COMPARISON OF FUEL CONSUMPTION IN BROCCOLI PRODUCTION

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Abstract. Broccoli is a highly valued vegetable for its high content of vitamins and health-promoting substances. The heads weight up to 0.7 kilograms and can grow to a diameter of 0.25 meters. Broccoli is a plant that is very demanding on moisture, so it cannot do without irrigation in the dry season. Growing vegetables is generally very labour intensive, but many operations in growing broccoli can already be automated. With broccoli, automation can be used in work operations such as planting and harvesting. This article presents the results of a field experiment comparing the fuel consumption of growing broccoli throughout the entire growing season. The field trial took place in the Czech Republic near the city of Hradec Králové in the 2021 season. Fuel consumption measurements were made at the plot where the stand was established at the beginning of the growing season and at the plot that was planted last. Fuel consumption was measured for each growing operation that was carried out on the plot. The distance of both plots from the farm was similar. The resulting amount of fuel consumed per one hectare of planted area was calculated by dividing the total fuel consumption for a certain cultivation operation by the planted area. Fuel consumption per one hectare of planted area is based on this calculation. The most fuel-intensive growing operation was harvesting broccoli. Harvesting broccoli consumed 35% of the total fuel consumption per hectare. The total fuel consumption for plot 1 was 216.1 litres per hectare, for plot 2 the total consumption was 199.4 litres per hectare. Individual work operations were compared with the norms and did not show statistically significant differences, except for soil preparation with a rotary tiller, where the value is twice as much as the norms.

Keywords: fuel consumption, planting system, vegetable production, broccoli.

Introduction

Vegetable production has its place in the Czech Republic. The year 2021 was a record year for vegetable production in Czech agriculture. A total of 16 001 hectares were planted with vegetables. In the long term, vegetable production has a fluctuating trend, with between 14-16 000 hectares planted each year. Broccoli has no place in the statistics, it is always listed with cauliflower, but the preliminary estimate of the area planted to broccoli for 2021 was 160 hectares. The average yield was 16.54 tons per hectare [1]. Vegetable cultivation is a sector of agriculture that is very much affected by the impact of the energy crisis, especially the uncertainty of the future development of energy prices. Energy and fuel are essential for the operation of irrigation, storage, mechanization, and other covered areas.

Broccoli is a cabbage family vegetable that originated from the wild broccoli plants that are native to the Mediterranean region. It was not until the 20th century that this vegetable began to be cultivated on a large scale in Italy [2]. Broccoli is best suited to the heavier, water-holding soils of beet-growing areas. The best quality heads of broccoli are those harvested during early summer and autumn [3]. Broccoli is one of the most demanding crops in terms of irrigation and nutrition, and is therefore grown in the first line, fertilized with manure at a rate of 40-50 tons per hectare [4]. Organic fertilizer is very important for broccoli, which can increase the yield [5]. Seedlings are in most cases imported already pre-grown in planters from the Netherlands, where the seedlings are pre-grown in huge greenhouses. The Netherlands is the home of vegetable production and therefore many interesting mechanization ways, which are often designed for only one specific operation in the growing process of a particular vegetable, comes from there. Some of the growing operations in broccoli production are very energy intensive, this stems from the time required as they are carried out at a low working speed. The most time-consuming operation is the harvesting of broccoli, which is carried out by winnowing and one field site is harvested up to three times at an interval of 14 days [6]. Currently, harvesting is done manually, but there is now a field robot that can perform selective harvesting without an operator. This field robot replaces up to 6 workers [7]. Robotic harvesting will have a major impact on the economics of broccoli cultivation. It will be possible to reduce the fuel consumption by electrifying farming, because in the future some work operations will be carried out by field robots powered by electricity [8]. The aim of broccoli cultivation is to breed varieties that allow selective harvesting to be carried out in the shortest possible time with the fewest passes [9].

It is also important to select suitable varieties for growing broccoli throughout the growing season, as some varieties are more suitable for growing in spring and the autumn and others are more suitable

DOI: 10.22616/ERDev.2024.23.TF173

for growing in summer [10]. By choosing the right variety, better economic results can be achieved, as the broccoli heads will be of better quality and have more weight [11]. Earlier harvesting protects the plants from having to be covered with non-woven fabric in spring. With non-woven fabric work operations are associated that will negatively affect the economics of the harvest but will extend the growing season.

