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Corn plant arrangement and its effect on silage quality

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ABSTRACT - This experiment was carried out to evaluate the effects of the row spacing between corn plants on silage quality. Different spacing between corn rows (40, 60, and 80 cm) was used, but the population of plants was maintained around 65,000/ha in all treatments. Analysis of variance was carried out and means were compared by Tukey's test at 5% of probability. A reduction in row spacing provided better spatial distribution of plants, but did not alter morphological composition or dry matter production. The corn with most equidistant spatial distribution (lowest row spacing) showed an increase in lignin concentration, neutral detergent fiber, and total carbohydrates, and showed a decrease in total digestible nutrients when compared with 80 cm row spacing. However, the organic digestibility matter was not affected by the treatments. The content and quality of protein were higher for 80 cm row spacing compared with the other levels; also, protein content was reduced as the spacing between rows became smaller. The only mineral affected was calcium, which had the lowest value at higher levels of spacing. Although differences were detected for many variables, the most appropriate spacing between rows should also take into account economic and practical aspects when choosing the best plant arrangement.

Key Words: carbohydrate fractionation, nutritional value, protein fractionation, row spacing

Introduction

Genetic advances in selection of corn genotypes with a higher yield potential, shorter cycle, and better architecture have required new studies on plant arrangements. Some studies have demonstrated the possibility of higher grain and forage yield with changes in row spacing and plant density (Argenta et al., 2001; Cox and Cherney, 2001; Cox et al., 2006). This response has been attributed to the higher efficiency of solar radiation interception when adequate plant arrangements are used (Argenta et al., 2001).

The most appropriate arrangement can be obtained by modifications in the distribution of plants between rows and between plants within the row. When plants have a more uniform distribution, the competition between them for water, light, and nutrients is reduced. Narrow rows allow plants to occupy the available space more quickly, reducing the critical period when weed species and corn plant compete for nutrients and light (Balbinot Junior and Fleck, 2004). Although a large number of studies can be found relating to the effect of plant arrangement on forage and grain yield, few studies have evaluated the changes in chemical composition of silages in relation to plant arrangement.

Therefore, the objective of this work was to test the effect of the arrangement of plants on corn silage quality. The hypothesis tested was that plants that are more equidistantly distributed produce more forage per area and with better nutritional composition as a result of lower competition for nutrients and light between plants.

Material and Methods

The experiment was conducted at the experimental station of the Department of Soil Science, Universidade Federal de Santa Maria (UFSM), Brazil. The site is physiographically located in the Central Depression of Rio Grande do Sul state, at an elevation of 95 m, 29º 43' south latitude, and 53º 42' west longitude. The soil is classified as Paleaudalf soil (Embrapa, 2006). The climate is Cfa (humid subtropical), according to Köppen classification, with average annual rainfall of 1769 mm, mean annual temperature of 19.2 ºC, with an average minimum of 9.3 ºC in July and an average maximum of 24.7 °C in January; 2212 hours of annual sunshine; and relative humidity of 82% (Moreno, 1961).

The establishment of the experiment was over tillage, succeeding native pasture. The type of hybrid used was

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simple modified (DOW 766), with a short cycle and dual purpose (grain and silage). For the soil analysis, the first 10 cm of top soil were collected, displaying the following characteristics: texture = 4; pH-H_2O = 5.5; pH-SMP = 6.2; P_2O_5 = 4.8 ppm; K_2O = 22.0 ppm; organic matter = 1.5%; exchangeable aluminum = 0, and base saturation = 67%. Fertilization consisted of 400 kg of a 5-20-20 NPK formula, as recommended by Comissão de Fertilidade do Solo RS/SC (2004).

The culture was grown in 5 m long plots with four rows in different spaces. The treatments were separated by 40, 60, and 80 cm spaces between rows. The plots were sown in mid-December, with emergence occurring 6 days after planting. After 7 and 21 days of plant emergence, manual weed control and selection of plants were carried out to obtain a stand population of around 65,000 plants per hectare. This population provided a distance of 37.0, 25.0, and 19.0 cm between lines and 40, 60, and 80 cm between rows. Nitrogen fertilization was performed when the plants had about 5–6, 7–8, and 10–12 fully expanded leaves, with the use of 70 kg/ha N for each application. Insecticide was applied 14 and 29 days after emergence.

