Buckwheat leaf area index and yield performance depending on plant population under full-season and stubble-crop growing periods

M. Bavec, F. Bavec, C. Plazovnik and S. Grobelnik Mlakar

Darstellung des Indexes der Buchweizenblattfläche und Kornernte abhängig von der Pflanzenpopulation in der Wachstumsperiode der Haupt- und Stoppelfrucht

1 Introduction

Buckwheat is becoming a popular food source outside traditional buckwheat growing areas (AUFHAMMER and KÜBLER, 1998). It is an important cash crop in Slovenia, with a 5-year average yield of 1022 and 1308 kg grains per ha for stubble and full-season crops, respectively. Because of its short life cycle (about 90 days) and a relatively long growing (frost-free) season in Slovenia (i.e. more than 150 days), buckwheat is primarily grown as a stubble-crop (i. e. following early vegetables, barley or wheat), and seldom as a full-seasonal crop.

Buckwheat seeds are rich in digestible proteins, vitamins B_1, B_2 and P, favourable fatty acids and minerals (POMERANZ and ROBBINGS, 1972; MICHALOVA et al., 1998; AUFHAMMER et al., 1999; LISZEVSKI, 1999; BAVEC and BAVEC, 2006). In alternative medicine, it is used for balancing the sugar and cholesterol levels in blood, associated with its high content of choline, which is known to reduce high blood pressure (JIANG et al., 1995).

The morphological character and grain yield of buckwheat vary according to genotypes and climatic circumstances. In general, early spring sowing of buckwheat leads to higher leaf area index (LAI), and grain yield, but the plants' growth can be damaged by late frost (AUFHAMMER et al., 1994) or by lodging; while late sowing may suffer from lack of moisture at seedling emergence, a short assim-

Zusammenfassung

In Slowenien ist der Buchweizenanbau *(Fagopyrum esculentum Moench)* in unterschiedlich langen Wachstumsperioden möglich. Das Ziel dieser Studie ist zu erforschen, welche Einwirkung die Population von 250 bis 1250 Pflanzen m^{-2}, gesät als Hauptfrucht (Wachstumsperiode 132 Tage) und Stoppelfrucht (89 Tage) auf die Buchweizenernte hat. Feldversuche wurden in Maribor mit der slowenischen Sorte Darja und der autochthonen Population in den Jahren 1997 und 1998 durchgeführt. Alle Hauptbehandlungen (Pflanzenpopulation, Wachstumsperiode, Genotyp und Jahr) wirkten sich auf den Index der Blattfläche (LAI), die Zahl der entwickelten Samen pro Pflanze und Kornernte (kg ha^{-1}) aus. Zahlreiche Doppel- und Dreifachinteraktionen sind statistisch charakteristisch. Die Zahl der Blütenstände unterscheidet sich hinsichtlich der Wachstumsperiode, Pflanzenpopulation und (Pflanzenpopulation × Genotyp, Pflanzenpopulation × Wachstumsperiode × Genotyp × Jahr) Interaktion, die Zahl der unentwickelten Samen wurden aber durch die Wachstumsperiode, das Jahr und die Interaktion × Pflanzenpopulation × Genotyp bewirkt. Eine dichtere Pflanzenpopulation bewirkt einen höheren LAI, eine niedrigere Zahl der Blütenstände, Blüten und entwickelten Samen pro Pflanze als eine spärliche Pflanzenpopulation. Trotz morphologischer Veränderungen der Pflanzen hat die Pflanzenpopulation keine Einwirkung auf die Kornernte (kg ha^{-1}), wenn diese von 250 bis 750 Pflanzen m^{-2} variiert, doch extrem dichte Population von 1250 Pflanzen m^{-2} vermindert die Ernte der Hauptfrucht. Deswegen ist die Anwendung einer spärlichen Pflanzenpopulation (das bedeutet eine niedrige Aussaatnorm) wirtschaftlich vorteilhafter, dichte Pflanzenpopulationen wären aber wegen eines höheren LAI geeigneter für die Unkrautkontrolle.