The objective of this study was to measure fuel consumption in broccoli cultivation for all growing operations. Fuel consumption measurements were made on a plot where the crop was established early in the growing season and on a plot that was planted last in the growing season under study. Each planting operation was recorded in detail and the output of the study is the fuel consumption per hectare of the planted area. An important indicator is the difference in the fuel consumption for the plot where the crop was established initially and at the end of the planting season in 2021.

Materials and methods

Fuel consumption for each growing operation was measured in 2021. The experiment was conducted on two different plots. The first broccoli crop was established early in the growing season and the second crop was, on the other hand, established at the very end of the growing season. Basic data on the fields where the measurements were carried out: plot 1 – Předměřice nad Labem site, 50.2659433N, 15.8037744E, altitude 256 m above sea level, average slope of the plot according to LPIS (LPIS is a geographic information system, GIS, that consists primarily of records of agricultural land use.) is 0.55º, the area of the plot is 9.95 ha, but 7.59 ha were planted with a total of 316 000 seedlings, the distance from the farmland is 6 150 m; plot 2 – Světí site, 50.2579128N, 15.7724892E, altitude 259.5 m above sea level, the average slope of the land according to the LPIS is 1.68º, the area of the land is 22.6 ha, but 17.22 ha have been planted with a total of 717 500 seedlings, the distance from the agricultural land is 5 650 m. The rest of the land area is made up of field headlands and paths between the planting blocks. The area of the plot that was planted with seedlings was generated from GPS navigation. These plots were chosen by the farm agronomist because they have the highest yield potential for broccoli cultivation and meet the cropping sequence. Only plots with water connection can be selected for vegetable cultivation because irrigation is needed.

Fuel consumption was measured for each cultivation operation that was carried out on the plot. The fuel consumption was measured as follows: before the cultivation operation was carried out the tank of the energy vehicle was refueled to full capacity, then the cultivation operation was carried out, and on return to the farm the tank was refueled to full capacity again. The amount of refueling was recorded. For cultivation operations that lasted longer (soil preparation, planting, harvesting) diesel consumption was recorded every day as soon as the return to the holding took place. The farm had a Kingspan twin tank diesel tank with a capacity of 5 000 litres. The fueling equipment included a K600 B/3 fuel gauge (Piusi, Italy) which was calibrated annually and had a maximum error of ± 0.5%.

The calculation of the resulting amount of the fuel consumed per hectare of the planted area for each cultivation operation was carried out by dividing the total consumption for a given cultivation operation by the area planted. The result of this calculation is the fuel consumption per hectare of the planted area for a given cultivation operation. The fuel consumption for transporting the machine to and from the plot was not included in the calculation as it is a relatively negligible amount of fuel in relation to the total consumption.

In monitoring the fuel consumption, many of the planting operations used common machinery that is also used for other crops. However, some growing operations used techniques that are only applicable to growing broccoli or other vegetables. GPS navigation was used for all operations where it is possible to ensure that operations were carried out as accurately as possible. Raven navigation (Netherlands) was used. The cultivation process includes the following work operations: subsoiling, ploughing, fertilization with fertilizer, soil preparation with a whirling cultivator, planting, transport of seedlings, chemical protection, transport of non-woven fabric, biding of soil to non-woven fabric, transport of irrigation components, mechanical treatment of paths and swales with a whirling cultivator, transport of non-woven fabric to the landfill, weeding, harvesting, transport of irrigation components, mulching, engraving of irrigation tubes, winding of tubes with a winch, loading of tubes, transport of tubes to the landfill. The operations associated with the handling of the non-woven fabric were only carried out for plot 1, as it was necessary to protect the vegetation from possible night frosts. The data were processed with MS Excel (Microsoft Corp., USA).

Results and discussion

The total fuel consumption during all cultivation operations in plot 1 was 216.1 $l \cdot ha^{-1}$ of the planted area. This is a relatively high figure, but growing vegetables is much more energy intensive than growing conventional field crops. In comparison, the fuel consumption for winter wheat production is 63.6 $l \cdot ha^{-1}$ [5].

In the table below, the work operations are ranked according to their intensity. The operations that have been carried out more than once are listed only once and the consumption is summed up, these are: fertilization with fertilizer, chemical protection, mechanical treatment of paths and swales. Included in the transport of ancillary material are operations that involve the transport and removal of irrigation components and, in plot 1, the transport of non-woven fabric.

