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TECHNOLOGICAL QUALITY OF POPCORN KERNEL IN COVER CROPS SYSTEM

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Abstract

In a two-year period, the influence of the application of microbiological fertilizer and different cover crops on the moisture content of kernel and the popping volume in the ZPSC 611k popcorn hybrid was investigated. The experiment was conducted on the experimental field of the Maize Research Institute "Zemun Polje" (Serbia) and set up according to a split-plot design in 4 replications. The cover crops consisted of plant species: common vetch, winter oats, winter forage pea and winter forage kale, and two mixtures (common vetch and winter oats, winter forage pea and winter oats) were included in the experiment, as well as a variant with mulch and a control. Application of microbiological fertilizer and cover crops had a statistically significant effect on the kernel quality of the tested hybrid. The average values of moisture content in kernel ranged from 13.1% to 15.0%. The dominant influence on both traits was the interaction of year factor x microbiological fertilizer x cover crop, which indicates a strong synergistic effect of meteorological conditions and agrotechnical measures. The highest average values of popping volume were obtained in varieties with legumes and their mixtures, especially with the application of microbiological fertilizer, at an optimal moisture content of about 14%. The results show that the use of cover crops, especially legumes and their mixtures with cereals, along with the application of microbiological fertilizers, is an effective way to improve the technological quality of popcorn kernels in conditions of a moderate continental climate.

Key words: legumes, microbiological fertilizer, moisture content, popping volume, sustainable agriculture

Introduction

Sustainable agriculture is based on the long-term application of principles that support crop productivity while preserving the agroecosystem (Dragičević et al., 2021). In low-input systems where the use of synthetic mineral fertilizers, pesticides and heavy machinery is minimized or completely excluded, cover crops become the primary tool for agroecosystem management (Dolijanović et al., 2022; Šević et al., 2025). Numerous studies show that leguminous cover crops improve soil quality and create more favorable conditions for the

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growth, development and yield of main crops (Kocira et al., 2020; Dragičević et al., 2024a). In addition to them, microbiological fertilizers represent an important tool of modern agriculture without negative impact on the environment. Roychowdhury et al. (2017) and Mącik et al. (2020) state that microbiological fertilizers are an indispensable part of integrated nutrient management, because they reduce the need for mineral fertilizers and ensure optimal plant supply (Rajičić et al., 2025a).

Popcorn (*Zea mays* L. subsp. *everta* (Sturtev.) Zhuk.) is a subspecies of corn that stands out for its exceptional ability to burst the kernel when heated, forming a characteristic flake (Janošević, 2017; Al et al., 2023). When popcorn kernels are heated, the water in the floury endosperm turns into water vapor and the kernel bursts, increasing its volume by 20-30 times. In doing so, the endosperm turns into a white, loose and porous mass (Janošević, 2021).

The most important feature of the quality of popcorn kernels is the popping volume, which is defined as the ratio of the volume of popped and unpopped kernels and is a decisive factor of economic value and acceptability for consumers (Ozturk et al., 2020; Oyeyemi et al., 2023). The volume of the kernel depends on the pericarp, the moisture content of the kernel and the conditions during production, harvesting and processing (Shavandi et al., 2015, Sweley et al., 2013). The optimal moisture content during coking is about 14%, because then the kernel reaches the maximum volume and the smallest percentage of unpopped kernels (Pajić et al., 2005; Srdić et al., 2015). Both too high and too low moisture content have a negative effect on the cracking process of popcorn kernels (Ullah et al., 2025).

Although the area under popcorn in Serbia is constantly increasing due to the growing demand for this profitable product, information on the influence of cover crops and bio-fertilizers on the popping volume and kernel water content is very limited (Dragičević et al., 2024b). Therefore, the aim of this research is to examine the influence of microbiological fertilizers and cover crops as sustainable measures on moisture content of kernel and popping volume. The novelty of the work is reflected in the assessment of the combined effect of sustainable measures on the basic quality parameters of popcorn kernels, which provides information on the possibilities for improving the technological quality of kernels in sustainable production systems with reduced use of mineral fertilizers.

