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Original scientific article

VARIATION OF HARVEST INDEX OF WHEAT AND TRITICALE IN MONOCROPS AND INTERCROPS SYSTEM OF CULTIVATION

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The harvest index of grain can be used as indicator for the potential yield of crop. The aim of this study was to determine the variation of the harvest index for wheat and triticale and differences in monocrops and intercrops systems of cultivation under different field environmental conditions. The experiment, carried out in field conditions for two consecutive years, was designed according to a randomized block system so that each species was sown in two cultivation systems as a single crop and a combined crop (wheat + pea and triticale + pea) in four replicates. The results show that, in the first year of the experiment, the value of the harvest index varied from 32.5% (triticale + pea) to 39.3% (wheat monocrop), while in the second year of the research, the value of the harvest index varied from 26.4% (wheat + pea) and 28.1% (triticale + pea). As for the components of harvest index, values of weight of grains spike^{-1} and weight of total above ground biomass were higher in intercrops than in monocrops system of cultivation. It can be concluded that the intercropping of cereals (triticale and wheat) and forage crops (pea) provided positive effects on weight of grains spike^{-1} and weight of total above ground biomass and does not diminish harvest index when compared to standard system of cultivation.
Key words: cultivation system, grain harvest index, pea, small grains

INTRODUCTION

Intercropping is the simultaneous cultivation of at least two crop species in close proximity at (approximately) the same time (LI *et al*., 2014). This increased interest in growing different types of plants in the mixture was initialy based on hypotheses that a system with two

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different crops in it should boost productivity by reducing mutual weaknesses (SOBKOWICZ, 2006).

Sustainable agriculture is becoming more popular around the globe, especially because in certain parts of the world, such as Asia and Africa, where is increased shortage of food due to rise in population (AZIZ *et al*., 2015). This is reflected in promotion of legumes and biodiversity which paved the way for Intercropping systems (KLIMEK-KOPYRA *et al*., 2018).

The increasing of yield in wheat, triticale and other plant species can be achieved, beside other factors, due to an increased Harvest Index (HI) and application of improved farming measures (KNEŽEVIĆ *et al*. 2008; PORKER *et al*., 2020; LJUBIČIĆ *et al*., 2021). Generally, HI represents proportion of grain mass and total above ground biomass and depends on the genotype (G), environments (E) and their interactions (G/E). Furthermore, it can be used as reliable parameter in the wheat breeding program. In other study showed that grain yield is in high correlation with biological yield and HI (DREISIGACKER *et al*., 2021). HIfor winter wheat was estimated to have considerable variationand ranges from 24% to 45% (ZEČEVIĆ and KNEŽEVIĆ, 1998). The same authors estimated that HI had positive correlation with grain yield and that show a positive genotypic correlation with grain yield. Recent studies for modern wheat varieties show HI values up to 50% (KNEŽEVIĆ *et al*., 2015; LJUBIČIĆ *et al*., 2021). The increasing of HI and further increase yield can achieve on increasing of total biomass what indicate efficiency of genotypes for nitrogen use, efficiency of more photosynthesis and translocation to grain. High portion of grain from biomass yield is favorably manifesting in the harvest index (UŽÍK, and ŽOFAJOVÁ, 2007; AISAWI *et al*., 2015). Although, the proportion of assimilates translocated to seed production may be reduced when grown in mixtures, it still have a higher yield in grains and vegetative masses compared to monoculture (CHEN *et al*., 2021).

The reason for this is that plants in intercrops usually do not compete for the same resources at the same place and time (BEDOUSSAC and JUSTES, 2010). Besides this, cultivation systems involving cereals with legumes is affecting many other parameters in a positive way. It has effect on weed control (GOLIJAN and MARKOVIĆ, 2018; SIMIĆ *et al*., 2018), affects plant diseases incidence (ESKANDARI, 2012; FERNÁNDEZ-APARICIO *et al*., 2010; MARKOVIĆ, 2013; ŽIVANOV *et al*., 2014) and insects (MITIKU *et al*., 2014; UDDIN and ADEWALE, 2014). Also, provides more efficiency of land use (BROOKER *et al*., 2015; DHIMA *et al*., 2007) and has positive effect on lodging of legumes due to the physical support provided via cereals (PELZER *et al*., 2012). In general, intercropping studies are based on cereal and legume mixtures. Many different combinations and seed ratios of legumes (such as pea) and cereals (barley, oat, triticale or wheat) have been investigated for exploring higher forage yield and protein concentration in Greece (LITHOURGIDIS *et al*., 2006; LITHOURGIDIS *et al*., 2007; LITHOURGIDIS *et al*., 2011).

