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THE PRODUCTIVE AND QUALITY TRAITS OF FORAGE MAIZE IN RELATION TO THE SOIL TYPE AND SOWING DENSITY

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ABSTRACT

Successful maize cropping for forage under rain-fed conditions is predominantly dependant on the meteorological conditions, as well as on the soil type and crop density. The aim of this study was to relate the productive characteristics of forage maize with the quality of the produced silage from crops cultivated on alluvium and hydromorphous black soil, under rain-fed conditions at four plant densities (68–74,000 plants ha^{-1}). The highest biomass yields were obtained at higher densities, mainly on hydromorphous black soil. The dry matter yield and cellulose content were strongly influenced by the D coefficient (coefficient of fractal dimension). Owing to the meteorological conditions, maize forage cropping on alluvium could be associated with a lower crop density with earlier harvesting, while the management recommendation for hydromorphous black soil could include a high plant density with a longer vegetation period.

Key words: D coefficient, fractals, forage maize, growing degree days, silage quality.

INTRODUCTION

Rain-fed cropping is still the most abundant maize cropping practice in many regions. Successful maize cropping for forage is mainly dependant on the meteorological conditions and the soil environment. Court et al. (1963) and Sileshi et al. (2010) showed that the different agricultural practices show best effects on light soils, increasing the dry matter and grain yield. On heavier, clayey soil, wheat had a higher fresh mass and better water use efficiency (Iqbal et al., 2003).

Almirall et al. (1996) emphasized that plant breeding is focused on increasing leaf number, stalk diameter and plant height of forage maize, which could be the best way to augment the yield of total digestible dry matter. In addition, increasing plant density provides for a more efficient use of soil moisture, nutrients and light (Cuomo et al., 1998). Likewise, Cusicanqui and Lauer (1999); Ahmad et al. (2008) and Fisher and Fairley (1982) highlighted that increased maize crop densities significantly increased grain, dry matter yield, protein content and decreased the fat content, while further density increase could induce stalk breakage and yield decrease (Neilsen, 1988; Haş et al., 2008).

The different crop densities are interrelated with plant spatial arrangements. When variations in crop spatial arrangements are observed, the variation over a continuum of scales is perceived, characterizing the crops as fractals. Theoretically, the fractal crop dimension is not a constant function of scale. Mandelbrot (1983) defined that the regression slope (D) of the straight line formed by plotting against logarithm of sequence indicates the degree of complexity, or in this specific case, the fractal dimension of the crop.

For maize grown under field conditions, temperature indices can often explain over 95% of the variability in crop development (Kinjry and Keener, 1982). Understanding maize growth in response to variable environmental conditions, especially

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temperature, has led to the concept of "growing degree days" (GDD) (Bonhomme et al., 1994). From this viewpoint, the timing of the harvest is an important management consideration for dairy and livestock operations. The dry matter yields increased as the GDD were accumulated (Darby and Lauer, 2002), while the silage quality depends on plant and environmental conditions: a high plant density, as well as a high GDD value could decrease the silage nutritive values (Baron et al., 2006; Stanton et al., 2007).

The definition of the best combination of practices in rain-fed cropping could achieve high forage yields and silage quality, dependent on the environmental conditions. The aim of this study was to relate the productive characteristics of forage maize and quality of the produced silage from crops cultivated on alluvium and hydromorphous black soil under rain-fed conditions at four plant densities (68-74,000 plants ha^{-1}).

