RESEARCH ARTICLE

Effect of morphostructural elements on buckwheat (*Fagopyrum esculentum Moench*) productivity

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The research was carried out at Vokė Branch of the Lithuanian Research Centre for Agriculture and Forestry in 2018-2019. The research objective was to determine the influence of relative proportion of stems, leaves and flower panicles on the formation of biomass and grain yield.

The research determined that the productivity of buckwheat was dependent on the proportion of morphological elements of plants, the influence of which was different in the process of formation of biomass and grain yield in organic and conventional agricultural systems. The dry matter yield of biomass was found to be strongly correlated with the relative proportion of stems in the morphostructure of the plants (r=0.82** in organic farming, r=0.64** in conventional farming system). The grain yield in organic farming was dependent on the relative proportion of flowers in the morphostructure (r=0.65**). For the conventional agricultural system, the buckwheat grain yield also increased depending on the relative proportion of flowers, however, the increase was statistically unreliable (r=0.47). A higher yield index and strong correlations between the yield index and morphostructural elements were observed during a drier summer.

Key Words: *Buckwheat; Morphostructure; Biomass; Grain yield*

INTRODUCTION

Common buckwheat (*Fagopyrum esculentum Moench*) is one of the oldest cultivated pseudocereals. It was cultivated in Asia 4-5 thousand years ago, and in Europe it was started much later, about 600 years ago [1,2]. Buckwheat has recently been grown in more than 20 countries around the world, but China (37.6% of total production), Russia (22.4%) and Ukraine (9.0%) are the largest producers [3]. Buckwheat is still an important agricultural crop. Its grain is eaten by humans and used to feed domestic animals [4]. The beginning of this century saw a decline in buckwheat production in East Asian countries and an increase in Western European countries [3]. Buckwheat production worldwide has been declining over the last two or three decades due to its low and volatile yields [5,6]. In some cases, low yields may have been influenced by a very low technological level of buckwheat production [7]. In spite of the negative aspect of yield, buckwheat is best suited for organic growing, as it is minimally demanding in terms of soil conditions, fertilisation and plant protection. Buckwheat grain is an important and healthy food that is increasingly gaining attention in the functional food production sector due to high quality protein, unsaturated fatty acids, minerals, vitamins, antioxidants and phenolic compounds [1,5]. In addition, buckwheat grain does not contain gluten, which makes it very important for people intolerant to gluten [8]. In this context, buckwheat has enough positive prospects for expanding its crop areas.

The studies on the effects of different agro-ecological conditions on buckwheat showed that buckwheat could be successfully grown on different soil types using natural soil fertility [9]. Popović [10] believes that organic agriculture is based on a strong relationship with nature and maintaining natural balance. In Serbia, the average grain yield in the organic buckwheat growing system was 1235 kg ha^{-1} and had stability (CV=5.05%) [10]. However, organic farming has not always provided high yields for agricultural crops. This was confirmed by Dutch researchers having analysed a meta-dataset of 362 published organic-conventional comparative crop yields [11]. The studies showed that the average yield difference between conventional and organic farming systems was more than 20%.

In Russia, the influence of mineral fertilisation on the yield of 19 buckwheat varieties of various morphotypes was investigated. The short-stem cultivars were found to be the best responders to mineral fertilisers with a 15% increase in productivity [12].

Buckwheat grain yield formation is a complex process depending on various factors. As buckwheat is a plant with specific biological properties, its productivity is closely related to both insect visitation and hydrothermal conditions during the vegetation period [13-15]. Although buckwheat blooming takes a long time (lasts about 2 months) and the formation of flowers is very abundant, the percentage of grain formation may be low [15]. Italian researchers say that the amount of buckwheat vegetative structures (stems, branches and leaves) helps to estimate a yield potential, since grain yield is directly dependent on biomass [16].

The research objective was to determine the influence of relative proportion of stems, leaves and flower panicles on the formation of biomass and grain yield.

MATERIALS AND METHODS

Site and soil

The investigations were conducted in the crop rotation during 2018-2019 at Vokė Branch of the Lithuanian Research Centre for Agriculture and Forestry which is located in Trakų Vokė (54°63' N, 25°10' E). The experimental plots were established on sandy loam on carbonaceous fluvial-glacial gravel eluviated soil (IDp), Haplic Luvisols (LVh) according to FAO-UNESCO classification [17]. Soil agrochemical characteristics: pHKCl-6.0, Corg-1.56%, mobile P_2O_5-281 mg kg^{-1}, mobile K_2O-204 mg kg^{-1}.