Positive effects on grain quality of triticale and forage crops grown in intercroping system were observed in experiments of LESTINGI *et al*., (2010) and NEFIR and TABĂRĂ, (2011). However, there are examples such as CHEN'S *et al*., (2021) research which shows that mixtures can increase yield but reduce HI in plants, possibly because common cultivars have been bred to give the best results in monoculture systems. Also, a research showsthat the values of spike harvest index (SHI) were significantly different between cereals grown as pure crops (monocrop) and intercrops with pea, but among same cereal species harvest index of spike was not significantly different (GRČAK *et al*., 2019). SALEHI'S *et al*., (2018) The research shows that the highest grain yield of triticale, as well as the highest forage yield, was estimated in monocrop compared to the intercropping with faba bean (*Vicia faba* L.), peas (*Pisum sativum* L.), vetch (*Vicia villosa* L.) and bitter vetch (*Vicia ervilia* L.).

The aim of this study was to determine the variation of the grain harvest index for wheat and triticale in monocrops and intercrops systems of cultivation under different ecoclimatic conditions in the period of two years.

MATERIALS AND METHODS

The field experiments were conducted for two consecutive seasons 2017/2018 and 2018/2019 at the experimental field of the Institute of Field and Vegetable Crops in Novi Sad (45°33'N, 19°84'E). The experiment was established in randomized complete block design (RCBD) in 4 replications. The size of the base plots was 5m^2. The trial consisted of four treatments: 1) wheat (*Triticum aestivum*, cultivar Ilina), 2) triticale (*Triticosecale*, cultivar Odisej) asmonocrop, 3) mixture wheat + pea (*Pisum sativum,* cultivar Kosmaj) as intercrop and 4) triticale + pea as intercrop.The sowing density for first and second treatment were 530 and 500 grains per m^{-2} while for the intercrop the ratio was 30:70% for small grains and peas, respectively. Apropos, sowing density for third and fourth treatment were 160 grains of wheat + 105 grains of pea per m^{-2} and 150 grains of triticale + 105 grains of pea per m^{-2}. Sampling for analysis was performed with 0.25 m^2 frame tool, for both monocrops and intercrops, and plants were put in a glasshouse for drying. For analysis of harvest index, used samples were harvested at the milky stage on June 4th, 2018 and on June 10th 2019 for both monocrops and intercrops. In total 40 plants per treatment were used i.e. 10 plants per plot. Then samples were moved to space with room temperature where the following parameters were assessed: grain weight per spike and weight of total above the ground biomass. Based on the acquired average values the harvest index was calculated following the method of YASIN *et al*. (2011) as follows:

$$Harvest\ index\ (\%) = \frac{weight\ of\ grains-^{spike}}{weight\ of\ total\ above\ ground\ biomass} * 100$$

Processing of statistical data was done using Excel and IBM SPSS Statistics 20 (trial version). Analysis of variance by monofactorial system and the significance of the differences was tested using the LSD test (Hadživuković, 1991) was performed by Excel. Euclidian distance and similarity among small grains species on the base of values of harvest index traits obtained in monocrops and intercrops with peas, analysed by using IBM SPSS Statistics 20 (trial version).

RESULTS

The weight of grains in 2017/2018 varied in the range from 1.18g in wheat grown as sole crop to 1.92 g in triticale grown with pea in the mixture. For weight of total above ground biomass was established variation in range from 2.98 g in wheat grown as solo crop to 5.72 g in triticale grown as a mixture with pea. HI in the first year was the highest in wheat solo crop (39.3%) and the lowest in triticale mixture with pea (32.5%) (Table 1).

