Journal of Agricultural Sciences
Vol. 61, No. 1, 2016
Pages 11-18

DOI: 10.2298/JAS1601011D
UDC: 633.15-154.32"2005/2010"
Original scientific paper

ENVIRONMENTAL CONDITIONS AND CROP DENSITY AS THE LIMITING FACTORS OF FORAGE MAIZE PRODUCTION

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Abstract: In rain-fed cropping, defining the best combination of practices could achieve high forage yield and silage quality. The aim of this study was to compare energetic quality of produced silage with productive characteristics of forage maize cultivated on alluvium and hydromorphous black soil in rain-fed conditions at four plant densities (68–74,000 plants ha^{-1}) during the period 2005–2010. Yield and energy parameters were increased to some extent at higher crop densities indicating that higher densities (74,000 plants ha^{-1}) were potentially better for high forage and DM yields, while lower densities (70,000 plants ha^{-1}) were better for the increase of energy parameters of produced silage.

Key words: forage maize, silage, yield, quality, energy.

Introduction

The rain-fed cropping is still the most abundant maize cropping practice in many regions. The successful maize cropping for forage is mainly dependant on environment: meteorological conditions (mainly during anthesis and grain filling period – July–August) and soil type. Sileshi et al. (2010) showed that different agricultural practices including fertilization and irrigation show the best effects on light soils, increasing dry matter and grain yield. On the other hand, on clayey soil the wheat plants had higher fresh matter and better water using efficiency (Iqbal et al., 2003). Randjelovic et al. (2011) also underlined the influence of precipitation on forage and dry matter production, as well as the chemical composition of produced silage.

Plant density plays an important role in successful forage production. Cusicanqui and Lauer (1999) and Ahmad et al. (2008) ascertained that higher

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maize crop densities significantly increased crop growth rate, and grain and dry matter yields. According to Millner et al. (2005), plant density affected forage yield, with lower effect on dry matter partitioning.

Estimating the energy value of maize silage is important, since the energy is the primary nutrient provided to dairy cattle by silage (Schwab et al., 2003). Tine et al. (2001) found that increased silage digestibility resulted in a greater metabolisable energy value in cows fed at maintenance energy intake. This suggests that the increase in milk production was primarily driven by increases in dry matter intake. Idikut et al. (2009) also achieved higher values of metabolisable energy from maize silage with higher dry matter, when sweet maize was used as the ensiling material.

Agricultural and environmental conditions can determine the maize crop yield. Therefore, knowledge about possibilities of different crop exploitations can be an important key for cost-effective forage maize production, considering environmental regulations (Van Waes and Carlier, 2000). Defining the best combination of practices in rain-fed cropping could achieve high forage yield and silage quality, depending on environmental conditions. The aim of this study was to compare productive characteristics of forage maize with energetic quality of silage produced from crops cultivated on alluvium and hydromorphous black soil in rain-fed conditions at four plant densities (68,000–74,000 plants ha^{-1}).

Materials and Methods

The experiment was performed in Padinska Skela (44°59’52’’N, 20°22’18’’E, 67–69 m altitude) with five maize hybrids (Staniša, Srećko, Dukat, Dijamant and Rubin, FAO 300–500), in the period 2005–2010, on two types of soil: on alluvium (as a model of sandy, light soil) and on hydromorphous black soil (as a model of clayey, heavy soil) under rain-fed conditions. The experiment design was a randomised complete block system on a total area of 216 ha in three replications, with an elementary plot of 6 ha. A pre-sowing soil preparation included conventional tillage and application of 250 kg ha^{-1} of urea. The sowing was performed during the second half of April and beginning of May. Investigated plant densities were: 68,000, 70,000, 72,000 and 74,000 plants ha^{-1}. The maize harvest was performed at dry matter content of 34–36%, depending on the meteorological conditions (during the second half of August and beginning of September). Results were presented as averages for years and hybrids.

Total forage yield, stem and ear yields (derived from stem and ear weights), as well as plant height and number of leaves per plant (30 plants per replication) were determined just before crop harvesting. Dry matter yield (DM) was calculated based on the DM content of each sample, after drying at 105°C.

Harvested material was transported to pit silos, inoculated with Sil-ALL (Alltech, UK) with 1 g t^{-1} of plant material, properly compressed, covered with a plastic sheet and kept pressed for 75 days. After that, silage samples were collected (three samples per silo pit: one from the middle and one from each end). The chemical composition of the silage samples was determined using the proximate chemical analysis according to "Standard accredited methods" (Official Gazette of SFRY, 1987). Based on the obtained silage composition, the gross energy (GE), metabolisable energy (ME), net energy for growth (NEG) and net energy for lactation (NEL) of silage were determined by the method of Obračević (1990).