Schlagworte: Buchweizen, Pflanzenpopulation, Wachstumsperiode, Morphologie, Genotyp.

Summary

Two ways of buckwheat *(Fagopyrum esculentum Moench)* growing (full-season and stubble crop production) are common in Slovenia, but different plant populations may be necessary for the best yield from each of them. The main objective of this study was to determine how yield is affected by plant population increase from 250 to 1250 plants per m^{-2}, and the growing period (full-season crop, 132 days and stubble crop, 89 days). The experiments were conducted in Maribor, using Slovene main buckwheat cultivar Darja and land race population, in 1997 and 1998. All the main treatments (plant population, growing period, genotype and year) affected leaf area index, the number of developed seeds $plant^{-1}$ and seed yield kg ha^{-1}. Numerous two- and three-way interactions were significant. The number of flower clusters differed according to the growing period, plant population and (plant population × genotype, plant population × growing period, × genotype, × year) interactions, but the number of undeveloped seeds was affected by the growing period, years and growing period × plant population × genotype interaction. High plant population gave greater LAI, but a lower number of flower clusters, flowers and developed seeds per plant than the low plant population. In spite of changed morphology, the plant population had the same effects on seed yield (kg ha^{-1}) at 250 and 750 plants m^{-2}, but with an extremely high plant population of 1250 plants m^{-2} reduced yield ha^{-1} only during the full season-crop vegetation period. Therefore, using low plant population (i. e. seed rate) instead of high seed rates is economically beneficial, whereas using higher plant population (due to higher LAI) may be more appropriate for weed control.

Key words: Buckwheat, plant population, vegetation period, morphology, genotype.

ilation period or the formation of short stems. The number of flowers, flower clusters, and seed sets vary according to the sowing date, often in relation to the risk of water shortage (AUFHAMMER et al., 1994; HAGIWARA et al., 1998; LISZEVSKI, 1999). Considerable differences among genotypes in growth pattern, flowering and ripening have been reported (RUSZOWSKI, 1986; HAGIWARA et al., 1998; MICHIYAMA et al., 1998; FUNATSUKI et al., 2000). In between the flowering and harvesting stages the minimum temperature exceeds 17.5 °C decreasing a 1000-grain mass (SUGIMOTO and SATO, 1999). Finally, grain yield (SINGH and ARYA, 1996) can be influenced or not by seed rates (GUBBELS and CAMPBELL, 1986; AUFHAMMER et al., 1994; THAKURIA and GOGOI, 2000; BARBUKOVÁ et al., 2000). In spite of all this information, additional knowledge on the effects of buckwheat leaf area index and cluster characters on yielding capacity might be helpful for improving the understanding of buckwheat yield formation, depending particularly on changing plant population density during different growing periods, i. e. full-season and stubble crop. We suppose that low plant population density compensates for seed yield by increasing branching, flower clusters and flowers per plant in comparison with high plant population, and that increasing yield limitations might exist depending on plant population density. However, interactions of plant population density with different growing periods, different climatic conditions over the years and genotype characteristics, might change the effects on leaf area index and yield capacity.

For these reasons, the objective of this study was to investigate the formation of leaf area index (leaf area is the main determinant of light interception and hence photosynthetic performance), flower clusters and associated yielding capacity, depending on different plant populations and interactions with full-season and stubble-crop growing periods, genotypes and years.

Genotype and genotype × growing periods' interaction was discussed (BAVEC et al., 2002a).