Experimental design and management

15 buckwheat varieties were studied in two farming systems: Organic and Conventional. The two-factor experiment was performed in 4 replicates. The soil for buckwheat trials was plowed in autumn, twice cultivated and harrowed in spring.

Fertilisation

Zero application in the organic farming system and N40P60K60 in conventional farming. The test plot area for variety trials-1 m^2. Seed rate-3 million ha^{-1} of fertile seeds. The buckwheat was sown during the 3rd ten-day period of May each year. Under the climatic conditions of Lithuania, the buckwheat bloomed intensively, formed and matured grain in July and August. The harvesting took place during the 1st ten-day period of September.

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Meteorological conditions

Climate data (monthly temperature and precipitation) for the two years were obtained from the Lithuanian Hydrometeorological Service. The average temperature of the summer months in Trakų Vokė area is 15.7-16.9 mm and the average precipitation is 68-78 mm. According to the climatological standard normal the hydrothermal regime should be: HTC=1.63 in June, HTC=1.49 in July, and HTC=1.35 in August.

Thermal and irrigation conditions during the summer season could be described by a widely used Selianinov's hydrothermal coefficient $HTC=\Sigma p/0.1\ \Sigma t$, where: Σp-total precipitation (mm) sum during a given period; Σt-total sum of active temperatures (°C) of the same period. If HTC>1.6-the irrigation is excessive, HTC=1.0…1.5-optimal irrigation, HTC=0.9…0.8-weak drought, HTC=0.7…0.6-moderate drought (arid), HTC=0.5…0.4-heavy drought, HTC<0.4-very heavy drought.

The weather conditions varied among the experimental years. During both experimental years, June was deficient in moisture. Extremely dry hydrothermal regime was observed in June of the second year of the study (HTC=0.36) (Figure 1). The hydrothermal regime in August also differed from the optimum in both the first (irrigation was excessive) and second year (heavy drought).

Biomass and grain harvesting

The relationship between buckwheat biomass and morphological elements (stems, leaves and flowers) was determined at flowering stage (BBCH 60), i.e. in July. Grain harvesting was accomplished in September.

Statistical analyses

The experimental data was statistically processed using analysis of variance and correlation- regression analysis methods employing software Anova, software package Selekcija. The treatment effect was tested by the least significant differences LSD05. Significance levels: **-p<0.01, *-p<0.05.

RESULTS

The research results show that the dry matter yield of buckwheat biomass in the organic farming system was on average 26.8% lower compared to that in the conventional agricultural system (Table 1). Grain yields differed less and not significantly for different agricultural systems annually. However, the harvest index in both survey years was significantly higher for the organic farming system.

TABLE 1

Yields and harvest indices of biomass dry matter and grain for organic and conventional farming systems

Indicator	Year	Agricultural systems	Indicator value	LSD05
Biomass dry matter yield, t ha^{-1}	First year	Organic	3.78	0.100
		Conventional	5.05	
	Second year	Organic	2.90	0.081
		Conventional	3.48	
Grain yield, t ha^{-1}	First year	Organic	2.66	0.079
		Conventional	2.64	
	Second year	Organic	3.12	0.102
		Conventional	3.43	
Harvest index	First year	Organic	0.41	0.009
		Conventional	0.35	
	Second year	Organic	0.52	0.011
		Conventional	0.49	

The buckwheat grown in the conventional agricultural system formed a much higher yield of biomass dry matter than grain, compared to the organic system. Variations in biomass dry matter and grain yields of the studied varieties were not proportional. This indicates that the yield of buckwheat grain did not always depend on the yield of plant biomass and was influenced by the agricultural systems used. Statistical evaluation of the data showed that the grain yield in the organic farming system was strongly correlated with the biomass dry matter yield (r=0.64**-0.76**) in both research years (Table 2). However, the correlations found in the conventional agricultural system were weak or very weak.

TABLE 2

Correlation between yield of buckwheat biomass dry matter (t ha^{-1}) and grain yield (t ha^{-1}) (n=15)

Year	Correlation coefficient (r)	
	Organic farming system	Conventional farming system
First year	0.64**	0.47
Second year	0.76**	0.19

** -Significant values with p<0.01

The buckwheat grain yield was found to be positively correlated with the relative proportion of stems and panicles, but negatively with the relative proportion of leaves during both study years (Table 3).