The experimental data were statistically processed by analysis of variance (ANOVA) by the LSD test (5%). Differences between two soils and examined plant densities in yielding potential (forage, stem, ear and DM yields) and quality parameters (GE, ME, NEG and NEL) were presented with Weibull analysis (Dodson, 2006):

$$F(x) = 1 - e^{-\left[\frac{x}{\alpha}\right]^{\beta}}, \text{ for } x > 0 \quad (1)$$

where β is a shape parameter and α is a measure of the scale (characteristic life), which were used for the survival probability calculation, to predict the parameter reaching the reliability of 0.50 (relatively favourable environmental conditions) and 0.99 (unfavourable environmental conditions).

Table 1. Monthly air temperatures (°C) and sums of precipitation (mm) during the period 2005–2010.

	IV	V	VI	VII	VIII	IX	Sum/Aver.
Years				Precipitation			
2005	12.2	30.3	84	46.7	132.8	65.9	371.9
2006	81.7	34.8	139.8	31.1	108.5	34.5	430.4
2007	5.5	43.1	55.9	18.8	81.1	73.1	277.5
2008	44.1	50.8	27.2	37.5	17.5	62.3	239.4
2009	7.8	45.1	83.6	106.7	60.5	1.2	304.9
2010	35.5	86.7	101.9	64.3	27.2	56.8	372.4
Average	31.1	48.5	82.1	50.9	71.3	49.0	332.8
				Temperature			
2005	11.8	17.4	19.7	22.2	20.2	18.1	18.2
2006	13.1	16.7	19.7	23.8	20.2	18.6	18.7
2007	13.8	18.9	23.1	25	23.8	15.7	20.1
2008	13.3	18.7	22.7	23.2	23.5	16.4	19.6
2009	15.1	18.8	20.4	23.2	23.1	20.1	20.1
2010	13.2	17.5	21	23.2	23.1	17.6	19.3
Average	13.4	18.0	21.1	23.4	22.3	17.8	19.3

Meteorological conditions: The research period was characterized by an increasing trend of average temperature, with the highest values obtained in 2007 and 2009 (Table 1). A precipitation sum varied among years, with the lowest average values in 2007 and 2008. The month with the highest average temperature was July, while the highest precipitations were in June and August. Opposite from average values, the importance of precipitation was emphasized during the grain filling period (July–August), with the lowest values in July of 2007 and in August of 2008, which in combination with the highest average temperatures indicated the draught conditions.

Results and Discussion

There were no significant differences in observed parameters achieved on two soils, irrespective of negligible higher values of yield parameters obtained on hydromorphous black soil and of higher values of energy parameters obtained on alluvium (Table 2).

Table 2. Forage yield, stem yield, ear yield, number of leaves per 1m of stem length, dry matter yield, gross energy, metabolisable energy, net energy for growth and lactation of silage produced from maize grown at different plant densities and on two soil types: alluvium and hydromorphous black (HB) soil.

Parameter	Soil	Plant density (number of plants ha^{-1})					LSD 0.05	
		68,000	70,000	72,000	74,000	Aver.		
Forage yield (t ha^{-1})	Alluv.	36.55	34.75	36.26	38.92	36.62	S X D	3.32
	HB sol	39.41	39.58	38.22	41.50	39.67	Soil	3.36
	Aver.	37.98	37.16	37.24	40.21	38.15	Density	3.41
Stem yield (t ha^{-1})	Alluv.	28.97	27.44	27.97	29.42	28.45	S X D	3.39
	HB sol	31.12	31.93	29.67	31.50	31.06	Soil	3.39
	Aver.	30.04	29.69	28.82	30.46	29.75	Density	3.46
Ear yield (t ha^{-1})	Alluv.	7.58	7.31	8.29	9.50	8.17	S X D	1.55
	HB sol	8.29	7.64	8.54	10.00	8.62	Soil	1.16
	Aver.	7.94	7.48	8.42	9.75	8.40	Density	1.54
Number of leaves (m^{-1})	Alluv.	4.04	3.96	4.05	3.87	3.98	S X D	0.22
	HB sol	4.01	3.95	3.97	3.91	3.96	Soil	0.22
	Aver.	4.02	3.96	4.01	3.89	3.97	Density	0.21
Dry matter yield (t ha^{-1})	Alluv.	13.82	12.77	13.25	13.91	13.44	S X D	1.19
	HB sol	13.72	13.26	12.92	14.57	13.62	Soil	1.20
	Aver.	13.77	13.02	13.09	14.24	13.53	Density	1.18
Gross energy (MJ kg DM^{-1})	Alluv.	11.29	11.29	11.36	11.35	11.32	S X D	0.09
	HB sol	11.33	11.34	11.42	11.26	11.34	Soil	0.10
	Aver.	11.31	11.31	11.39	11.31	11.33	Density	0.10
Metabolisable energy (MJ kg DM^{-1})	Alluv.	9.16	9.23	9.21	9.20	9.20	S X D	0.07
	HB sol	9.20	9.24	9.21	9.11	9.19	Soil	0.08
	Aver.	9.18	9.24	9.21	9.15	9.19	Density	0.07
Net energy for growth (J kg DM^{-1})	Alluv.	6.70	6.78	6.73	6.72	6.73	S X D	0.07
	HB sol	6.72	6.77	6.70	6.64	6.71	Soil	0.07
	Aver.	6.71	6.77	6.71	6.68	6.72	Density	0.06
Net energy for lactation (MJ kg DM^{-1})	Alluv.	5.88	5.94	5.91	5.90	5.91	S X D	0.06
	HB sol	5.90	5.94	5.90	5.84	5.89	Soil	0.06
	Aver.	5.89	5.94	5.90	5.87	5.90	Density	0.05