Material and methods

Location and experimental design

The research was conducted at the experimental field of the Maize Research Institute "Zemun Polje" in Belgrade, Serbia (44°52'N, 20°20'E, 110 m altitude) during two growing seasons (2013/14 and 2014/15). A three-factorial experiment was set up according to a split-plot design with 4 replications. Observed factors in addition to years of research are microbiological fertilizer (commercial name Uniker), which acts as a nutrient mobilizer and promotes the mineralization of plant residues. It contains a large number of active bacteria of the genus *Bacillus*, which have high activity of proteolytic and cellulolytic enzymes. It was applied to half of the elementary plot immediately before plowing cover crops in the spring (in the amount of 10 l ha^{-1}), and before sowing the main crop of ZPSC 611k popcorn hybrid. . Sowing was done manually, in mid-May at a density of 65.000 plants ha^{-1} (70 × 22 cm). The plants were grown under rainfed condition. Popcorn was harvested at full maturity at the beginning of October in the first year and at the end of September in the second year.

The cover crops factor included 4 plant species: CV – common vetch (*Vicia sativa* L., variety NS-Neoplanta); WFP – winter fodder pea (*Pisum sativum* L., variety NS-Pionir); WO – winter oats (*Avena sativa* L., variety NS-Jadar) and WFK – winter fodder kale (*Brassica oleracea* convar. *acephala*, variety NS-Perast). Two mixtures were also included in the experiment: CV + WO – common vetch + winter

oats (70:30) and WFP + WO – winter fodder peas + winter oats (70:30), then a variant with mulch (straw) and a control (uncovered soil). Sowing of cover crops was done by hand at the end of October/beginning of November. Sowing norms were: vetch 120 kg ha^{-1}, oats 160 kg ha^{-1}, kale 15 kg ha^{-1}, peas 150 kg ha^{-1}, with appropriate sowing depths.

Fertilization is planned to provide the main crop with 120 kg ha^{-1} N, 90 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O. Phosphorus and potassium were introduced in the fall, and nitrogen (Urea 46% N) in the spring when sowing the main crop, with a reduction in the dose for legumes due to biological nitrogen fixation.

Soil characteristics in the experimental field

Soil sampling for agrochemical analyzes was carried out in the fall before setting up the experiment. The pH, content of organic matter, accessible N, P and K were determined (Table 1). The research was conducted on the weak carbonate chernozem of northeastern Srem. The soil is characterized by a deep humus-accumulative horizon (0–50 cm), a favorable textural composition (powdery-clay loam with about 32% clay), good porosity (47–50% vol.) and favorable water-physical properties (field capacity 35–40% vol.). The soil reaction is neutral to slightly alkaline with favorable supplies of accessible nutrients (P and K) and organic matter content as determined by Magdoff (1996). Nitrogen was determined according to Scharpf and Wehrmann (1975), phosphorus according to Olsen et al. (1954), and potassium ion-selective electrode and ICP-OES methods (EPA Method 200.7, Martin et al., 1994).

Table 1. Agrochemical properties of the soil in the experimental field

Tabela 1. Agrohemijske osobine zemljišta na eksperimentalnom polju

Depth (cm)	pH H_2O	pH nKCl	N total	NH_4	NO_3	P	K	P_2O_5 ppm (mg kg^{-1})	K_2O (ppm)
			(kg ha^{-1})			(kg ha^{-1})			
0-20	7.05	7.04	44.4	1.8	42.6	26.0	280.4	29.7	150.8
20-40			21.7	0.7	21.0	33.2	298.5	38.0	160.5

Determination of kernel moisture content and popping volume

The kernel moisture content was determined using a Dickey-john GAK II moisture meter (Srdić et al., 2018; Rajičić et al., 2025b) and is shown as a percentage. The industry standard instrument for measuring the bulkiness volume (cm^3 g^{-1}) is the MWVT- Metric Weight Volume Tester, (Srdić et al., 2015). Popcorn cobs for chemical analyzes were peeled by hand to avoid damage to the pericarp. A standard sample of 250 g (analysed) was shot in three replicates on a Cretors 2300W apparatus (oil test). The poping volume is expressed as cm^3 per gram of kernel before cracking.

Meteorological conditions

During the two-year research (2013/14-2014/15), significant variations in meteorological conditions were recorded. Compared to the multi-year average (1992-2012), the winter and spring periods are characterized by higher air temperatures, especially in the first year, but with lower amounts of precipitation. The vegetation period of the main crop in the first year was marked by significant amounts of precipitation (858 mm), but with an unfavorable distribution. The second year was more favorable for cover crops, while for popcorn it was extremely dry in the summer months. These differences in air temperature and precipitation distribution made it possible to assess the impact of microbiological fertilizers and cover crops in the changing agro-ecological conditions of Serbia.