TABLE 3

Correlation coefficients (r) between relative proportions of morphological elements and grain yield, and harvest index each year (n=15)

Morphological elements	Correlation coefficients (r)			
	First year		Second year	
	Yield	Harvest index	Yield	Harvest index
Organic farming system				
Stems, %	0.60*	-0.43	0.44	-0.46
Leaves, %	-0.72**	-0.46	-0.1	-0.65**
Flowers, %	0.50*	0.45	0.68**	0.57*
Conventional farming system				
Stems, %	0.51*	-0.21	0.35	-0.61*
Leaves, %	-0.71**	-0.31	-0.4	-0.80**
Flowers, %	0.38	0.34	0.33	0.60*

* -Significant values with p<0.05; ** -Significant values with p<0.01

It is noteworthy that these correlations were stronger and statistically reliable during the first year of the research for both farming systems. The dependence of the harvest index on the relative proportion of morphostructural elements had different tendencies. The estimated correlation coefficients showed that the yield index decreased with increasing relative proportions of stems and leaves. On the contrary, the increase in the relative proportion of flowers increased the harvest index. However, statistically significant correlations were found during the second year of the study.

With the average data of two years of the study, the relative proportion of buckwheat stems, leaves and flowers had a various effect on the biomass dry matter yield, however, the correlations found showed similar tendencies for both farming systems (Figure 2). The dry matter yield of buckwheat biomass was found to increase with the relative proportion of stems in the morphostructure. An increase in relative leaf proportion led to a declining tendency of biomass dry matter yield. The relative proportion of flowers had an even smaller effect on the biomass dry matter yield, especially for the conventional farming system.

The correlations between the relative proportion of buckwheat morphostructural elements and grain yield were not analogous to the correlations between the morphostructural elements and biomass dry matter yield. The increase in the relative proportion of the same morphostructural elements in different agricultural systems had the opposite effect on the buckwheat grain yield. It was found that the relative proportion of stems had a greater influence on the formation of buckwheat grain yield in the organic farming system compared to the conventional one: the grain yield in the organic farming system increased until the proportion of stems exceeded 54% (Figure 3). The increase of relative leaf proportion in the buckwheat morphostructure did not have any positive effect on the grain yield, as with an increasing leaf proportion, the grain yield decreased. However, only in the conventional agricultural system, there was a tendency for grain yield to increase with the relative leaf proportion increase up to 32%. An increase in the relative flowers proportion to 18% resulted in an increased grain yield as well. It should be noted that an even higher proportion of flowers did not ensure higher grain yield.

DISCUSSION

Low yields of buckwheat, averaging 902 kg ha^{-1} in Europe, are the main reason for the low production of buckwheat compared to other cereals [6]. In addition to the low yields of buckwheat grain for different farming systems, they have a tendency of volatility. According to the data of 10 years of research in Lithuania, the variation of buckwheat grain yield for the conventional agricultural system was CV=24.3-45.5% [18]. This shows that under Lithuanian climatic conditions mineral fertiliser (N30P50K40) application does not produce consistent grain yields every year. Other studies have shown that the conventional agricultural system, where fertilisation was one of the agrotechnical measures applied, produced a positive effect on buckwheat green mass yield, i.e. it increased by an average of 45.6% [19]. The results of our research showed that the dry matter yield of buckwheat biomass was on average one third higher compared to the organic farming system (Table 1). It should be noted that the yields of buckwheat biomass dry matter and grain varied statistically significantly between different agricultural systems (Table 1). Although due to mineral fertilisation (conventional farming system), buckwheat produced a higher yield of biomass dry matter, no positive effect on grain yield changes was observed. The results of statistical evaluation showed that in the conventional farming system, buckwheat grain yield was only 3%-22% dependent on biomass yield (r=0.19-0.47) (Table 2). However, the biomass content determined the formation of buckwheat grain yield by 40.1-57.8% in the organic farming system.