MATERIAL AND METHODS

The trial was set up in the PKB Corporation (44° 59' 52'' N, 20° 22' 18'' E, 67–69 m altitude) with three maize hybrids, Staniša – H1 (FAO 300-350), Dukat – H2 (FAO 450-500) and Srećko – H3 (FAO 500–550) during 2005, 2006, 2007, 2008, 2009 and 2010. The crops were established on alluvium (as a model of sandy, light soil) and hydromorphous black soil (as a model of clayey, heavy soil) under rain-fed conditions. The experiment was aligned in a random block system on a total area of 216 ha in three replications with an elementary plot of 6 ha. The sowing was performed during second half of April and beginning of May. Pre-sowing soil preparation included conventional tillage with an input of 250 kg urea ha^{-1}. The plants were cultivated at densities of 68,000, 70,000, 72,000 and 74,000 plants ha^{-1}. The maize harvesting was performed when the dry matter was 34-36%, depending on the meteorological conditions: during second half of August and beginning of September. The fresh matter (FM), height and ear proportion of 30 maize plants per replication were determined just before crop harvesting. The dry matter (DM) yield was calculated based on the DM content of each sample, after drying at 105°C.

The harvested material was transported to pit silos where it was inoculated with Sil-ALL (Alltech, UK) at 1 g t^{-1} plant material, compressed properly, covered with a plastic sheet and compressed for 75 days, when silage samples were collected (three samples per silo pit, at middle and the two ends). The crude protein, fat, cellulose and ash in the silage samples were determined by "Standard accredited methods" (Official Gazette – Službeni list SFRJ 1987; AOAC 1990).

The GDD was calculated by the formula proposed by Cross and Zuber (1972):

$$GDD = (T_{max} + T_{min})/2 - T_{base}$$

where T_{max} is the maximum daily temperature and was set equal to 30 °C when the temperatures exceeded this level, T_{min} is minimum daily temperature and was set equal to 10°C when the temperature fall below this value, and T_{base} was taken as 10°C for maize (Cross and Zuber, 1972).

The relation between the plant density and the plant height was calculated using a fractal equation, where the regression slope (D) of the straight line formed by plotting log [N(s)] against log (1/s) indicates the degree of complexity, or fractal dimension (Mandelbrot, 1983):

$$\log [N(s)] = \log (K) + D \log (1/s)$$

where: K is the distance between the rows, which was constant (K = 0.7 m) and N(s) is the plant height (proportional to (1/s), where s is the distance between the plants in a row).

The experimental data of GDD, D, FM and DM yield, ear proportion, crude protein, fat, cellulose and ash were statistically processed by analysis of the variance (ANOVA) by the LSD test (5%), while the dependence between the productive and quality parameters was obtained by regression analysis of GDD and D.

RESULTS AND DISCUSSION

There was no remarkable difference in the average D coefficient between the soils, but significantly higher values were associated with higher plant densities (Table 1). Plant growth was also confirmed by the significant positive correlation between D and FM yield to a greater extent than the GDD (Figures 1c and 2c), with the highest FMs acquired at a high plant density on hydromorphous black soil (Table 1). Subedi et al. (2006) also found a linear correlation between maize forage yield and crop density, while Iqbal et al. (2003) confirmed the higher FM production on heavier soil types. Moreover, higher GDD values on the alluvium (Table 1) indicated prolonging of the vegetation. The significant negative correlation of GDD and the FM yield on both soils (Figures 1a and 2a) suggests that the extended vegetation period could induce biomass losses (Herrmann et al., 2005). The increasing value of the ear percentage at higher densities (Table 1) was contrary to a lower cob to stover ratio on increasing maize density, obtained by Stanton et al. (2007) and Sarlangue et al. (2007). The exceptions were in the lowest crop density: the highest ear percentage for H2 was recorded on the hydromorphous black soil (22.98%), while for H3 it was on the alluvium soil (26.15%).