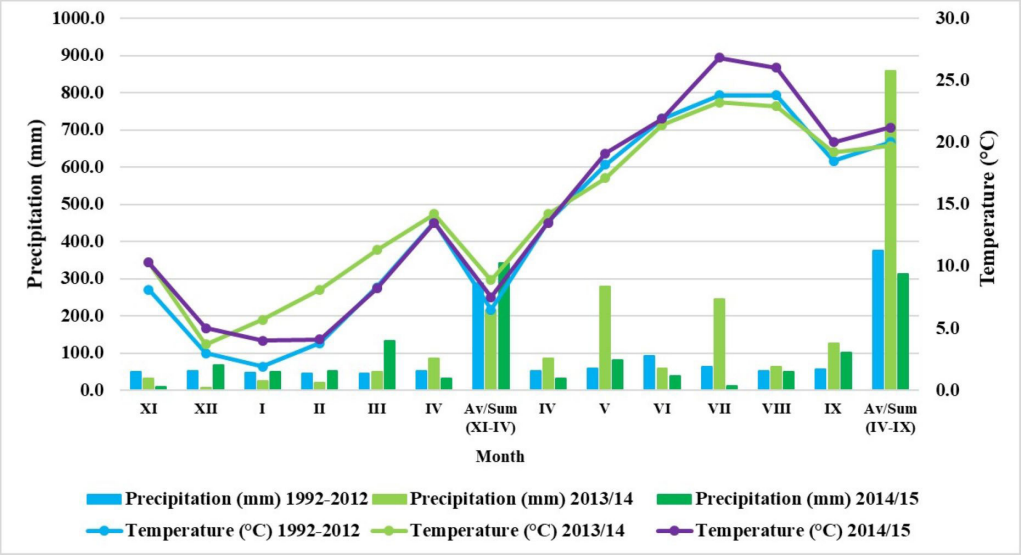

Figure 1. Meteorological conditions during the experiment for cover crops and the main crop popcorn (2013/14–2014/15) and the multi-year average (1992-2012) for the investigated location
Grafikon 1. Meteorološki uslovi tokom izvođenja ogleda za pokrovne useve i glavni usev kukuruz kokičar((2013/14-2014/15) i višegodišnji prosek (1992-2012) za ispitivani lokalitet

Table 2. Analysis of variance for the examined factors and the significance of their influence on the percentage of moisture in popcorn kernels
Tabela 2. Analiza varijanse za posmatrane faktore i značajnost njihovog uticaja na procenat vlage u zrnu kukuruza kokičara

Source	DF	SS	MS	F - test	P-Value
Year	1	30.5176	30.5176	1629.87	0.000**
Fertilizer	1	0.2907	0.2907	15.53	0.000**
Cover crops	7	1.3362	0.1909	10.19	0.000**
Year × Fertilizer	1	0.0413	0.0413	2.21	0.141^{ns}
Year × Cover crops	7	2.6018	0.3717	19.85	0.000**
Fertilizer × Cover crops	7	2.5762	0.3680	19.66	0.000**
Year × Fertilizer × Cover crops	7	2.2755	0.3251	17.36	0.000**
Total	127				
Coef. Var. (%) 0.802					
St. Dev. 0.571					

DF – Degrees of freedom; SS – Sum of Squares; MS-Mean Squares; F test – F value calculated; **Significant at 1% probability level; *Significant at 5% probability level; ns – Non Significant at 5% probability level; Coef. Var – Coefficient of variation; St. Dev – Standard Deviation.