2 Materials and methods

2.1 Experimental site and overview of the treatments

Field experiments were conducted at the University of Maribor, Faculty of Agriculture, Slovenia (43° 34' N Lat., 15° 38' E Long.) on sandy loam Mollisoils with 2.3 % organic C and pH 6.9 or 6.5 (0.1 KCl). Three plant populations of two buckwheat genotypes were established at two different growing periods vs. two production systems (GP1: full-season crop sown on May 17^{th} and 20^{th} calculated as first sowing date, GP2: stubble crop sown on July 21^{th} and 15^{th} calculated as second sowing date, in 1997 and 1998, respectively). Seeds were sown by hand in rows 0.12 m apart. Plants were over-seeded and thinned at the stage of 2–3 leaves to a final stand of 250, 750 and 1250 plants m^{-2}. An extremely high plant population (PP) of 1250 plants m^{-2} is interesting only from the theoretical aspects and not in regard to production. Two Slovene common buckwheat genotypes were evaluated: cultivar Darja (registered in 1988), and a land race population grown by farmers from the Dolenjska region. In both years, the experimental design was a randomized complete block with four replications. Individual plot size was 5 × 2 m plus border area, which amounted to 0.5 m.

The preceding crop (one year before the experiments) was potato fertilized with 40 t cattle manure ha^{-1}, and ploughing for the experiments was in October. Fertilizers were not used because of the high soil test values. The content of K was 55.9 mg K_2O 100 g^{-1} soil (ammonium lactate) in both years. The content of P was 33.3 and 40.7 mg P_2O_5 100 g^{-1} soil (ammonium lactate), and the mineral nitrogen content (NO_3-N plus NH_4-N) was 61 and 58 kg Nmin ha^{-1} extracted with $CaCl_2$, on sampled soil to a 0.60 m depth. The soil was sampled on May 4th, 1997 and 1998. The section of the field intended for stubble-cropping was tilled prior to sowing. Chemical protection was not required and weeds were removed (mainly between plots) by hand. For adequate pollination, the hives of honey bees (*Apis melifera* L.) were placed near the field during the vegetation period.

The average 30-year annual rainfall in the experimental area is 999 mm with 766 mm in the growth period from April to October, with two annual maxima in June (121.6 mm) and August (130.8 mm). In the experimental periods in June, July and August, the rainfall was higher (Table 1) in both years than the 30-year average. The 30-year average temperature from April to October is 9.2 °C, with 58 days of temperatures over 25 °C; average July temperature is 19.3 °C. Over the entire experimental period there were small deviations from average temperature between the years, except the June-August period when we noted higher monthly temperature deviations (Table 1).

2.2 Data collection

For leaf area investigations, 10 plants were sampled in the middle of the plots, 0.5 m from the border area. The surface areas of all individual-green leaves without peduncles were measured destructively by using a scanner linked to a personal computer and by counting the number of black dots on the monitor screen according to Bavec and Bavec (2002b). Leaf areas were measured when the main stalk and 2-3 branches were developed (i.e. July 4th and August 25th in 1997, July 1st and August 19th in 1998, for the full-season and stubble growing periods, respectively), and the leaf area index (LAI) calculated. We expected to cover the maximum leaf area of the investigated plant stage.

Ten plants from the middle of each plot were marked with textile strip and the seeds for each counting by thread, separately. The number of opened flowers was counted in intervals of 7–10 days, as well as the number of fully-formed seeds. A certain length of time was needed for a flower to pass from the opened-flower stage to fully-formed seeds. The number of developed seeds was monitored for all 10 plants but the green seeds and seeds without endosperm were disregarded.

Ten m^2 per plot inside border areas were harvested by hand because the seed losses using a combine-harvester can be 40–50 % (Lee et al., 1996). Full-season GP1 buckwheat was harvested from the 26th to 29th of September and stubble-crop GP2 buckwheat from the 12th and 18th of October, in both years. The seed yield was calculated at 13 % moisture in the seeds.

2.3 Statistical analysis

Analysis of variance (ANOVA) for factorial experiments was conducted using a STATGRAPHICH© *Plus* 4.0, and the significance determined at $P \leq 0.05$ (*) and 0.01 (**), respectively. Tukey's test was used to determine significant

Table 1: Rainfall and average temperatures during the growth period under experimental circumstances
Tabelle 1: Niederschläge und Durchschnittstemperaturen in der Wachstumsperiode auf dem Versuchsfeld

Month	1st year		2nd year	
	Temperature (° C)	Rainfall (mm)	Temperature (° C)	Rainfall (mm)
May	14.1	58.9	13.3	49.3
June	17.2	158.7	17.9	152.5
July	17.8	176.2	18.8	247.2
August	17.1	215.3	18.6	137.9
September	13.7	77.1	13.7	174.6
October	7.1	16.4	9.2	164.7

differences (at $P \leq 0.05$) among (3) plant populations, (2) vegetation periods, (2) genotypes and years (2). Pearson's correlation (using SPSSX 7.5) between variables was calculated, using average data (n = 96).