Table 1. The influence different soil types and plant density on GDD, D, FM and DM yield and ear proportion in maize plants

	Plant density	GDD	D	FM yield (t ha^{-1})	Ear (%)	DM yield (t ha^{-1})
			H1			
Aluvium	68,000	1235.54	1.39	41.90	19.77	15.58
	70,000	1644.76	1.40	34.02	23.85	12.01
	72,000	1644.46	1.39	33.64	32.47	11.97
	74,000	1394.24	1.38	38.01	27.74	13.89
	Mean	1479.75	1.39	36.89	25.96	13.36
Hydromorp. black soil	68,000	1308.58	1.40	43.84	16.55	15.01
	70,000	1596.58	1.40	36.78	21.66	12.19
	72,000	1731.04	1.40	37.38	22.31	12.44
	74,000	1310.38	1.40	40.18	34.64	14.06
	Mean	1486.64	1.40	39.55	23.79	13.42
LSD 0.05 (density)		27.54	0.01	5.07	2.81	0.97
LSD 0.05 (soil)		0.37	0.23	1.84	0.35	8.92
			H2			
Aluvium	68,000	2000.36	1.33	34.32	20.45	13.28
	70,000	1603.08	1.34	37.16	23.56	12.99
	72,000	1205.18	1.38	39.93	18.43	15.17
	74,000	1302.34	1.41	38.66	23.89	14.32
	Mean	1527.74	1.37	37.52	21.58	13.94
Hydromorp. black soil	68,000	2098.24	1.35	37.16	22.98	13.09
	70,000	1633.33	1.38	38.06	19.92	12.69
	72,000	1229.71	1.37	40.60	18.60	13.39
	74,000	1289.91	1.43	42.85	21.47	15.25
	Mean	1562.79	1.38	39.67	20.74	13.61
LSD 0.05 (density)		171.83	0.05	2.64	1.90	1.07
LSD 0.05 (soil)		0.28	0.07	2.46	0.45	5.09

			H3			
Aluvium	68,000	1561.95	1.48	40.90	26.15	14.35
	70,000	1719.76	1.34	31.35	23.80	12.07
	72,000	1585.53	1.38	33.75	20.20	12.31
	74,000	1484.84	1.44	39.73	21.74	14.02
	Mean	1588.02	1.41	36.43	22.97	13.19
Hydromorp. black soil	68,000	1323.16	1.40	43.97	16.77	15.00
	70,000	1690.15	1.36	35.10	16.69	11.77
	72,000	1684.18	1.42	36.59	21.34	12.88
	74,000	1411.34	1.42	41.53	22.24	15.01
	Mean	1527.21	1.40	39.30	19.26	13.67
LSD 0.05 (density)		3.45	0.24	6.66	0.06	0.50
LSD 0.05 (soil)		0.55	0.25	1.42	5.98	1.76