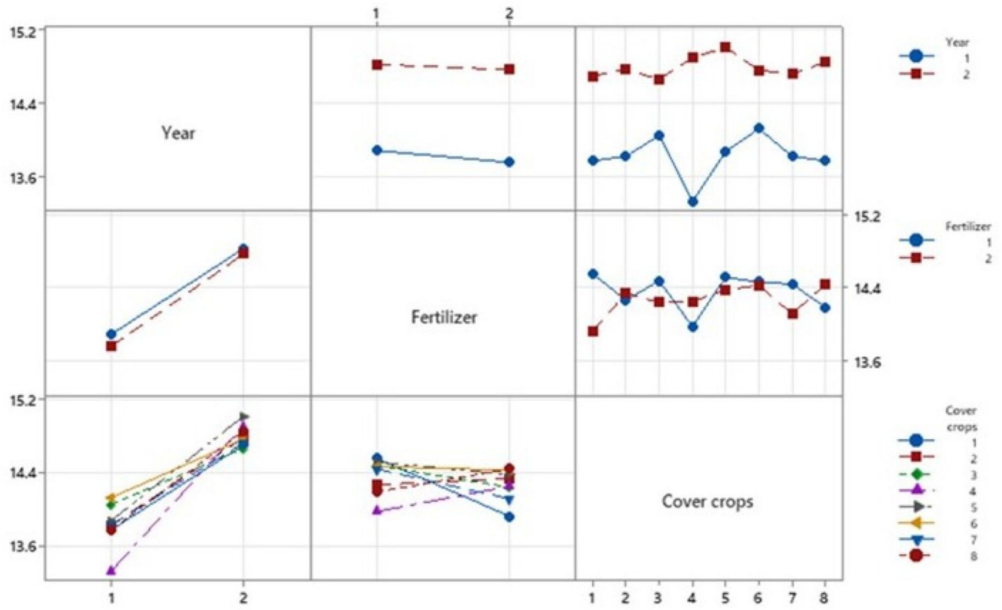

Figure 2. Interaction Plot for percentage of moisture in popcorn kernels.
Grafikon 2. Interakcijski dijagram za procenat vlage u zrnu kukuruza kokičara

The average values of moisture content in popcorn kernels at harvest ranged from 13.1% to 15.0% (Table 3). The kernel moisture content was statistically significantly lower in the first compared to the second year of testing. Srdić and Pajić, (2011) state that the influence of year was dominant, which is in agreement with these results. The interaction of cover crops with other factors showed a very significant difference in terms of moisture content in the kernel, which indicates that this characteristic mainly changes under the synergistic action of several factors, especially the meteorological conditions that prevailed during the growing season.

Table 3. Percentage of moisture in popcorn kernels (%)
Tabela 3. Procenat vlage u zrnu kukuruza kokičara (%)

Year	**2014**		**2015**	
Cover crops	**FØ**	**F**	**FØ**	**F**
CV	14.3^{def}	13.3^{kl}	14.8^{abc}	14.6^{cde}
WO	13.7^{ij}	14.0^{fghi}	14.9^{abc}	14.7^{abcd}
WFK	14.3^{ef}	13.9^{ghij}	14.7^{abc}	14.6^{bcde}
WFP + WO	13.1l	13.6^{jk}	14.9^{abc}	14.9^{abc}
Mulch	14.0^{fghi}	13.8^{hij}	15.0^{a}	15.0^{ab}
CV +WO	14.2^{fg}	14.1^{fgh}	14.7^{abc}	14.8^{abc}
WFP	14.2^{fg}	13.5^{jk}	14.7^{abc}	14.7^{abc}
Control	13.5^{jk}	14.1^{fgh}	14.9^{abc}	14.8^{abc}
Average	13.9	13.8	14.8	14.8

Fertilizer: FØ – without fertilizer; F – with fertilizer; Cover crops: CV–common vetch; WO – winter oats; WFK – winter fodder kale; WFP + WO – winter fodder peas + winter oats; Mulch – straw; CV +WO – common vetch+winter oats; WFP – winter fodder pea; Control – without cover crops. Tukey's test HSD (Honestly Significant Difference) – Means that do not share a letter are significantly different.

In addition to the yield potential, the popping volume is the most important characteristic of popcorn. Several factors influence it: genotype, conditions of production, processing and storage of kernels, as well as methods of coking. The maximum potential of kernel volume is only achieved if the hybrid has reached full maturity. However, the most important influence is the moisture content at the time of ripening (Srdić et al., 2018). In the period when the air temperatures are lower, during the later harvest, the process of moisture release from the grains is slower. The volume of kernels, as a specific characteristic of this subspecies of corn, showed significant variation depending on the variety of cover crop and the interaction of cover crop and fertilizer (Table 4, Figure 3).

Table 4. Analysis of variance for the examined factors and the significance of their influence on poping volume
Tabela 4. Analiza varijanse za posmtrane faktore i značajnost njihovog uticaja na zapreminu kokičavosti

Source	DF	SS	MS	F-test	P-Value
Year	1	0.000	0.0000	0.00	0.997^{ns}
Fertilizer	1	0.128	0.1275	0.14	0.710^{ns}
Cover crops	7	146.793	20.9704	22.88	0.000**
Year × Fertilizer	1	0.000	0.0000	0.00	0.997^{ns}
Year × Cover crops	7	0.000	0.0000	0.00	1.000^{ns}
Fertilizer × Cover crops	7	70.833	10.1189	11.04	0.000**
Year × Fertilizer x Cover crops	7	0.000	0.0000	0.00	1.000^{ns}
Total	127	305.734			
St.Dev. 1.552					
Coef.Var. (%) 3.410					