3 Results and discussion

Under these climatic conditions, the buckwheat sown as stubble-crop GP2 had a shorter growing period, from the sowing date to the beginning of the flowering stage, than the full-season GP1 crop. There were no differences between plant populations but the number of flowers in all treatments increased until 50–55 days after the sowing date. AUFHAMMER et al. (1994) reported increasing numbers of flowers per plant until 60–70 days after sowing. Plant lodging is a usual problem in buckwheat production but, in our case, the plants were not lodged.

ANOVA and Tukey's tests showed that all the main factors significantly influenced LAI and the number of developed seeds and seed yield, except for the number of flower clusters which was not influenced by genotypes and years. In addition the genotypes did not affect the number of flowers and the PP did not significantly change the number of undeveloped seeds (Table 2).

In the experiments, on average, LAI also showed significant correlation with seed yield (r = 0.96*) and the number of developed seeds (r = 0.66*), as found by RAJBHANDARI et

Table 2: Significance of the effects of two buckwheat genotypes (Gen) cultivated over 2 years (Y) at 3 plant populations PP (PP: 250, 750 and 1250 plants per m2) under two growing periods (GP: sown as stubble- and full-season crop) on leaf area index (LAI), grain yield, number of flower clusters, flowers, undeveloped and developed seeds per plant during growing period (and harvested developed seeds per plant (HS, n = 10) and weight of 1000 seeds (WS) at harvesting based on average data without repetitions)

Tabelle 2: Statistisch charakteristische Unterschiede der Einwirkung von zwei Buchweizen-Genotypen, angebaut 2 Jahre lang mit Pflanzenpopulationen von 250, 750 und 1250 Pflanzen m-2 in zwei Wachstumsperioden (gesät als Haupt- und Stoppelfrucht) auf Index der Blattfläche, die Kornernte, die Zahl der Blütenstände, Blüten, unentwickelte und entwickelte Samen pro Pflanze (gezählt bei der Ernte) (HS, n = 10) und Masse von 1000 Korn (WS) bei der Ernte (Durchschnitt der Wiederholungen)

Factor	LAI	Seed yield (000 kg ha^{-1})	Number per plant			
			Flower clusters	Flowers	Undeveloped seeds	Developed seeds (HS, WS (g))
Year (Y)	*,**	*,**	n.s.	*,**	*,**	*,**
GP (growing period)	*,**	*,**	*,**	*,**	*,**	*,**
PP (plant population)	*,**	*,**	*,**	*,**	n.s.	*,**
Gen (genotype)	*,**	*,**	n.s.	n.s.	n.s.	*,**
YxPP	*,**	n.s.	n.s.	*	n.s.	n.s.
GPxPP	*,**	*,**	*,**	n.s.	n.s.	n.s.
PPxGen	*,**	n.s.	*	n.s.	n.s.	*
YxGPxPP	*,**	n.s.	n.s.	n.s.	n.s.	*
YxPPxGen	*,**	n.s.	n.s.	n.s.	*	*
GPxPPxGen	n.s.	n.s.	*,**	n.s.	*,**	n.s.
YxGPxPPxGen	n.s.	n.s	*,**	n.s.	n.s.	n.s.
PP (plants per m^{-2})						
250	3.2c	1.388a	6.6a	180.6a	8.0a	29.0a (23.2; 24.0)
750	6.9b	1.336a	5.6b	146.6b	12.3a	23.1ab (7.9; 23.2)
1250	9.6a	1.164b	4.6b	131.4b	11.0a	17.3b (5.3; 17.3)
Growing period						
FS (full-season crop)	8.4a	1.628a	6.9a	175.2a	16.2a	31.4a (12.1; 18.0)
S (stubble crop)	4.7b	0.964b	4.4b	130.6b	8.6b	14.9b (5.8; 22.0)
Genotype						
Cultivar Darja	8.1a	1.572a	4.8a	141.5a	11.9a	29.7a (11.6; 18.0)
Land race population	5.0b	1.020b	4.5a	121.6a	10.1a	16.6b (6.5; 21.0)
Year						
1997	4.0b	1.421a	4.7a	126.4b	13.9a	19.4b (8.1; 23.5)
1998	9.1a	1.171b	4.6a	179.4a	10.9a	26.9a (9.8; 16.0)