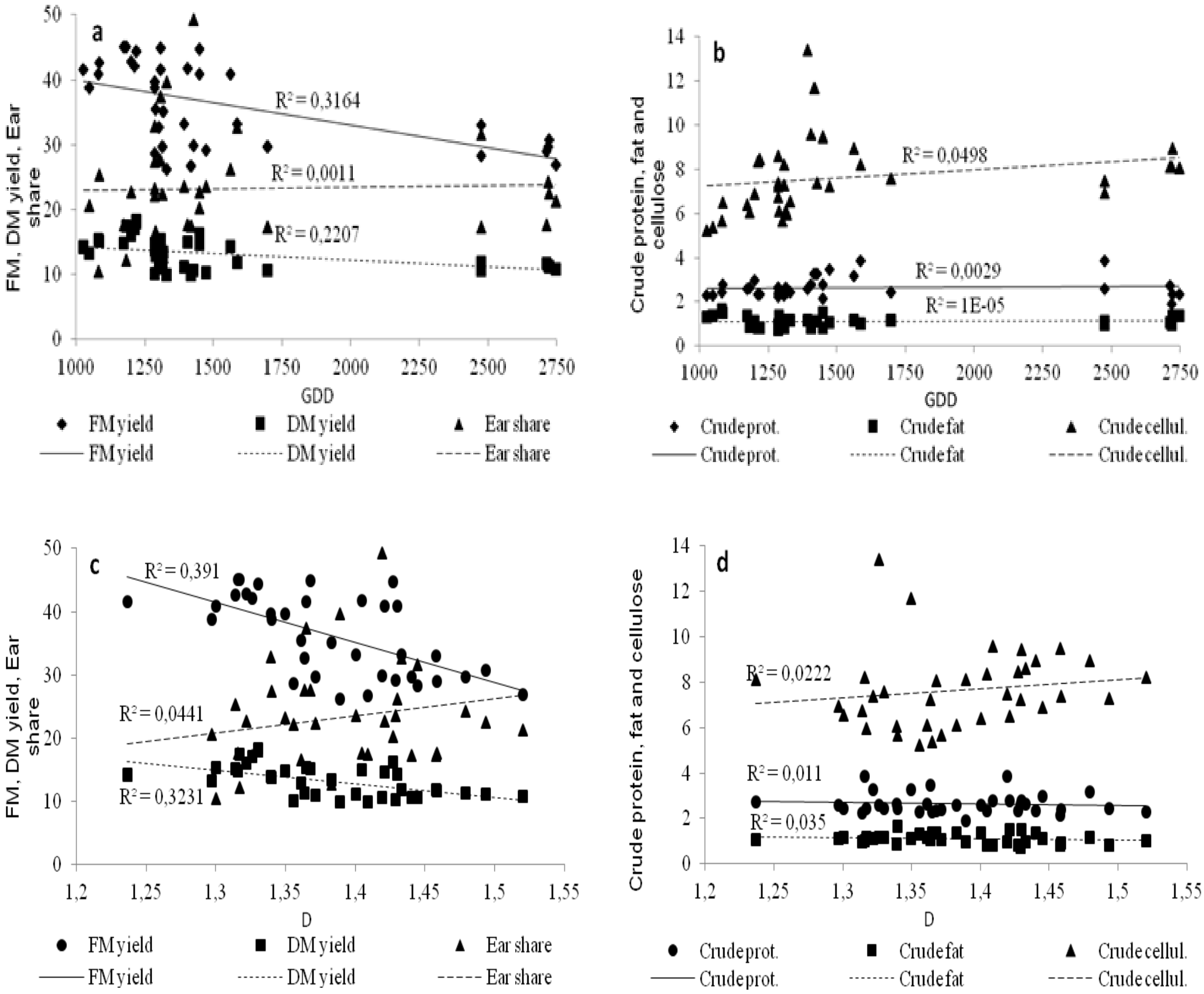

Figure 1. Regression interdependence between growth degree days (GDD) and biomass yield, dry matter yield, ear share (a); content of crude protein, fat and cellulose (b); fractal coefficient and biomass yield, dry matter yield, ear share (c); content of crude protein, fat and cellulose (d) on alluvium soil

