Production of Forage Maize Yield under the Zinc Foliar Fertilization and Irrigation System

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Summary

The objective of presented study was to evaluate the effects of zinc foliar fertilizer and drip irrigation system on some qualitative and quantitative parameters of forage maize. Soil water deficit, drought and unbalanced fertilization are the main reasons maize grain and forage yields decrease. In this trial, the basic NPK fertilization was applied on basis of soil analysis with additional foliar application of zinc at the fifth leaf stage. Trial was set up as complete randomized design in three replications. The zinc foliar treatment with or without irrigation system gave up to 18% higher yield compared to the control treatment. Other parameters such as hectoliter mass (1.12%), nitrogen yield content (6.25%), phosphorus (13.51%), potassium (5.38%) and zinc content (70%) had higher recorded values in treatment with included foliar zinc fertilization and irrigation system compared to the control. The foliar zinc applications had positive effect on measured parameters along with drip irrigations system. However, it is necessary to establish the economic justification for introducing an irrigation system in the production of forage maize.

Key words

forage maize, zinc availability, zinc deficiency, nutritional quality

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Introduction

Production of the forage maize (*Zea mays* L.) is important due to the high dry matter yield and favorable quality characteristics for optimum animal production. Yield and quality are under effect of many factors such as environment, agricultural practices, genetics and their interactions. Maize is a very favorable crop for forage production due to the high production of green mass per unit area (12-25 tons total dry matter per hectare), high-energy content of dry matter and silage quality (Mandić et al., 2013). Powell (1985) estimated that the corn forage quality was generally highly correlated with its grain content. This assumption led to the conclusion that the best maize hybrids for grain yield would be the best available for forage production. The grain composition and yield of maize fodder regarding the stover produced during drought tends to contain much of the carbohydrates and the proteins normally allocated to the grain (Goodchild, 1997). Generally, high grain-producing hybrids have grain to stover ratio of 1:1 or greater at maturity and grain is potentially the major contributor to digestible nutrients of forage maize (Pordesimo et al., 2004). A high grain/stover ratio has considered important for forage nutritive value because of the high digestibility of grain (Fairey, 1980; Anon, 1999). Dunn et al. (1955) concluded that grain in maize silage had the same value for milk production as corn grain fed in the form of dry corn and cob meal. Farmers have their own methods to evaluate stover quality and they often select a cultivar based on a grain yield along with stover yield. Seed characteristics are not the only useful criteria. Soil water deficit, drought and unbalanced fertilization program are the main reasons for maize grain and forage yield to decrease. Among nutrient disorders, zinc has been recognized as one of limiting factors (Sharma et al., 2012). According to the Cakmak (2000), zinc is required for regulation and maintenance of the gene expression for tolerance to environmental stresses in plants. Plants require an adequate supply of macro- and micro-elements for their normal physiological and biochemical function (Bergmann, 1992). Zinc plays an important role as a metal component and as functional, structural or regulatory cofactor of a large number of enzymes. The mobility of zinc within the plants is poor. Zn is relatively immobile (with minimal solubility at pH 7) in typical agriculture soil except in acid soils where H^+ promotes its uptake (Farago, 1994). Zinc deficiency in soils and plants has tagged as global micronutrient deficiency problem reported in many countries (Sillanpaa, 1982; Alloway, 2004). Maize is one of the most susceptible cereal crops to Zn deficiency (Zhang et al., 2013). Nearly 50% of the cereal-grown areas in the world have soils with low plant availability of Zn (Graham and Welch, 1996; Cakmak, 2002; Mathpal et al., 2015, Singh et al., 2018). Studies focused specifically on increasing Zn concentration in grain (or other edible parts) are very rare, although a large number of studies are available on the role of soil and foliar applications of Zn fertilizers for correction of Zn deficiency and increase of plant growth and yield (Martens and Westermann, 1991; Mortvedt and Gilkes, 1993; Rengel et al., 1999). Nearly half of the world's agricultural soils contain inadequate levels of available zinc (Zn), resulting in Zn deficiency in one-third of the global human population (International Zinc Association, 2010; Khattak et al., 2015; Cakmak and Kutman, 2018).

The objective of this study was to evaluate the effect of fertilization with zinc foliar fertilizer and drip irrigation system on some qualitative and quantitative parameters of maize hybrid Pioneer P9241 AQUAmax in fodder production. In this research, we have focused on grain composition and yield of fodder maize.