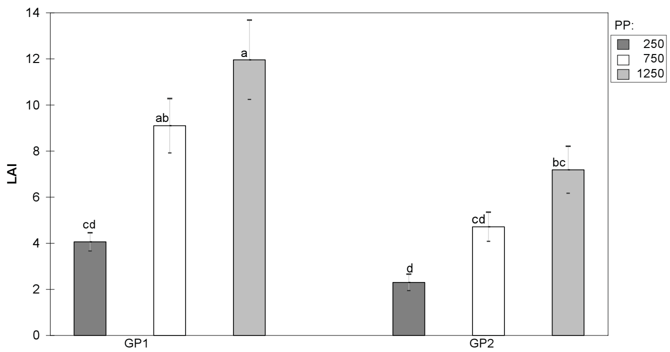
[ns] no significant differences
* significance indicated at $P = 0.05$, ** at $P = 0.01$
[a,b] means within a column followed by different letters are significantly different at the 95 % confidence level (Tukey's test)

al. (1995). We also found a significant correlation between the number of developed seeds per plant and the grain yield (r = 0.71*), and between the number of developed seeds and number of flowers per plant (r = 0.44*).

3.1 PP and LAI relationships

LAI was changed significantly by PP. An increase in PP from 250 to 730 to 1250 plants m^{-2} increased LAI from 3.2 to 6.9 to 9.6, respectively. In addition, most interactions involving PP influenced LAI significantly (PP × year, GP × PP, PP × genotype, GP × PP × year, GP × PP × genotype, PP × GP × genotype × year interactions) (Table 2). LAI reached significantly higher values under high PP (750 and 1250 plants m-2) under full-season crop GP1 than under GP2 stubble-crop GP2 (Figure 1), but increasing PP in both vegetation periods produced similar trends of increasing LAI. PP × GP and PP × genotype interactions including the year 1998 which gave significantly higher LAI and GP1 treatment compared with other treatments (data not shown). On that basis, we can infer that yearly circumstances should dominate the expression of LAI in buckwheat.

In addition, due to higher LAI in higher PP, the summer weeds were suppressed more (3-8 poorly developed weeds m^{-2}) than in low PP (16 weeds m^{-2}), on average. This is additional information to that of SCHOENBECK et al. (1991), who concluded that some buckwheat plantings suppressed the summer weeds effectively, but others failed because of drought.



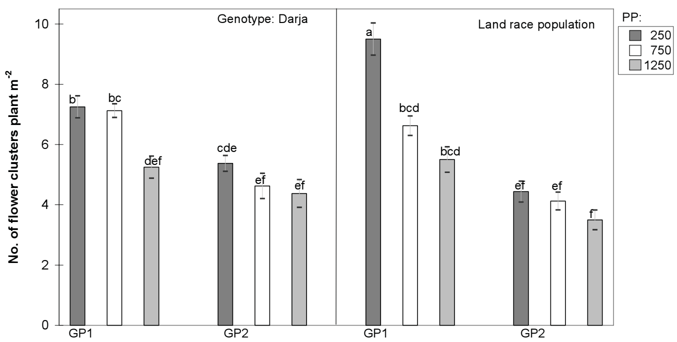
[a,b] Means followed by different letter are significantly different by Tukey HSD test at P ≤ 0,05.
I Error bars represent ± 1 SE.