Japanese researchers have found that mineral fertilisers are readily available for plant growth under favourable climatic conditions, as grain yields declined due to higher temperatures and heavy rainfall [20]. According to multi-year studies in Lithuania, buckwheat requires an optimum moisture hydrothermal regime (HTC 1.0-1.5) at the beginning of vegetation (June) and during grain maturity (August), and a sufficiently moist hydrothermal regime during grain formation (July) (HTC 1.5-2.5) [18]. We believe that in our studies buckwheat productivity was influenced by the hydrothermal regime of each year, which was contrasting in June and August during both years. There were particularly unfavourable meteorological conditions for buckwheat at the beginning of vegetation during the second year of our study due to lack of moisture in June (HTC 0.36) (Figure 1). Due to droughty meteorological conditions buckwheat was shorter and produced lower biomass, which could have affected the grain yield. Italian researchers, who studied the relationship between buckwheat biomass and grain yield found that buckwheat grain yield was positively correlated with vegetative biomass (r=0.66**) [16]. The results of our research also showed that the influence of biomass on buckwheat grain yield formation had a significant influence in the organic farming system (r=0.64**-0.76**) (Table 2). In contrast, no strong correlations were found for the conventional farming system. Better nutrient supply in conventional farming led to more intensive growth and branching of buckwheat, resulting in higher biomass yields. Buckwheat plants have specific biological properties (the growth stages are not clearly distinguished but occur overlapping throughout the growing season), i.e. plants grow by forming vegetative and generative organs at the same time. Therefore, the wet weather conditions that favoured the growth of vegetative organs were not favorable for flower pollination and grain formation. The results of our research showed that during the first year of the study, when August received surplus rainfall (HTC 2.12), organic grain yields were 17.3% and conventional ones were 29.9% lower, on average (Table 1). When the grain yield was lower, the harvest index was correspondingly lower as well.

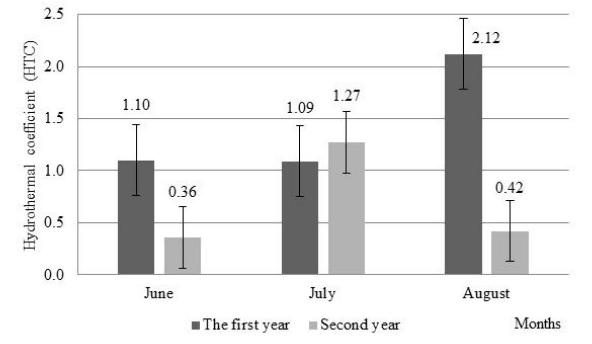

Figure 1) *Hydrothermal conditions during summer periods*

The proportion of morphological fractions in biomass influenced both the biomass dry matter yield and the grain yield. It should be noted that the biomass dry matter yield was positively correlated with the relative proportion of stems in both agricultural systems: Organic-r=0.82** and Conventional-r=0.64** (Figure 2). On the contrary, the increase in the relative proportion of leaves and flowers predetermined the decrease of biomass dry matter. This can be explained by the fact that the relative proportion of stems accounted for their greater proportion in the morphostructure of buckwheat plants compared to leaves or flowers.

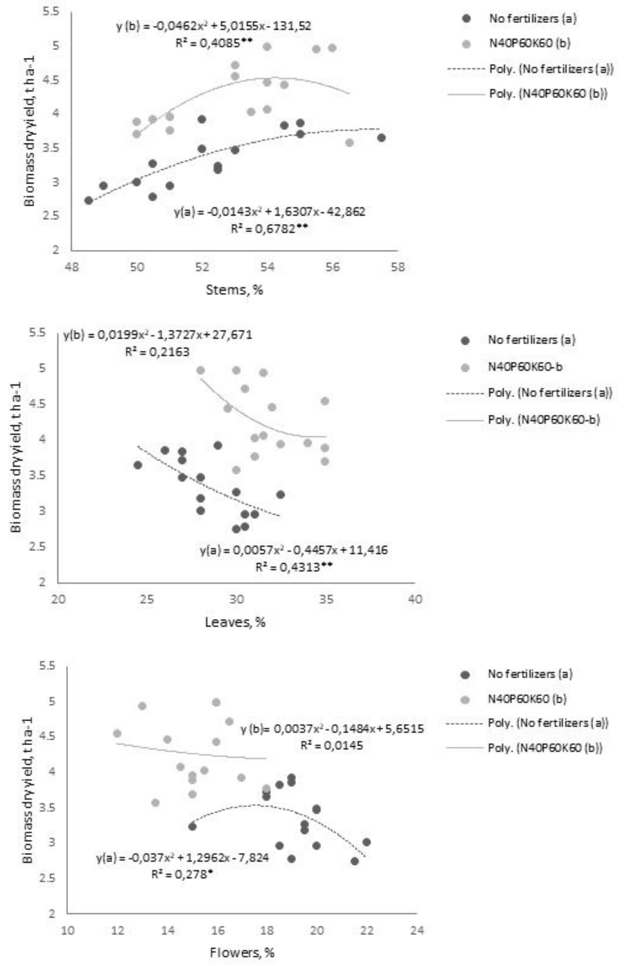

Figure 2) *Correlation between morphostructural elements of buckwheat plants and biomass dry matter yield*

The buckwheat grain yield was most dependent on the relative proportion of flowers (r=0.47-0.65**) (Figure 3). The tendencies of grain yield increase with the relative proportion of flowers in plants were also observed while analysing the data of individual research years. In addition, correlation coefficients showed that not all morphostructural elements played the same role in buckwheat grain yield during both research years. It should be noted that the relative proportion of flowers influenced buckwheat grain yield, especially in the organic farming system. In addition, the dependence of buckwheat grain yield on the proportion of flowers formed varied little each year (r=0.50* and 0.68** in organic farming, and r=0.38 and 0.33 in the conventional farming system) (Table 3).