Materials and methods

The survey has conducted at location Kiseljak, Bosnia and Herzegovina during 2017 growing vegetation season on 1260 m^2 surface. Trial was conducted to determine the zinc foliar fertilization effects under a different irrigation regime on yield and quality of hybrid Pioneer P9241 AQUAmax (FAO 320 group) for silage production. Plant density was set up to 65,000 plants ha^{-1}, which is a standard density used in Bosnia and Herzegovina. The basic NPK fertilization was applied on basis of soil analysis with additional foliar application of Zn at the fifth leaf stage. Complete randomized block design in three replications was used. The basic soil fertilization included 100 kg N ha^{-1}, 150 kg P_2O_5 ha^{-1}, 230 kg K_2O ha^{-1} and additional fertilization with 10% water-soluble Zn (CINK FAST, Cifo) was applied during the vegetative stage. Besides the basic fertilization, Zn foliar spraying at the stage of 5 to 6 leaves was used in combination with water irrigation and without irrigation. The third treatment was control, where only basic fertilization of NPK fertilizers carried out, with no foliar treatment of Zn and without irrigation. The maize was irrigated using drop-by-drop irrigation system and the total amount of irrigation water used in short term on the experimental surface was 12.5 L m^{-2} over the period of 10 days in phase of tasseling. Soil analyses were done before sowing: pH reaction by potentiometric method (BAS ISO 10390:2009) v/v 1:2.5; total carbonate content ($CaCO_3$) by method of Scheibler, and active lime by method of Druineau – Gallet (JDPZ, 1966). Total nitrogen content in soil was detected by modified Kjeldahl method (BAS ISO 11261:2010). Concentration of phosphorus (spectrophotometer) and potassium (flame photometer) in soil samples were determined by ammonium lactate method (Egner et al., 1960). Content of soil organic matter was analyzed by Kotzmann method (JDPZ, 1966). Plant material was harvested manually; ten randomly selected plants per plot picked at technological maturity of grains. Yield has calculated per plant, and converted to tons per hectare. Moisture content was determined on collected grain material using gravimetric method by oven draying at 105° C. Data on maize cob length, diameter (cm) and hectoliter mass kg hL^{-1} were measured. Total nitrogen concentration of plant material was determined by following the salicylic Kjeldahl N digestion procedure (AOAC, 1970). After wet digestion by MLS procedure, determinations of: K_2O was done by flame photometry; P_2O_5 by color spectrometry, and Zn by atomic absorption spectrometry. All data were evaluated by ANOVA, and mean separation was done by Duncan's multiple range test (DMRT), $p<0.05$, $p<0.01$ (GenStat for Windows 7th Ed).

Results and discussion

General soil fertility parameter, indicated by soil characteristics, was generally unfavorable for maize production (Table 1). Active and substitution soil pH was in acid to very acid range in experimental year. The content of available potassium was slightly high compared to phosphorus content, whose level was under the optimal. In spite of good content of organic matter, soil nitrogen

Table 1. Chemical analysis of average soil sample randomly collected on several spots at experimental location from 0-30 cm soil depth

Soil depth (cm)	Soil pH reaction			Total $CaCO_3$ (%)	Active lime (%)	Total nitrogen (N %)	Potassium mg K_2O/ 100 g soil	Phosphorus mg P_2O_5/ 100 g soil	Organic matter (%)
	pH H_2O	pH 1M KCl	Hydrolytic acidity						
0-30	5.18±0.03	4.01±0.03	6.05±0.02	N.D.	N.D.	0.19±0.01	30.47±0.03	14.87±0.02	3.28±0.07