Figure 1: Effect of interaction of buckwheat plant population (PP) × growing period (GP1 – full- season, GP2 – stubble crop) on LAI

Abbildung 1: Die Einwirkung der Interaktion von Buchweizen Pflanzenpopulationen (PP) × Wachstumsperioden (GP1 – gesät als Hauptfrucht und GP2 – gesät als Stoppelfrucht) auf den Index der Blattfläche

3.2 Effect of PP on yielding capacity

Increasing PP from 250 to 1250 plants m^{-2} decreased the number of flower clusters (6.6 to 4.6 clusters) and the number of flowers (181 to 131 flowers) per plant. Their numbers were significantly higher at low density (250 plants m^{-2}) than at higher densities. Buckwheat, as a full-season GP1 crop, formed a higher number of flowers and flower clusters than with the stubble crop GP2 (Table 2). But PP × GP interaction significantly influenced only the number of flower clusters. The highest number of flower clusters was developed in land race population under the full-season crop GP1 than in the stubble-crop GP2 season (data not shown). The lower numbers of flower clusters were developed in the genotype Darja under GP1 at 250 and 750 plants m^{-2}, and in the land race population under the stubble-crop GP2. The effect of increased PP in both genotypes did not express significant differences in flower clusters under GP2 (Figure 2). The number of flower clusters also varied under additional yearly effect (GP × PP × genotype × year interaction, data not shown). The number of flowers per plant however varied significantly by PP × year interaction.



[a,b] Means followed by different letter are significantly different by Tukey HSD test at P ≤ 0,05.
I Error bars represent ± 1 SE.

Figure 2: Effect of interaction of buckwheat plant population (PP) × growing period (GP1 – full- season, GP2 – stubble crop) × genotype (Darja, land race population) on number of flower clusters

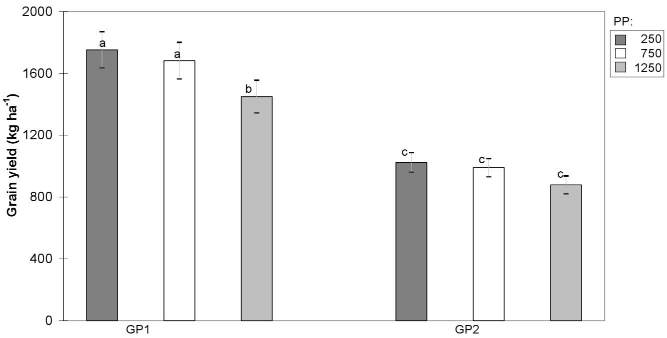
Abbildung 2: Die Einwirkung der Interaktion von Buchweizen Pflanzenpopulationen (PP) × Wachstumsperioden (GP1 – gesät als Hauptfrucht und GP2 – gesät als Stoppelfrucht) × Genotypen (der Sorte Darja, der autochthonen Population) auf die Zahl der Blütenstände

The number of undeveloped seeds expressed significant variation, depending on the year and GP, and their interactions. The highest number of undeveloped seeds formed a land race population under GP1 and 250 plants m^{-2}, in comparison with other treatments (data not shown). The number of developed seeds was significantly influenced by all the main factors and following interactions, which include PP (PP × genotype, year × PP × GP and year × PP × genotype). These effects of the three treatments interactions on the numbers of developed and undeveloped seeds could be explained by the specific reactions of genotype and PP under different temperatures and moisture regimes during GP and the years.