DF – Degrees of freedom; SS – Sum of Squares ; MS – Mean Squares; F test – F value calculated; ** – Significant at 1% probability level; ns – Non Significant at 5% probability level; CoefVar – Coefficient of variation; StDev – Standard Deviation

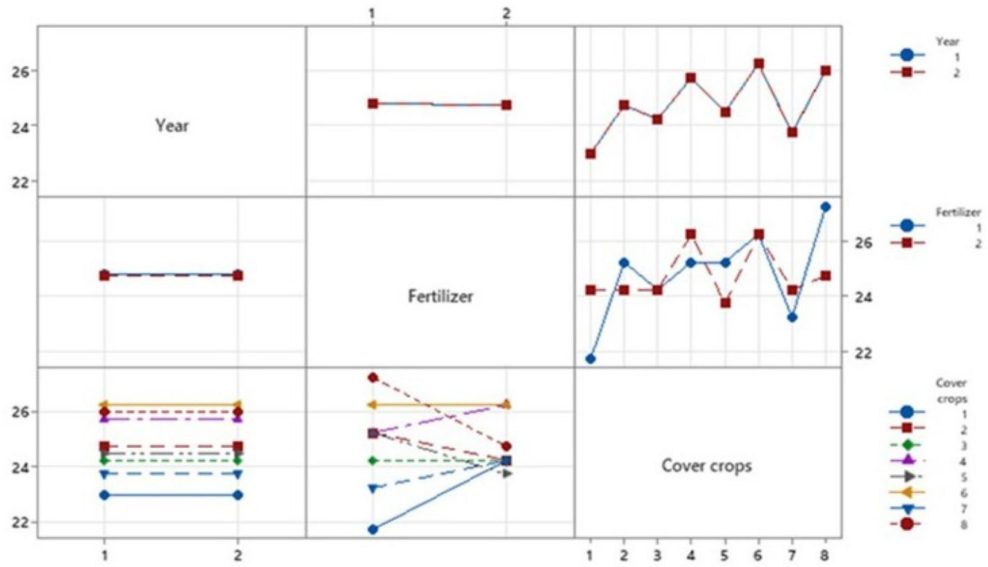

Figure 3. Interaction Plot for popping volume.
Grafikon 3. Interakcijski dijagram za zapreminu kokičavosti

The maximum values of the kernel quality are reached when the moisture content in the kernel is about 14%, according to the research by Pajić et al. (2006). If the moisture content is lower than that, not enough pressure is created to burst the pericarp and endosperm starch grains. For popcorn, which has a kernel that bursts into popcorn or flakes during the heating process, the main characteristic besides the yield is the quality of the popped kernel, especially its volume. Ozturk, et al., (2020) point out that this is one of the features that differentiates popcorn from other subspecies of corn. The differences in the volume of the kernel depending on the genotypes, locations and their interactions were statistically very significant and in the tests conducted by Öz and Kapar (2011), the average volume of the kernel was 42.0 cm3 g^{-1}. In this research, in the first year, the highest average values were recorded in the control variant (27.3 cm3 g^{-1}) without fertilizer application, while in the second year, the highest value was in the variant with fertilizer application WFP+WO (26.3 cm3 g^{-1}) (Table 5).

Table 5. Popcorn volume (cm3 g-1)
Tabela 5. Zapemina kokičavosti (cm3 g-1)

Year	2014		2015	
Cover crops	FØ	F	FØ	F
CV	21.8^{d}	24.3^{bcd}	21.8^{d}	24.3^{bcd}
WO	25.3^{abc}	24.3^{bcd}	25.3^{abc}	24.3^{bcd}
WFK	24.3^{bcd}	24.3^{bcd}	24.3^{bcd}	24.3^{bcd}
WFP + WO	25.3^{abc}	26.3^{ab}	25.3^{abc}	26.3^{ab}
Mulch	25.3^{abc}	23.8^{bcd}	25.3^{abc}	23.8^{bcd}
CV + WO	26.3^{ab}	26.3^{ab}	26.3^{ab}	26.3^{ab}
WFP	23.3^{cd}	24.3^{bcd}	23.3^{cd}	24.3^{bcd}
Control	27.3^{a}	24.8^{abc}	27.3^{a}	24.8^{abc}
Average	24.8	24.8	24.8	24.8

Fertilizer: FØ – without fertilizer; F – with fertilizer; Cover crops: CV – common vetch; WO – winter oats;WFK – winter fodder kale; WFP + WO – winter fodder peas + winter oats; Mulch – straw; CV +WO – common vetch+winter oats; WFP – winter fodder pea; Control – without cover crops. Tukey's test HSD (Honestly Significant Difference) – Means that do not share a letter are significantly different.