Table 1. The characteristics of small grains genotypes in solo crops and intercrops with pea

	2017/2018			2018/2019		
Genotype in monocrops and intercrops cultivation	Weight of grainsspike^{-1} (g)	Weight of total above ground biomass (g)	Harvest index (%)	Weight of grainsspike^{-1} (g)	Weight of total above ground biomass (g)	Harvest index (%)
Wheat/pea	1.19	3.32	34.4	0.86	3.19	26.4
Triticale/pea	1.92	5.72	32.5	1.35	4.74	28.1
Wheat	1.18	2.98	39.3	0.75	2.68	27.7
Triticale	1.73	5.07	33.8	1.25	4.54	26.8
Average	1.50	4.27	35.0	1.05	3.78	27.2

During 2018/2019 the weight of grains per spike varied from 0.75g in wheat grown as solo crop to 1.35g in triticale in mixture with pea. Weight of total above ground biomass had the lowest value in wheat grown as solo crop (2.68 g) and the highest value in triticale mixture (4.74 g). HI was the lowest 26.4% in wheat which cultivated in mixture with pea and the highest (28.1%) in triticale grown in mixture with pea (Table 1).

Based on the analysis of variance it can be stated that there were no statistically significant differences for weight of grains per spike in the first vegetation season (2017/2018). In triticale grown in the mixture weight of grains per spike (1.92 g) was higher than that of wheat grown individually (1.18g) and in mixture (1.19 g) but there were no statistically significant differences among them. There were also no statistically significant differences between triticale in mono crop and in mixture with pea (1.73g). When it comes to wheat, there were no statistically significant differences among solo crops and mixtures of this cereal with pea (Table 2).

Table 2. ANOVA for weight of grains per spike in small grains genotypes in solo crops and mixture with pea

Vegetation season	2017/2018						2018/2019					
Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*	*F crit*	*df*	*SS*	*MS*	*F*	*P-value*	*F crit*
Replication	3	0.343	0.114	0.611	0.625	3.862	3	0.104	0.035	0.731	0.559	3.862
Genotype in monocrops and intercrops	3	1.706	0.569	3.0423	0.085	3.862	3	1.028	0.343	7.214	0.009	3.862
Error	9	1.682	0.187				9	0.427	0.047			
Total	15	3.731					15	1.559				
LSD 0.05	0.973						1.786					
LSD 0.01	0.490						0.900					

Results observed for experimental research in 2018/2019 in analysis of variance for weight of grains per spike indicated that there are significant differences between groups. Results show that triticale grown in mixtures had significantly higher weight of grains per spike (1.35 g) than wheat grown as monocrop (0.75 g). Its weight of grains was higher than of triticale grown as monocrop but those differences were not statistically significant. In wheat grown in mixture with pea, the weight of grain spike^{-1} (0.86 g) was higher than weight of grain spike^{-1} (0.75 g) in wheat cultivated as monocrop, but this difference was not significant (Table 2).

Analysis of variance for weight of total above ground biomass indicates that there was significant difference between groups ($p<0.05$) in the first vegetation season (2017/2018)..On the base of LSD test values it can be concluded that weight of total above ground biomass in triticale grown as mixture (5.72 g) was higher than in triticale monocrop (5.07g) but not significantly, and significantly higher than wheat monocrop (2.98 g) and wheat in mixture (3.32 g). Triticale grown as monocrop was significantly higher than wheat in both cultivation systems. Even though value of the weight of total above ground biomass was higher in wheat grown as mixture, there were no significant differences among wheat intercrop and wheat grown as monocrop (Table3).

Table 3. ANOVA for weight of total above ground biomass in small grains genotypes in solo crops and mixture with pea

Vegetation season	2017/2018						2018/2019					
Source of Variation	df	SS	MS	F	P-value	F crit	df	SS	MS	F	P-value	F crit
Replication	3	1.380	0.460	0.947	0.458	3.862	3	0.432	0.144	0.659	0.597	3.862
Genotype in monocrops and intercrops	3	21.299	7.100	14.609	0.0008	3.862	3	12.255	4.085	18.685	0.0003	3.862
Error	9	4.374	0.486				9	1.967	0.219			
Total	15	27.053					15	14.655				
LSD 0.05	1.569						1.052					
LSD 0.01	2.879						1.931					

The analysis of variance of the weight of total above ground biomass in both cultivation systems showed significant differences in second vegetation season (2018/2019). Triticale grown in mixture with pea had significantly higher weight of total above ground biomass (4.74 g) then wheat in monocrop and wheat grown in mixture. It also has a higher weight than triticale grown as monocrop but this difference is not statistically significant. Wheat grown in mixture with pea had a higher weight of total above ground biomass (3.19 g) than wheat grown as monocrop (2.68 g) but it was not statistically significant difference (Table 3).

