT technology pollutes the least with a rate of CO_2 emission 2.4 times lower than the control technology.

Having evaluated the technological energy consumption with energy efficiency calculations and energy generated from the corn crop, the optimum energy efficiency ratio (14.0) is achieved using the NT technology. The conventional deep ploughing has an energy efficiency ratio of 12.4.

Note

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