The number of flower clusters per plant was significantly influenced by PP, GP and GP × PP, PP × genotype, PP × GP × genotype, PP × GP × genotype × year interactions were significant. The number of flowers per plant was affected only by PP, GP, year and only the interaction PP × year was significant. Our results are similar to those of AUFHAMMER et al. (1994) who also found that the number of flowers varied with year and sowing dates, but in our case the difference between the periods of full-season GP1 and stubble-crop GP2 sowing dates was longer. In contrast to AUFHAMMER et al., 1994; HAGIWARA et al., 1998; MICHIYAMA et al., 1998; BARBUKOVÁ et al., 2000; FUNATSUKI et al., 2000; in our case the number of flowers per plant did not differ between genotypes. Increasing PP from 250 to the extreme 1250 plants m^{-2}, GP and PP × year interaction, in our case significantly affected the number of flowers, contradictory to BARBUKOVÁ et al. (2000), the small difference between PP (250 to 350 plants m^{-2}) does not have a significant effect on the number of flowers. The total number of flowers per plant (126 to 181) was high, but a small percentage of developed seeds were formed (12 to 19 %), and a greater percentage (50 to 65 %) of them was lost by shattering before harvesting. ANOVA shows that PP, GP, genotype, year and PP × genotype, PP × GP × year, PP × genotype × year interactions significantly affect the number of developed seeds (Table 2). The number of undeveloped seeds varied with GP, year, and the interaction GP × PP × genotype was significant.

3.4 PP and seed yield relationships

Seed yield (kg ha^{-1}) was influenced by all the main treatments: PP, GP, genotype and year (Table 2), and only for GP1 (full-season) was there a significant decrease in yield at the highest PP (1250 plants m^{-2}) compared to the lower PP (Figure 3). Seed yield response at PP 250 and 750 plants m^{-2} did not differ in GP (GP1 and GP2). This large difference in PP, as is noted in our case (250 and 1250 plants m^{-2}), can affect seed yield, was also discovered by AUFHAMMER et al. (1994). This cannot be said for smaller values of PP (GUBBELS and CAMPBELL, 1986; BARBUKOVÁ et al., 2000). The effect of GP on seed yield observed in our trial, with 1628 kg ha^{-1} under GP1 (full-season) and 964 kg seed yield ha^{-1} under GP2 (stubble-crop) is similar to AUFHAMMER et al. (1994) data who observed that sowing in May gave a significantly higher seed yield (1500 kg ha^{-1}) than in August and April. Hence the seed losses' real yields during harvesting were lower than those calculated from the observed number of developed seeds and the weight of 1000 seeds. In our case, the calculated theoretical yield reached 4239 kg seed yield ha^{-1}; compared to 5744 kg seed yield ha^{-1} as found by BARBUKOVÁ et al. (2000).



[a,b] Means followed by different letter are significantly different by Tukey HSD test at P ≤ 0,05.
I Error bars represent ± 1 SE.

Figure 3: The effects of buckwheat plant population interaction (PP) × growing period (GP1 – full – season, GP2 – stubble crop) on seed yield

Abbildung 3: Die Einwirkung der Interaktion von Buchweizen Pflanzenpopulationen (PP) × Wachstumsperioden (GP1 – gesät als Hauptfrucht und GP2 – gesät als Stoppelfrucht) auf die Kornernte

4 Conclusions

In addition to year and genotype – the plant population, growing period (full-season GP1 132 days, and stubble-crop GP2, 89 days) and plant population × growing period and certain other interactions affecting LAI, number of flower clusters, flowers, developed seeds per plant and seed yield. Due to a decrease in number of flowers per plant and number of developed seeds per plant at high plant populations, the lower plant population (250 plants m^{-2}) gave seed yield kg ha^{-1} close to the one obtained with PP 750 plants m^{-2}. Extremely high PP 1250 plants m^{-2} even reduces seed yield, mostly in the full-season GP1 in comparison with the stubble-crop GP2 growing period. Low plant populations instead of high are still economically beneficial (less seeds), but higher PP can be (due to higher LAI) more appropriate for efficient weed control.

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Address of authors

Assist. Prof. Dr. Martina Bavec, Prof. Dr. Franc Bavec, Cvetka Plazovnik B.Sc. and **Assist. Silva Grobelnik Mlakar M.Sc.**, University of Maribor, Faculty of Agriculture, Vrbanska 30, 2000 Maribor, Slovenia;
E-Mail: franci.bavec@uni-mb.si

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