Table 1

Fuel consumption on plot 1 sorted by energy intensity

Number of operations	Type of operation	Fuel consumption, $l \cdot ha^{-1}$
1	Harvest	77.2
2	Ploughing	22.6
3	Soil preparation	22.5
4	Planting	18.9
5	Grubbing irrigation tubes	10.8
6	Mulching	8.9
7	Coiling the tubes	7.6
8	Mechanical preparation of paths and swales	7.2
9	Removal of ancillary material to landfill	7.2
10	Condition	6.9
11	Chemical protection	6.8
12	Weeding	5.5
13	Transport of seedlings	4.5
14	Fertilization with fertilizer	4.0
15	Transport of auxiliary material	3.0
16	Throwing of soil to non-woven fabrics	2.1
17	Loading of tubes	0.4

Figure 1 shows the fuel consumption of plot 1. The number of the cultivation operation is the same as the operation number given in the table above. The left axis shows the fuel consumption $l \cdot ha^{-1}$ and the right axis shows the cumulative frequency. This is a Pareto diagram with a Lorenz curve. It is clear from the graph that the most labour intensive operation is the harvesting of broccoli, it is an energy intensive operation as the working speed here is usually only 300-500 metres per hour and each part of the planted area is harvested three times.

The total fuel consumption during all cultivation operations on plot 2 was 199.4 $l \cdot ha^{-1}$ of the planted area. The table below again ranks the work operations according to their intensity. A detailed explanation of the table is already described above. However, for plot 2 there are no operations that are associated with non-woven fabric as the seedlings did not need to be covered. The other missing operation is subsoiling, this operation does not occur here, because the field was ploughed immediately after the pre-crop harvest.

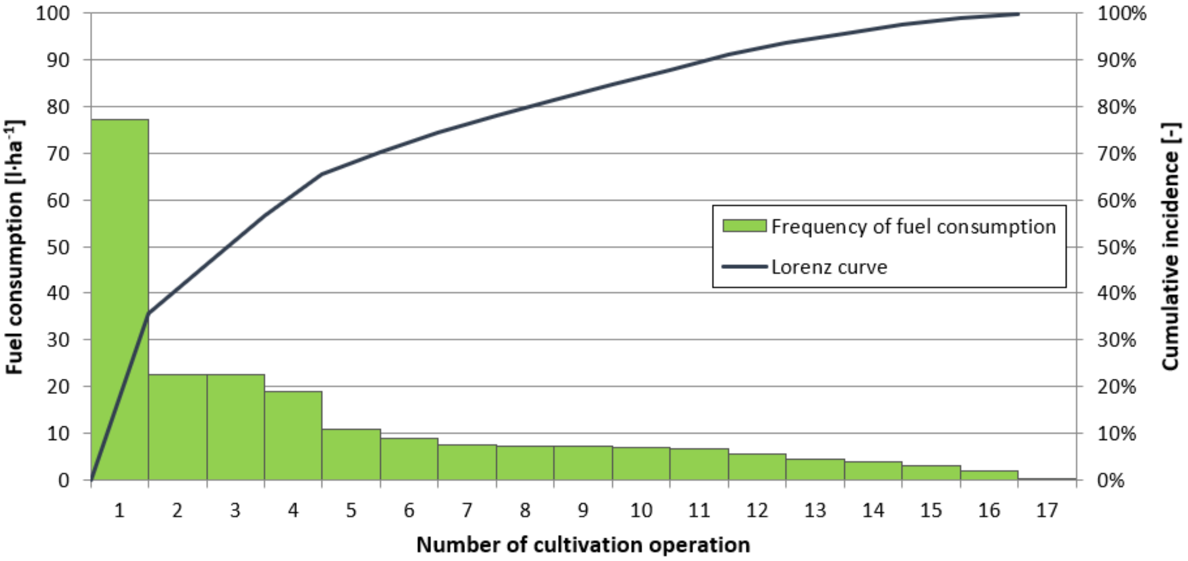

Fig. 1. **Pareto diagram of fuel consumption on plot 1**

Table 2

Fuel consumption on plot 2 sorted by energy intensity

Number of operations	Type of operation	Fuel consumption, $l \cdot ha^{-1}$
1	Harvest	70.6
2	Ploughing	24.9
3	Soil preparation	23.8
4	Planting	17.9
5	Mechanical preparation of paths and swales	10.1
6	Digging irrigation tubes	9.4
7	Mulching	8.3
8	Coiling the tubes	8.2
9	Chemical protection	6.2
10	Weeding	5.8
11	Removal of ancillary material to landfill	4.4
12	Fertilization with fertilizer	4.2
13	Transport of seedlings	4.0
14	Transport of auxiliary material	1.0
15	Loading of tubes	0.6

Figure 2 shows the fuel consumption of plot 2. The number of the cultivation operation matches the operation number given in the table above. This is the same type of graph as shown above. Again, the graph shows that the most labour intensive operation is the broccoli harvest. When comparing the different work operations, the fuel consumption is approximately the same and there are no outliers.