Based on the analysis of variance of the harvest index in the first vegetation season (2017/2018) and values of LSD test significant difference it can be concluded that wheat grown as monocrop had higher value (39.3%) than any other combination but it was not statistically significant. There were also no statistically significant differences observed between triticale grown in intercrop (32.5%), triticale grows as monocrop (33.8%) and wheat grown as mixture with pea (34.4%) Table 4.

Table 4. ANOVA for harvest index in small grains genotypes in solo crops and mixture with pea

Vegetation season	2017/2018						2018/2019					
Source of Variation	df	SS	MS	F	P-value	F crit	df	SS	MS	F	P-value	F crit
Replication	3	57.210	19.070	0.677	0.588	3.862	3	17.055	5.685	0.328	0.805	3.862
Genotype in monocrops and intercrops	3	107.252	35.750	1.269	0.342	3.862	3	7.435	2.478	0.143	0.932	3.862
Error	9	253.509	28.168				9	155.948	17.328			
Total	15	417.970					15	180.438				
LSD 0.05	11.943						9.367					
LSD 0.01	21.920						17.192					

The analysis of variance for harvest index in second vegetation season (2018/2019) showed that there were not statistically significant differences between genotypes of wheat and triticale cultivated in two cultivation systems (Table 4).

In the first vegetation season (2017/2018) the similarity with Euclidean distance ilustrated on dendogram that the least distance was established between wheat grown as mixture with pea and triticale. According to harvest index, within the cluster the wheat + pea combination and triticale expressed the least distance with triticale in mixture with pea in the range of 2.0 units. Wheat grown in monocrop had distance of 25.0 units with cluster (wheat + pea, triticale, triticale + pea) in the range of 25.0 units (Figure 1).

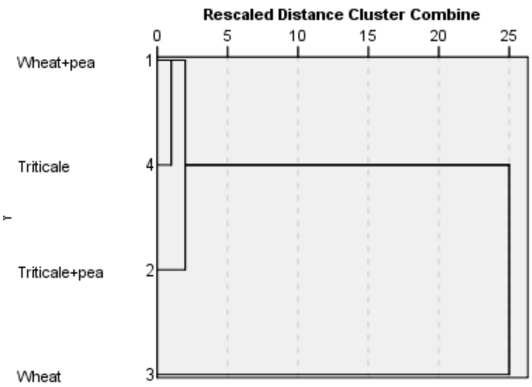

Figure 1. Dendogram for distance among cereal according to value of harvest index obtained in single crop and in intercropping system pea/small grains species (2017/2018)

The values obtained for the harvest index of cereals grown in monocrop and intercrop system for 2018/2019 were compared to each other using hierarchical methods of Euclidean distance and showed that the least distance was noticed in the first cluster between wheat in mixture and triticale in monocrop, in the range of 1.0 unit. The second pair (cluster), mixture crop triticale + pea and wheat in monocrop had distance in the range of 2.0 units. These two pair had the greatest distance in the range of 25.0 units for harvest index (Figure 2).

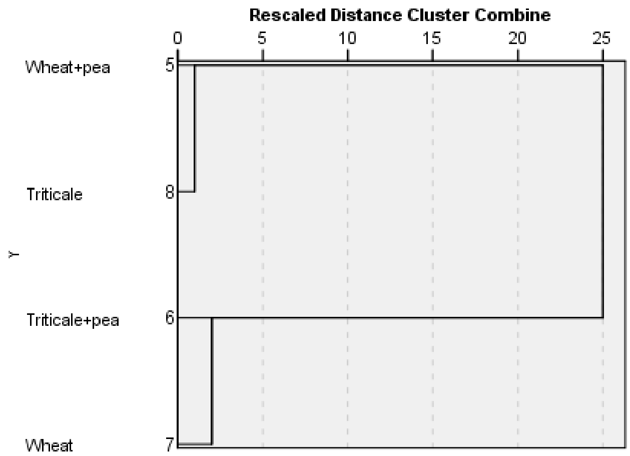

Figure 2. Dendogram for distance among cereal according to value of harvest index obtained in single crop and in intercropping system pea/small grains species (2018/2019)