The significant influence of both genetic and environmental factors on the popping volume was confirmed in other studies (Pajić et al., 2012). In this study the factor of cover crops and their interaction with fertilizer showed a statistically significant effect. However, Ullah et. al (2025) in their research stated that the cracking characteristics of popcorn kernels are largely closely related to the kernel structure and genetics, and not to the conditions that prevailed during the growing season. Significant effects on the volume of kernels were achieved in varieties with legumes (common vetch, winter fodder pea) and their mixtures with winter oats, with and without the application of microbiological fertilizer.

Conclusion

Based on the two-year results, it can be concluded that the application of microbiological fertilizers and cover crops significantly affect the moisture content of the kernel and the popping volume. The year of the research had a dominant influence on the examined

traits, which is in line with earlier research. The interactions of the factors (year × fertilizer × cover crop) were statistically very significant, which indicates that the quality of popcorn kernels can be improved most successfully by the action of several agrotechnical measures. Given that the maximum popping volume is achieved at a kernel moisture content of around 14%, cover crops contribute to a more stable water regime and slower kernel drying in the later stages, which is especially important for this subspecies of corn. The application of cover crops in combination with microbiological fertilizers is a sustainable agrotechnical measure that enables the reduction of fertilization with mineral fertilizers and the achievement of high technological quality of popcorn kernels, which is of particular importance for producers who strive for added value and ecological sustainability of production.

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Author contributios

Conceptualization, B.Š. and Ž.D.; Methodology, Ž.D.; Software, B.Š.; Preparation of data, B.Š. and J.S.; Formal analysis of V.R. and I.T.; Research, B.Š. J.S.; Resources, Ž.D.; Project management, Ž.D.; Supervision of I.T., V.R., M.U. and N.Đ.; Visualization, I.T., M.U., N.R. and N.Đ.; Validacija, Ž.D., B.Š., J.S., N.R. and N.Đ.; Securing financing, Ž.D.; Writing — original preparation of the paper draft, B.Š. and J.S.; Writing — review and editing, B.Š. and J.S.

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TEHNOLOŠKI KVALITET ZRNA KOKIČARA U SISTEMU POKROVNIH USEVA

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Izvod

U dvogodišnjem periodu ispitivan je uticaj primene mikrobiološkog đubriva i različitih pokrovnih useva na sadržaj vlage i zapreminu kokičavosti zrna hibrida kukuruza kokičara ZPSC 611k. Ogled je sproveden na eksperimentalnom polju Instituta za kukuruz „Zemun Polje" (Srbija) i postavljen po split-plot dizajnu u 4 ponavljanja. Pokrovne useve su činile biljne vrste: obična grahorica, ozimi ovas, ozimi krmni grašak i ozimi krmni kelj, a u ogled su uključene dve smeše (obična grahorica i ozimi ovas, ozimi krmni grašak i ozimi ovas), kao i varijanta sa malčem i kontrola. Primena mikrobiološkog đubriva i pokrovnih useva je statistički značajno uticala na kvalitet zrna ispitivanog hibrida. Prosečne vrednosti sadržaja vlage u zrnu kretale su se u intervalu od 13,1% do 15,0%. Dominantan uticaj na obe osobine imala je interakcija fakora godina × mikrobiološko đubrivo × pokrovi usev, što ukazuje na jak sinergistički efekat meteoroloških uslova i agrotehničkih mera. Najveće prosečne vrednosti zapremine kokičavosti dobijene su u varijantama sa leguminozama i njihovim smešama, posebno uz primenu mikrobiološkog đubriva, pri optimalnom sadržaju vlage oko 14%. Rezultati pokazuju da upotreba pokrovnih useva, naročito leguminoza i njihovih smeša sa žitima, uz primenu mikrobioloških đubriva, predstavlja efikasan način za poboljšanje tehnološkog kvaliteta zrna kukuruza kokičara u uslovima umerenog kontinentalnog podneblja.

Ključne reči: leguminoze, mikrobiološko đubrivo, sadržaj vlage, zapremina kokičavosti, održiva poljoprivreda

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