N.D. not detected

content was low. Total carbonate content and active lime were not measured and therefore the hydrolytic acidity was included for providing liming measure. Maize plant as a plant with C4 photosynthesis pathway may have efficient conversion of CO_2 into carbohydrates and final grain yield, especially under high nutrient input systems (Ghannoum et al., 2011). During the maize vegetation season, plants growth was highly affected by water availability and temperatures (Figure 1). The amount of rainfalls and their distribution was semi-optimal for maize growth, especially during the intensive vegetative growth in May and June. The occurring water shortages were combined with an increase of the average monthly temperatures (2–3° C) as compared to long-term averages. The infrequent rainfall with monthly average for June and Julie of 55 mm and 66.5 mm and for same period high daily temperatures ranging from 33.5° C to 35° C occurred (FHMZBIH; Meteorological data for 2017). This inadequate weather period coincided with the phenomenon of intense growth, one of the critical periods of maize moisture requirements. Lobell et al. (2013) showed that the often-observed relationship between air temperature and yield that indicated yield growth for corn, soybean, and cotton (Schlenker and Roberts, 2009) could gradually increase with temperatures up to 29° C to 32° C and then sharply decrease with temperature increases beyond this threshold. According to Awosanm et al. (2016) maize yield can be reduced by as much as 90% if the crop is exposed to drought stress from a few days before tassel emergence to the beginning of grain filling. Based on the statistical analysis there are significant differences for all measured parameters between the zinc treatment with the applied irrigation system and without the irrigation system, as well as the control (treatment without Zn fertilization and without the irrigation system). The results of the hectoliter mass, potassium content, phosphorus content, nitrogen content, yield, length and the diameter of corn cob (Table 2) showed that the zinc foliar fertilization with and without irrigation system treatment gave significantly higher yield values compared to the control treatment. Malavolta (2006) had reported that foliar application of micronutrients was a more efficient method compared to the ground fertilization, and zinc should be applied as foliar application to the maize, especially in zinc-deficient soils. Maize yield development is a chronological process in which the potential number of ears per plant is determined first, followed by grain number per inflorescence and by grain size (Sangoi, 2000). Following three years (2011–2013) of on-farm industry-scale testing Gaffney et al. (2015) reported yield of a large sample of AQUAmax hybrids (78 hybrids) to a large sample of industry-leading hybrids (4287 hybrids) grown in the US Corn Belt. The AQUAmax hybrids had on average 6.5% higher yield under water-limited conditions (2006 locations) and 1.9% higher yield under favorable growing conditions (8725 locations). The average yield during testing period in good environmental conditions was about 13.54 t ha^{-1}, while water limited condition had average yield about 6.08 t ha^{-1} (Gaffney et al., 2015). Our research has confirmed that AQUAmax hybrids in favorable condition under addition of zinc foliar treatment yielded of 16.51±2,06 t ha^{-1}, while under drought condition and without additional foliar fertilization yield decreased 26% (11.06±2,18 t ha^{-1}) in the area of Kiseljak (Bosnia and Herzegovina). According to the Pordesimo et al. (2004) actual stover yield will vary between hybrids, sites, year and time of year when grain is harvested. Water stress (drought, unbalance rainfall occurrence) promoted a faster development in plants that results in smaller grain due to the shorter life cycle, hence, shorter reproductive duration consequently follows by lower yield potential (Hatfield and Prueger, 2015). Plants under conditions of water stress, because of drought, built up relatively lower vegetative mass, and consequently larger nitrogen pool is accumulated in grain. It have been well documented that detasseling after anthesis increased grain protein concentration (Jenner, 1980). Bąk et al. (2016) carried out a study on different maize hybrids during several seasons, aiming to determine the effect of differentiated phosphorus and potassium fertilization rates on N, P, and K content in grain. Results have shown potassium ranging from 0.32 % to 0.37%, phosphorus from 0.22% to 0.24% and nitrogen from 1.32% to 1.37%. Stanford (1973) found 1.20% to 1.30% of N content at maximum yield of grain and stover. These results were in accordance with our results with AQUAmax hybrid. Treatment with zinc showed 1.28±0.02% and 1.27±0.01% of N. The low level of nitrogen in the maize grain in the control treatment (1.13±0.03%) resulted in significantly lower yield compared to the other two treatments of the experiment. Pierre et al. (1977) determined the critical percentages of N values from several year trial on maize (1.54%, 1.57% and 1.68%) in grain. Cox and Barnes (2002) reported about plant phosphorus critical levels in maize, and potassium values ranged from 0.75% to 1.27%. Slightly higher result on potassium content in presented research in AQUAmax hybrid was due to the good soil fertility. The results of the total

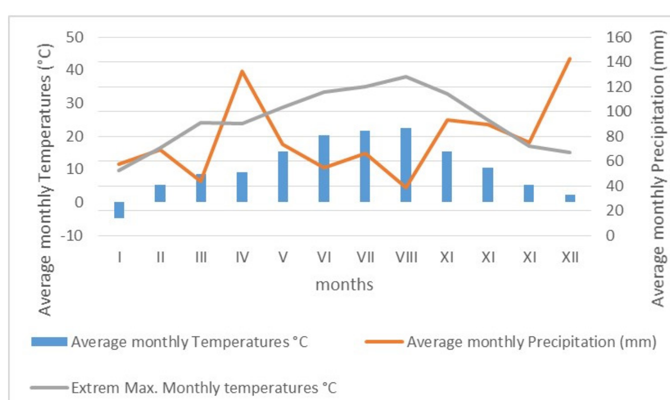

Figure 1. Average monthly values of temperatures (°C) and precipitation (mm) during vegetation season of maize in 2017

Table 2. Average values (± SD) of measured parameters of hybrid Pioneer P9241 AQUAmax corn, n=3 replications