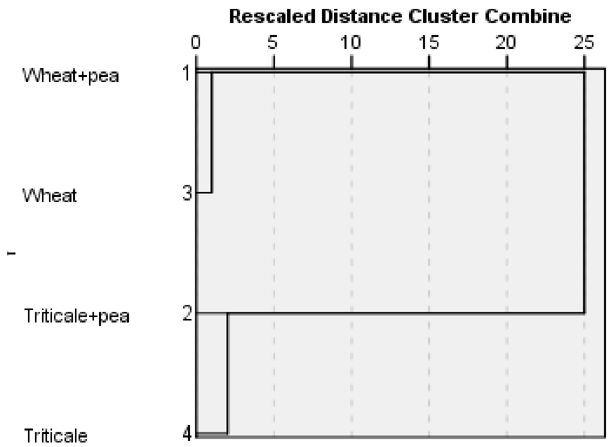

Figure 3. Dendogram for distance among cereal according to value of weight of total above ground biomass obtained in single crop and in intercropping system pea/small grains species *(2017/2018)*

In terms of components of HI, a similarity with Euclidean distance can be observed in the following dendograms. Comparing values of the total above-ground mass of plants, it is noticed that the smallest distance in the first cluster between the mixture of wheat + peas and wheat in monoculture is 1.0 unit, which indicates a great similarity. In the second cluster, the distance between triticale + pea mixture and triticale in monocrop is in the range of 2.0 units. The second cluster had a distance of 25.0 units from the first cluster (Figure 3).

While comparing the total above ground biomass values in wheat and triticale for a period 2018/2019 the least distance between biomass in mixture crop of triticale + pea and triticale in monocrop was noticed. That distance was in the range of 1.0 unit and indicates a great similarity. The greater distances between mixture crop wheat + peas and wheat in monocrop were expressed in range of 2.0 units. These two pairs (cluster) had mutual distance of 25.0 units, which means the least similarity (Figure 4).

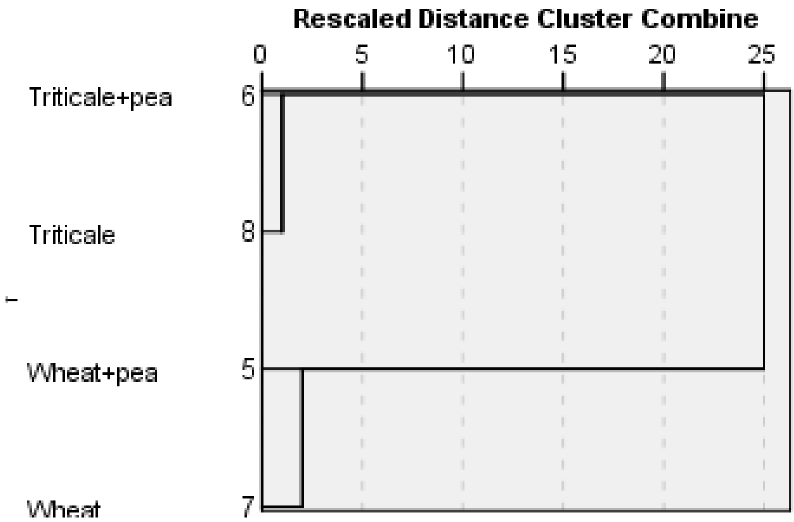

Figure 4. Dendogram for distance among cereal according to value of weight of total above ground biomass obtained in single crop and in intercropping system pea/small grains species (2018/2019)

The similarity with Euclidean distance for the weight of grains per spike in small grains was estimated showing the least distance between wheat + pea mixture and wheat monocropin the range of 1.0 units. The distance between mixture crop triticale + pea and monocrop of triticale was in the range 3.0 units for grains per spike. These two pair (clusters) had distance of 25.0 units (Figure 5 and Figure 6).

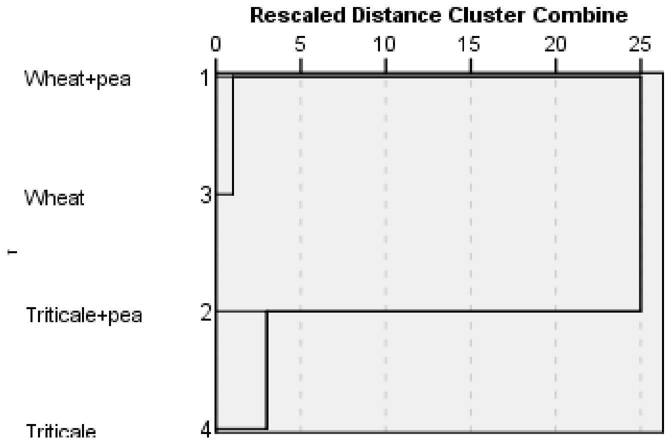

Figure 5. Dendogram for distance among cereal according to value of weight of grains per spike obtained in single crop and in intercropping system pea/small grains species (2017/2018)

The obtained values of weight of grains per spike in the period 2018/2019 were compared to each other and presented on the dendogram (Figure 6). Among four samples there were two clusters. The distance in the first cluster between triticale + pea mixture and triticale in monocrop was 1.0 units, the same as the distance in the second cluster between wheat + pea mixture and wheat monocrop. The distance between the two was 25.0 units.