The difference in fuel consumption is 16.7 $l \cdot ha^{-1}$. Comparisons can only be made for some work operations with the norms because broccoli production as a whole has not been previously studied. Some work operations are very specific, and no source can be found to compare whether the measured consumption is normal or not. An example of this is harvesting of broccoli heads, which is done in many ways and there are no standardized procedures. The work operations that were listed in the norms by Abraham [12] did not differ significantly from the tabular values, except for the preparation of the soil, which was carried out with a rotary cultivator, there is such an explanation that the work speed was significantly lower than that calculated in the norms. But there are many factors that can affect the resulting consumption, such factors can be, for example: different shape of land, different soil properties, technical condition of machines, performing work operations at inappropriate time. The difference in consumption is also due to the fact that the first plot had to be covered with a non-woven fabric that protects the growth from possible frosts. For covering plot 1 and manipulation with non-woven fabric, 6.7 $l \cdot ha^{-1}$ were needed.

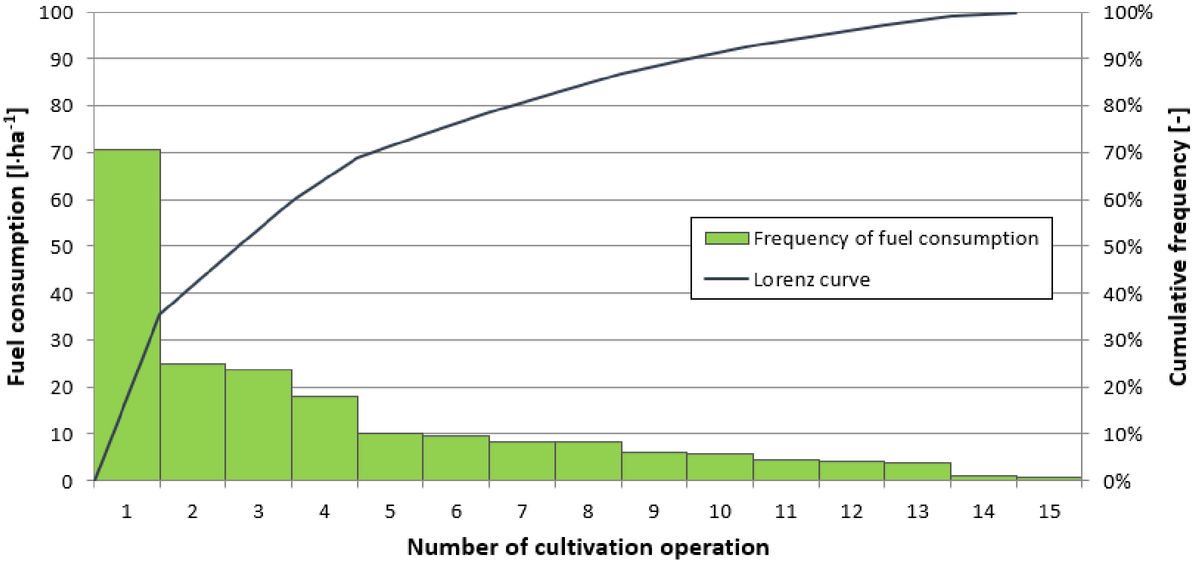

Fig. 2. **Pareto diagram of fuel consumption on plot 2**

For comparison, a study was found where fuel consumption was monitored for tomato and watermelon production. For tomato production 285.6 $l \cdot ha^{-1}$ were consumed. For watermelon production 244.8 $l \cdot ha^{-1}$ [13]. Broccoli production was considered in this study, with 216.1 $l \cdot ha^{-1}$ consumed for plot 1 and 199.4 $l \cdot ha^{-1}$ consumed for plot 2. With these results it can be said that vegetable production is very energy intensive.

Conclusions

The results of the fuel consumption measurements show that stands that are established at the beginning of the growing season are more energy-intensive, as they include work operations that are associated with covering the stand with non-woven fabric. The production of broccoli is very energy-intensive, as during the entire growing season three times more amount of fuel is consumed than in the production of winter wheat. The research will continue along the path of finding labour and energy savings for individual work operations. The development will consist in the automation of some cultivation operations. The output will be a calculation of energy savings. This research is unique because horticulture is a very narrow field in which much knowledge is not recorded.

Author contributions

The entire author team contributed equally to this research in all its aspects. All authors have read and agreed to the published version of the manuscript.

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