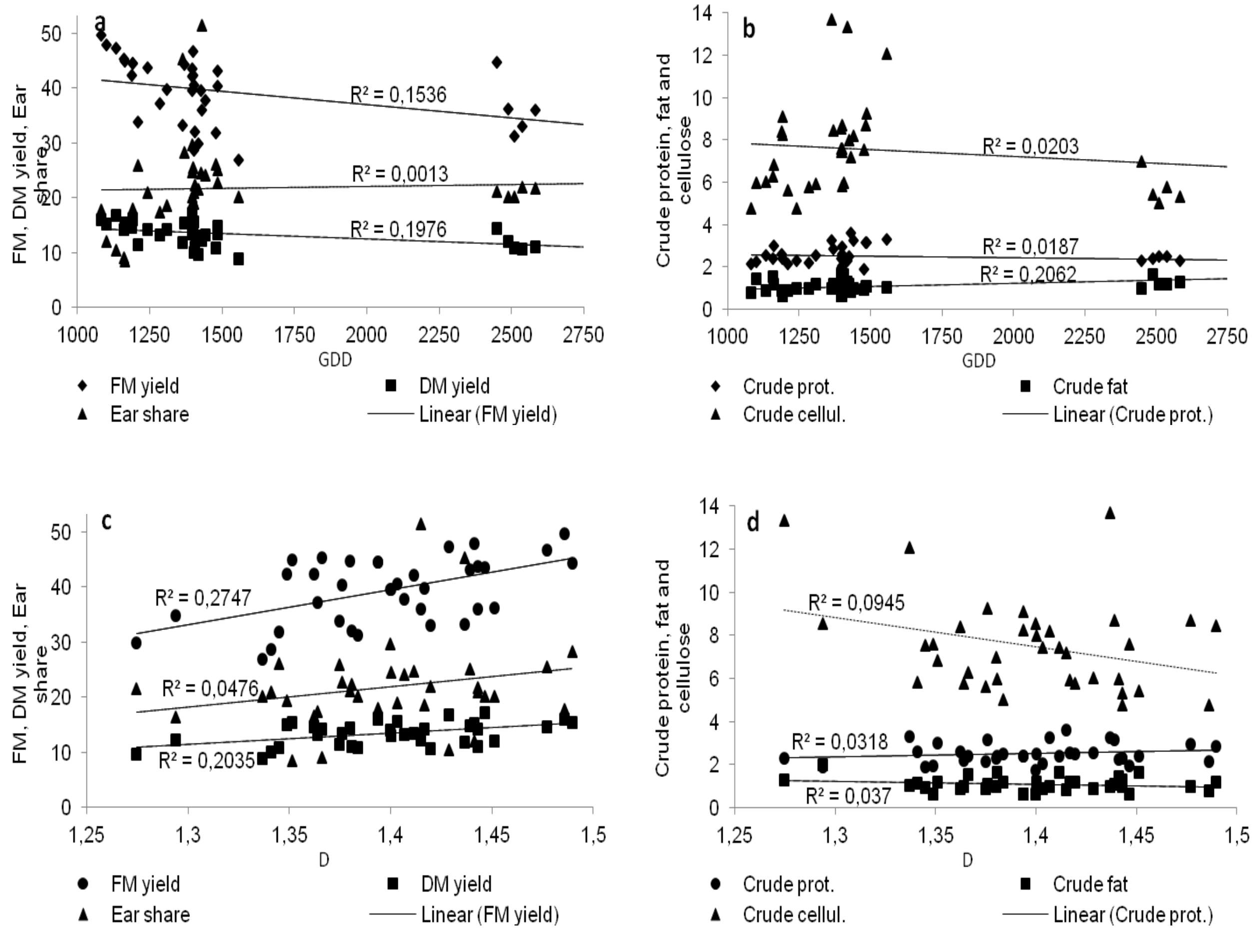

Figure 2. Regression interdependence between growth degree days (GDD) and biomass yield, dry matter yield, ear share (a); content of crude protein, fat and cellulose (b); fractal coefficient and biomass yield, dry matter yield, ear share (c); content of crude protein, fat and cellulose (d) on hydromorphous black soil

The synchronization in the FM and DM accumulation is well known: Cusicanqui and Lauer (1999) determined an increase in the FM and DM production by increasing the plant density. However, a low plant density increases the leaf and stem FM but it decreases the ear FM (Ramezani et al., 2011), which is similar to the results obtained in the present study (Table 1), with about 2.2% higher average ear percentage achieved on alluvium. Relative to the positive impact of plant densities, the D coefficient has a significant influence on the DM yield, higher than on the FM yield (Figures 1c and 2c). Temperature is a presumable factor for DM accumulation, and a key point for determining the moment of forage harvesting (Fairey, 1983; Darby and Lauer, 2002); hence, the crop with a higher density could always be harvested later.

Whereas a late harvest could increase both the DM and cellulose content (Firdous and Gilani, 1999), no significant correlation between GDD and cellulose was found in the present study. A positive impact of the D coefficient on cellulose accumulation was observed on alluvium (Figure 1d). Ayub et al. (1999) also recorded a positive influence of increasing plant density on the crude cellulose content.