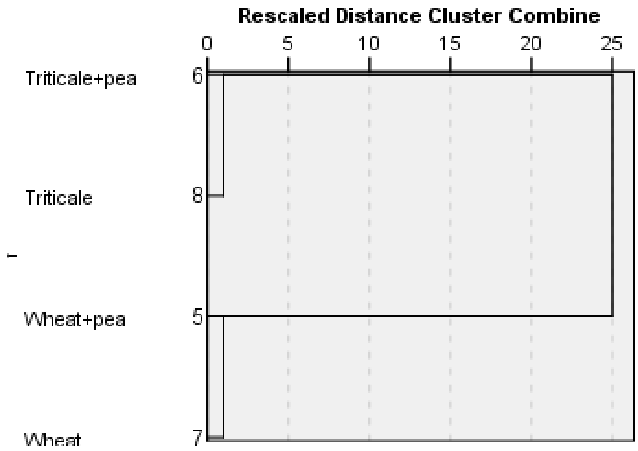

Figure 6. Dendogram for distance among cereal according to value of weight of grains per spike obtained in single crop and in intercropping system pea/small grains species (2018/2019)

DISCUSSION

Harvest index is proportion of economic yield (grain mass) and total biomass at harvest time, and can use as a measure of reproductive efficiency. It varies depending on the genotype, environment and application of agricultural measure. The second half of 20th century of wheat breeding is characterized by a genetic increase in yield achieved by an increased harvest index (DIMITRIJEVIĆ *et al*., 2002). In modern Serbian winter wheat varieties, in its full maturity stage, grown in monocrop system, the value of HI varies between 33% and 43% (KNEŽEVIĆ *et al*., 2015). HI is considered one of the principal factors contributing to yield improvement and, in this context, a useful measure of yield efficiency. HI could be used as a selection criteria for the improved yielding ability of a given crop as it is an appropriate trait to target for increasing yield potentials for crop breeding activities (SADRAS and RICHARDS, 2014), which varies and achieves up to 52% in modern cultivars (DREISIGACKER *et al*., 2021). The system of plant production can greatly contribute to a better understanding of HI and is based on the changes in HI accomplished among different genotypes (ASEFA, 2019).

The present study was designed to determine the variation of the HI for wheat and triticale in monocrops and intercrops systems of cultivation under different climatic conditions in two years. In the first year of the experiment, the values of the HI are higher than in the second year in both cultivation systems (monocrop and crop mixture), which indicates that the plants taken for the analysis in the second year accumulated less organic matter in seed. Filling seeds is a physiological-biochemical process of synthesis and accumulation of dry matter and conversion into final products - carbohydrates, proteins and fats. Seed filling phase starts from the phase of fertilization trough the phase of milk maturity to the beginning of waxy maturity. During the milk ripening phase, 70% or more of dry matter accumulates. While the water content in this phase is very high, about 60% which decrease to 40% at the beginning of the wax stage of seed ripening. A high water content in the phase of milk maturity of seeds means that the content of the dry matter is a lower mass of seed, which is reflected in lower seed yield and obtaining lower values of the harvest index. Comparing these two cultivation systems, the results of the two-year experiment showed that there were no statistically significant differences in terms of harvest index. The results in the first year of the research showed that the highest value of the harvest index was recorded in the independent wheat crop (39.3%). In wheat grown in the mixture, a harvest index of 34.4% was recorded, while the harvest index in triticale was 32.5% when grown in the mixture and 33.8% in the monocrop system of growing. These results are in accordance with the research of CHEN *et al*. (2021) which found that the harvest index in wheat monocultures was higher than in mixtures. The authors conclude that harvest index was not under a significant influence by species, ecotype and fertility of soil. Also, in their research of the harvest index in wheat in the system of growing in mixture of four species, a lower value for 4% in Spain and for 5% in Switzerland than in crops of two-species mixtures was observed.