In silage production, quality is important, beside the high forage yield. Cusicanqui and Lauer (1999) also observed an increase in fresh and dry matter at the higher plant density. Meanwhile, DM compartmenting induced by changes in crop density is unequal: the low plant density increases leaf and stem fresh matters but it decreases ear fresh matter (Ramezani et al., 2011), similarly to an increase in stem yield and a decrease in ear yield received on hydromorphous black soil. The significantly higher average values of energy factors, including ME, NEG and NEL were obtained at a population of 70,000 plants ha^{-1}. The same crop density was characterized by the significantly lower values of forage and stems yields on alluvium, and high values of forage and stem yields on hydromorphous black soil. Iqbal et al. (2003) confirmed that higher forage yields were produced on heavier soil types. At plant density of 74,000 plants ha^{-1}, a significantly higher ear yield was achieved, irrespective of soil type, similar to the results of Subedi et al. (2006) who also found the linear correlation between increased crop density and maize forage yield. On the other hand, energy parameters (GE, ME, NEG and NEL) expressed the lowest values on hydromorphous black soil at a population of 74,000 plants ha^{-1}. The highest values of energy parameters were noticed at a population of 70,000 plants ha^{-1} on both soils. These observations could indicate changes in chemical composition of produced silage, opposite to findings of Cammell et al. (2000) and Millner et al. (2005) who ascertained that variations in maize density altered silage composition, but without any effect on ME.

Agricultural and environmental conditions can determine the final cropping result. According to Van Waes and Carlier (2000), crop behaviour for different exploitations can be an important key to producing maize silage in a cost-effective way, taking into account the environment. In rain-fed cropping, variations in meteorological factors could induce higher or lower yield losses and could also affect silage quality. Combining certain crop practices could attain stable yields with high reliability. According to the results presented in Table 3, the highest values of forage, stem, ear and DM yields could be achieved at the highest density (74,000 plants ha^{-1}) on both soils with reliability of 50%. This degree of reliability could exclude higher alterations in meteorological factors, indicating favourable conditions. Therefore, the highest GE values were recorded at a population of 74,000 plants ha^{-1} on alluvium and at a population of 72,000 plants ha^{-1} on hydromorphous black soil. Greater differences between soil types and examined plant densities were present in ability to reach high ME, NEG and NEL values, underlining 70,000 plants ha^{-1} on alluvium and 70–72,000 plants ha^{-1} on hydromorphous black soil.

Differences between soils and densities in examined parameters were present at a reliability level of 99% (Table 3). The highest density (74,000 plants ha^{-1}) was appropriate for achieving higher forage and DM yields on both soils. The best GE results were realized at a population of 70,000 plants ha^{-1} on alluvium and at a population of 74,000 plants ha^{-1} on hydromorphous black soil. What is more, a population of 70,000 plants ha^{-1} showed the impact on an increase in ME, NEG and NEL values on both soils. The prediction of yield and energy parameters, in an unfavourable environment, leads to deprivations in yield, mainly ear yield, with a minor effect on energy parameters. It is also noticeable that higher losses of forage, DM yield and GE were more evident on alluvium, while energy parameters had the lowest values on hydromorphous black soil. Mahanna (2011) emphasized that differences in forage yield and compositions were mainly dependent on environment, indicating that limited water supply is the main factor in yield losses, also approved by this research. The differences in yield parameters between reliability of 50% and 99% were obtained at lower densities and on alluvium.