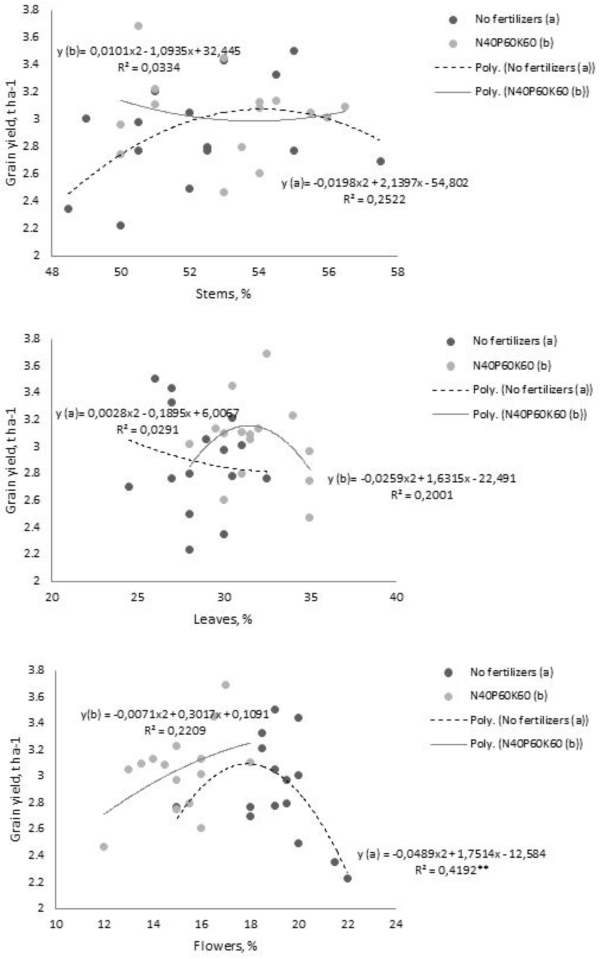

Figure 3) *Correlation between morphostructural elements of buckwheat plants and grain yield*

The statistical analysis of the relationship between the harvest index and morphostructural elements revealed general tendencies regarding the influence of individual morphostructural elements on the harvest index value. According to the research data, the harvest index decreased significantly with an increase in the relative proportion of stems and leaves. In contrast, an increase in the relative proportion of flowers in the morphostructure of buckwheat resulted in an increase in the harvest index. There was a stronger correlation between the morphostructural elements and the harvest index in the second year of the study, when precipitation was 50% lower than the climatological standard normal. The obtained results showed that in the absence of rainfall during the growing season the harvest index was more dependent on the relative property of morphostructural elements. The harvest index is the ratio of grain yield to total plant biomass, which formed in a drier summer. We believe that due to lesser biomass caused by unfavourable abiotic factors, the formation of buckwheat grain yields was determined by better distribution of photosynthetic products between vegetative structural elements (stems, leaves) and reproductive structural elements (flowers, grains). In Russia, the investigation of the yield formation patterns of buckwheat cultivars with different morphostructures revealed that better distribution of assimilates in determinant plants was the main factor in buckwheat yield increase [21]. It should be noted that the determinant types of buckwheat varieties have limited branching and foliage. The results of our research showed that the role of leaves formed in buckwheat plants was less important in the process of grain yield formation. The correlation coefficients found between the leaf proportion and the grain yield or harvest index were negative [22].

CONCLUSION

The dry matter yield of buckwheat biomass was found to be statistically significantly ($p<0.01$) dependent on the relative property of stems in the plant morphostructure ($r=0.82^{**}$ for organic farming, $r=0.64^{**}$ for conventional).

The buckwheat grain yield in the organic farming system was statistically significantly ($p<0.01$) dependent on the relative property of flowers in the morphostructure ($r=0.65^{**}$). The rising tendencies for buckwheat grain yield with increasing relative proportion of flowers were observed in the conventional agricultural system, ($r=0.47$).

The harvest index was higher and its relationship with morphostructural elements was reliable ($p<0.05$ or $p<0.01$) in the less humid growing season.

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