	Hect. mass kg/hL	K (%)	P (%)	(N %)	Zn mg/kg	Yield t/ha	Mois. cont. (%)	Length of corn (cm)	Radius of corn (cm)
Zn + irrigation	66a±0.25	0,653a±0.01	0.375a±0.01	1.285a±0.02	24.37a±0.58	16.51a±2.06	13.54c±0.61	20.14a±1.45	5.06a±0.53
Zn	65.43b±0.65	0.598c±0.01	0.295c±0.01	1.27ab±0.01	26.47a±1.29	13.47b±2.70	15.73b±0.49	16.60bc±2.02	4.9ab±0.31
Control	65.08b±0.79	0.642b±0.01	0.354b±0.01	1.136bc±0.03	7.07b±0.96	11.06c±2.18	16.49a±0.49	16.65b±1.59	4.49c±0.32
F-test	**	**	**	**	**	**	**	**	**
$LSD_{5\%}$	0.57	0.0104	0.009	0.022	3.34	2.14	0.491	1.567	0.37
$LSD_{1\%}$	0.77	0.014	0.012	0.03	4.52	2.89	0.663	2.11	0.5

zinc content (mg kg^{-1}) in the grain dry matter showed about 8% higher values (although not significantly) in the treatment only with zinc foliar application compared to the Zn foliar fertilization treatment with the irrigation system. The values of Zn determined in the maize grain for both Zn treatments have about 72% higher average values compared to control. The zinc values in the maize grain vary from 7.07±0.96 mg Zn kg^{-1} to 26.47±1.29 mg Zn kg^{-1} dry matter. Mahmodi and Yarnia (2012) in their study reported that the foliar application of zinc could increase maize grain yield up to 40% compared to control. According to Ruffo et al. (2016) the zinc concentrations in maize tissue ranged from control treatments up to the maximum zinc application (of 11.2 kg Zn ha^{-1}) depending on the location of the experiment as well as the monitoring year from the 9.1 mg kg^{-1} (trial 2011) to 66.5 mg kg^{-1} (trail 2012). Since Zn concentrations in vegetative plant parts could be increased by zinc foliar or soil application resulting in homeostasis with the zinc content in the phloem, but its translocation to grain is limited (Herren and Feller, 1997; Stomph et al., 2011). The limitations and weaker fluxes and translocation of zinc may be the result of a low concentration of N and P, which can lead to other antagonistic interactions (Cakmak, 2008; Nuss and Tanumihardjo, 2010). Grzebisz et al. (2008) indicated that foliar treatment of zinc in the early stage of maize produced significantly higher yields. Steele et al. (1981) reported that relative grain yield of maize (the yield expressed as percentage of maximum yield) is related to the concentration of N in grain at harvest and maximum relative yield was obtained when N grain content was about 1.5% otherwise yield declined. In our research, N grain content was close to the optimum ranging from 1.13±0.03% to 1.28%±0.02 N. The lowest moisture content (13.54±0.61%) was found in grain of maize with the applied zinc fertilizer treatment and irrigation system. The control had the highest moisture content of 16.49±0.49%. The maize cob length is an essential feature of the selection, especially for hybrids of later ripening groups, where a higher yield is due to the larger number of grains and cob length. Since the goal of selection is to increase the number of grain per unit area and thus directly increase the yield, this trait is of great importance. Hybrid AQUAmax has demonstrated its largest cob length of 20.14±1.45 cm in consistence with the largest diameter of 5.06±0.53 mm obtained in the treatment with the zinc foliar application and the irrigation system. López et al. (2018) in trial with eight maize hybrids in two sowing seasons (spring and summer) for two consecutive years under irrigation have found that the corncob length ranged from 15-17 cm and diameter from 1.9 to 2.5 cm with grain yield from 5.5 to 9.9 t ha^{-1}. They concluded that most of the grain variables have been under the impact of growing season and hybrid genotype. Even the temperatures were not so extreme during our trial, yet they (heat stress) affected the grain weight (Maddonni et al., 1998; Mayer et al., 2014), its components and yield (Badu-Apraku et al., 1983; Muchow, 1990; Wilhelm and Wortmann, 2004; Rattalino et al., 2014). Heat stress reduced maize grain weight due to proportional losses in grain composition (starch, protein and oil content) and due to its direct effect during the grain-filling period that caused a cessation of grain filling (Rattalino et al., 2014; Wilhelm et al., 1999).

Conclusion

The zinc foliar treatment with or without irrigation system on maize AQUAmax hybrid showed up to 18% higher yield compared to the control treatment. Other parameters such as hectoliter mass, nitrogen grain content, phosphorus, potassium and zinc content showed higher recorded values in treatment with included foliar zinc fertilization and irrigation system. Applied zinc fertilizations did not significantly affect its grain content, but it had a significant effect on yield and hectoliter mass between treatments with and without irrigation. The foliar zinc application showed positive effect on measured parameters along with drip irrigations system. However, it is necessary to establish the economic justification for introducing an irrigation system in the production of forage maize. Fertilizers represent one of the main inputs in the process of agricultural production, and the quantity and quality of this type of input greatly determines the quality and quantity of the yield, therefore the further evaluation of efficiency of the respective process is needed.

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