Table 3. Prediction of forage yield, stem yield, ear yield, number of leaves per 1m of stem length, dry matter yield, gross energy (GE), metabolisable energy (ME), net energy for growth (NEG) and lactation (NEL) of silage produced from maize grown at different plant densities and on two soil types: alluvium and hydromorphous black soil, according to Weibull analysis.

Soil type	Alluvium				Hydromorphous black soil			
Plant density	68,000	70,000	72,000	74,000	68,000	70,000	72,000	74,000
Parameters	Relatively favourable environmental conditions							
Forage yield (t ha^{-1})	36.80	35.08	36.66	39.37	39.84	39.58	39.10	41.87
Stem yield (t ha^{-1})	29.06	27.11	27.79	29.28	30.52	31.08	30.10	31.85
Ear yield (t ha^{-1})	7.30	7.26	8.22	9.30	8.15	7.87	8.27	9.52
Dry matter yield (t ha^{-1})	13.94	12.91	13.39	14.06	13.88	13.35	13.16	14.56
GE (MJ kg DM^{-1})	11.30	11.30	11.38	11.39	11.36	11.35	11.46	11.27
ME (MJ kg DM^{-1})	9.17	9.25	9.23	9.22	9.22	9.24	9.25	9.13
NEG (MJ kg DM^{-1})	6.70	6.79	6.74	6.74	6.74	6.77	6.75	6.67
NEL (MJ kg DM^{-1})	5.89	5.95	5.92	5.92	5.91	5.94	5.93	5.86
	Unfavourable environmental conditions							
Forage yield (t ha^{-1})	14.42	15.60	17.80	23.05	21.36	17.91	21.18	29.18
Stem yield (t ha^{-1})	11.16	6.90	10.48	11.72	11.28	12.52	12.67	7.22
Ear yield (t ha^{-1})	1.26	1.92	2.12	2.05	1.79	2.56	2.62	2.25
Dry matter yield (t ha^{-1})	6.43	6.19	6.27	7.29	7.89	6.32	7.20	8.81
GE (MJ kg DM^{-1})	10.74	10.92	10.83	10.49	10.57	10.60	10.54	10.69
ME (MJ kg DM^{-1})	8.68	8.42	8.77	8.71	8.81	8.46	8.75	8.55
NEG (MJ kg DM^{-1})	6.18	6.15	6.33	6.30	6.30	5.97	6.22	6.16
NEL (MJ kg DM^{-1})	5.49	5.41	5.59	5.57	5.59	5.33	5.55	5.45

According to the obtained results for forage yield and energy parameters of produced silage, it could be indicated that higher variations in yield, influenced by environmental factors, have a lower impact on energy parameters.

Conclusion

According to our results, it could be concluded that variations in environmental factors, such as temperature and amount of precipitation, could affect forage and DM yields, particularly on alluvium, as light soil. Furthermore, by changing crop densities, yield and energy parameters could be increased to a certain amount, indicating that higher density, such as a population of 74,000 plants ha^{-1}, was potentially better for high forage and DM yields, while a population of 70,000 plants ha^{-1} was better for an increase in energy parameters of produced silage, particularly NEG and NEL.

Acknowledgements

This study was supported by the Ministry of Education and Science of the Republic of Serbia (Project TR-31037). The authors are grateful to MSc Snjezana Pupovac (Ekolab D.O.O.) for laboratory analysis.

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Received: October 30, 2015
Accepted: December 3, 2015

USLOVI OKOLINE I GUSTINA USEVA KAO LIMITIRAJUĆI FAKTORI PROIZVODNJE SILAŽNOG KUKURUZA

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R e z i m e

U uslovima prirodnog vodnog režima, definisanje adekvatne kombinacije mera gajenja može doprineti povećanju prinosa i kvaliteta silaže. Cilj eksperimenta je bio da se uporede energetski kvalitet silaže sa produktivnim osobinama silažnog kukuruza gajenog na aluvijumu i ritskoj crnici u uslovima prirodnog vodnog režima, pri četiri gustine useva (68–74.000 biljaka ha^{-1}) tokom 2005–2010. godine. Prinos i energetski parametri su povećani u određenom stepenu pri većoj gustini gajenja, ukazujući da su veće gustine (74.000 biljaka ha^{-1}) potencijalno bolje za povećanje prinosa biomase i suve materije, dok su manje gustine (70.000 biljaka ha^{-1}) bolje za povećanje energetskih parametara proizvedene silaže.

Ključne reči: silažni kukuruz, silaža, prinos, kvalitet, energija.

Primljeno: 30. oktobra 2015.
Odobreno: 3. decembra 2015.

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