The quality parameters, reflected through the crude protein, fat and ash content (Table 2), varied insignificantly among the soil types, densities and hybrids, similarly to the results obtained by Budakli Carpici et al. (2010). On the other hand, GDD and the D coefficient, as environmental factors, significantly influenced the quality parameters (Figures 1b, 1d, 2b and 2d). The significance of the D coefficient was reflected through an increase in the crude protein and a decrease of the fat accumulation (Table 2), by increasing of crop density, akin to results of Cusicanqui and Lauer (1999) and Ahmad et al. (2008). The observed dependences between GDD and quality parameters (Figures 1 and 2) on hydromorphous black soil indicates its greater influence on heavier soils, in relation to the D coefficient, which influenced quality parameters to a greater extent on alluvium.

Table 2. The influence different soil types and plant density on crude protein, fat cellulose and ash content and nutritive units of maize silage

	Plant density	Crude protein (%)	Fat (%)	Cellulose (%)	Ash (%)
H1					
Aluvium	68,000	2.63	0.93	7.35	1.57
	70,000	2.90	1.12	6.87	1.41
	72,000	2.82	1.07	9.06	1.42
	74,000	3.42	1.08	7.55	1.48
	Mean	2.94	1.05	7.71	1.47
Hydromorp. black soil	68,000	2.85	1.01	7.66	1.34
	70,000	2.51	1.26	6.80	1.27
	72,000	2.13	0.93	6.18	1.35
	74,000	3.02	0.74	7.72	1.56
	Mean	2.63	0.98	7.09	1.38
LSD 0.05 (density)		1.89	1.47	0.27	0.09
LSD 0.05 (soil)		2.42	0.52	1.78	0.28
H2					
Aluvium	68,000	2.70	0.89	7.69	1.30
	70,000	2.42	1.13	6.58	1.37
	72,000	2.51	1.16	6.95	1.38
	74,000	2.48	1.05	8.82	1.36
	Mean	2.53	1.06	7.51	1.35
Hydromorp. black soil	68,000	1.80	1.34	8.56	1.11
	70,000	2.53	1.02	7.41	1.32
	72,000	2.34	0.98	8.83	1.17
	74,000	2.61	1.00	7.83	1.39
	Mean	2.32	1.08	8.16	1.25
LSD 0.05 (density)		0.30	0.08	0.92	0.1
LSD 0.05 (soil)		1.94	0.09	2.00	0.40
H3					
Aluvium	68,000	3.15	1.17	8.95	1.76
	70,000	2.39	1.38	6.76	1.34
	72,000	2.58	1.22	8.12	1.35
	74,000	2.28	1.00	8.43	1.40
	Mean	2.60	1.19	8.07	1.46
Hydromorp. black soil	68,000	3.06	1.15	7.77	1.67
	70,000	2.49	1.30	5.71	1.30
	72,000	2.54	1.28	6.75	1.37
	74,000	2.22	0.92	7.79	1.43
	Mean	2.57	1.16	7.00	1.44
LSD 0.05 (density)		0.09	0.22	2.98	0.46
LSD 0.05 (soil)		0.17	0.13	4.09	0.05

CONCLUSIONS

Higher forage yields (FM, DM and ear percentage) could always be obtained by cropping at higher plant densities (74,000 plants ha^{-1}) on hydromorphous black soil. However, on alluvium, 68,000 plants ha^{-1} is advantageous, according to the lower level of cellulose in the forage. The higher crop density could always be harvested later, according to the relation between GDD, D and DM, with the risk that the extended vegetation could induce biomass losses. Higher values of the quality parameters could be achieved to a greater extent at lower temperatures and by increasing the plant density on hydromorphous black soil and at lower densities on alluvium. Generally, a lower density with earlier harvesting (lower than GDD of 1,600) could be applied on alluvium (light soil), while a high plant density and a longer vegetation period (GDD of about 1,600) could be applied on hydromorphous black soil (heavy soil).

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