The results of the second year of the research showed that the highest value of the harvest index was recorded in triticale grown in the mixture (28.1%), than in wheat monocrop (27.7%), triticale monocrop (26.8%) and finally in wheat intercrop with pea (26.4%). After a statistical analysis of the data, it was determined that there were no statistically significant differences between cereals grown in the mixture (intercropping cultivation system) and cereals grown in monocrop cultivation system.

In this research, low values of harvest index in wheat and triticale grown in monocrop and intercrop system of growing with pea were obtained in both year of experiment. Since the samples of plants for analysis were taken in the milk phase of seed filling, the values of seed mass are lower than in the phase of full maturity, which also affects the obtaining of lower values of the harvest index. In milky stage physiological translocation and remobilization of photosynthates from leaves and stem into seeds was not completed. In the phase of full maturity, the seeds are filled with organic matter, the water content is reduced, and a higher mass of dry matter is accumulated in the seed, so that the mass of the seed is higher, which affects the increase of the harvest index.

In a two-year research, CHAPAGAIN *et al*. (2018) showed that the harvest index for wheat was higher than in our investigation. They established the values of harvest index in wheat in monocrop 45% and in intercrop (with pea) 46%, which were not significantly different. They also found that the location and conditions of the year of wheat growing and their interactions did not have a significant impact. Other research such as CHEN'S *et al*., (2021) shows that the intercropping system of cultivation can increase yield but reduce harvest index in plants due to the fact that common cultivars have been bred to produce the best outcomes in monoculture or monocrop systems of cultivation.

CONCLUSION

The research showed that the values of weight of grains spike^{-1} and the weight of total above ground biomass were significantly different among cereal species and higher in mixtures than in genotypes grown as monocrops. The weight of grains spike^{-1} in 2018/2019 varied between 1.35g (triticale intercrop) and 0.75g (wheat grown as monocrop). While in the same cereal species weight of grains spike^{-1} and weight of total above ground biomass were higher in plants grown in intercropping than in monocrops, those values were usually not significantly different.

The harvest index varies between 39.3% (wheat monocrop) and 32.5% (triticale intercrop) in 2017/2018 but it wasn't statistically significant. For the period 2018/2019, the harvest index varied between 28.1% and 26.4% without a statistically significant difference.

It can be concluded that the intercropping of cereals (triticale and wheat) and forage crops (pea) has a positive effects on weight of grains spike^{-1} and the weight of total above ground biomass and does not diminish harvest index values when compared to the standard system of cultivation.

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VARIRANJE ŽETVENOG INDEKSA KOD PŠENICE I TRITIKALEA U POJEDINAČNOM I ZDRUŽENOM USEVU GAJENJA

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Izvod

Žetveni indeks zrna može se koristiti kao indikator potencijalnog prinosa useva. Cilj ovog rada bio je da se utvrdi varijacija žetvenog indeksa pšenice i tritikale i razlike u pojedinačnom i združenom sistemu gajenja u različitim uslovima životne sredine na oglednom polju. Ogled je izveden u poljskim uslovima dve uzastopne godine, koji je koncipiran po randomizovanom blok sistemu tako da je svaka vrsta zasejana u dva sistema gajenja kao pojedinačni usev i združeni usev (pšenica + grašak i tritikale + grašak) sa četiri ponavljanja. Uzorci biljaka za analizu žetvenog indeksa su uzeti u završnom delu faze mlečnog nalivanja semena. Rezultati pokazuju da je u prvoj godini eksperimenta vrednost žetvenog indeksa varirala od 32,5% (tritikale + grašak) do 39,3% (monokultura pšenice), dok je u drugoj godini istraživanja vrednost žetvenog indeksa varirala od 26,4% (pšenica + grašak) do 28,1% (tritikale + grašak). Što se tiče komponenti žetvenog indeksa, vrednosti mase zrna po klasu i mase ukupne nadzemne biomase bile su veće u združenom sistemu nego u pojedinačnom sistemu gajenja. Može se zaključiti da je združeni usev žitarica (tritikale i pšenica) i krmnog bilja (grašak) dao pozitivne efekte na masu zrna po klasu i masu ukupne nadzemne biomase i ne umanjuje žetveni indeks u poređenju sa standardnim sistemom gajenja.

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