Plants were harvested 93 days after emergence, at 20.0 cm above the soil, using the two central rows of the plots. Of these, 15 representative plants were collected to assess height, ear insertion, and stem circumference. The stem circumference was measured just above the second node, with a caliper rule. The plant height and ear insertion height were obtained by considering, respectively, the distance of the stem of each plant to the apex of the tassel and to the point of first ear formed, using a measuring tape graduated in centimeters. Components (stem, dead leaf, green leaf, grain, cob, and ear husks) were separated manually. Plant components and another sample with three plants were chopped and packed in paper bags to be dried in an oven with forced air at 55 °C for 72 hours.

The remainder of the forage of central rows of the plots was chopped into particles of two centimeter average size and ensiled in mini silos (60 × 10 cm) of polyvinyl chloride (PVC), which were opened 50 days after ensiling and analyzed at Núcleo Integrado de Desenvolvimento de Análises Laboratoriais (NIDAL), of Universidade Federal de Santa Maria (UFSM), Brazil.

Three fresh samples were taken from each silo. One sample was used to determine pH values (digital potentiometer-Digimed). Another sample was subjected to effluent extraction with a hydraulic press for ammonia ($N-NH_3$) determination, by distillation with magnesium oxide (Bremmer and Keeney, 1965).

The other fresh silage sample, approximately 500 g, was dried in an oven with forced air ventilation at 55 °C for 72 hours and ground in a Wiley mill with sieve screen of 1 millimeter in size. This was used to determine dry matter (DM) by drying at 105 °C for 12 hours (Easley et al., 1965), organic matter by burning in an oven at 550 °C (AOAC, 1975), nitrogen content (N) by the Kjeldahl method (AOAC, 1975), and ether extract (EE) in a Soxhlet extractor with petroleum ether. The fiber analysis was performed according to Van Soest et al. (1991), including acid detergent fiber (ADF) excluding the ash content and neutral detergent fiber (NDF) without the use of amylase. The *in vitro* organic matter digestibility (IVOMD) was analyzed following the protocol of Tilley and Terry (1963).

The non-fibrous carbohydrates (NFC) and total digestible nutrients (TDN) were estimated according to the NRC (2001) by the following equations: NFC (%) = 100 – (CP + Ash + NDF + EE) and $TDN_{1x} = NFC_{td} + CP_{td} + (EE - 1) \times 2.25 + NDF_{td} - 7$, in which TDN_{1x}(%) = total digestible nutrients for one-time maintenance requirements; NFC_{td} = truly digestible NFC; CP_{td} = truly digestible crude protein; NDF_{td} = truly digestible NDF; and the constant “7” refers to the discount of metabolic fecal constituents.

Protein fractionation was performed by determining the fractions of non-protein nitrogen (NPN), soluble nitrogen (SN), neutral detergent in soluble nitrogen (NDIN), and acid detergent in soluble nitrogen (ADIN), according to Licitra et al. (1996), and used in the fractionation as follows: A (NPN), B_1 (SN-NPN), B_2 (100-A-B_1-B_3-C), B_3 (NDIN-ADIN), and C (ADIN). The total carbohydrates (TC) were calculated by summing the NFC and NDF. The fractionation of carbohydrates was performed by determination of organic acids (OA), soluble sugar (SS), starch, soluble fiber (SF), hemicellulose (HEM), cellulose (CEL), and acid detergent lignin (ADL) according to the methodology proposed by Hall (2000), and were grouped into fractions: A (OA+SS), B_1 (starch+SF), B_2 (HEM+CEL), and C (ADL).

Mineral fractions were determined by a nitro-perchloric digestion of organic matter as recommended by Tedesco et al. (1995). Calcium (Ca) and magnesium (Mg) were quantified by atomic absorption; phosphorus (P) by visible spectrophotometry; and sodium (Na) and potassium (K) by flame photometry.

The experimental design was set in randomized blocks with three treatments and four replications, in which the experimental unit was the plot. The experimental data were analyzed by analysis of variance (ANOVA) and Tukey’s test at 5% of probability, using the Statistical Analysis System (SAS, version 8.02).

Results and Discussion

The corn plants grown in different spatial arrangements produced on average 15.70 kg/ha DM, with no significant difference between treatments. The morphological characteristics of the plants were not affected by different arrangements (Table 1). Also, no differences in fermentation parameters (DM, pH and N-NH_3) were detected ($P>0.05$; Table 2).

The morphological composition of the corn plant can define the quality of silage. Plants that have a major production of grain can combine high yield with high nutritional value. Reducing row spacing is a way to increase the proportion of grain in the silage and DM yield (Roth, 1996; Cox et al., 1998; Cox et al., 2006). On the other hand, some small plot experiments (Cox and Cherney, 2001; Beres et al., 2008) and field-scale studies (Cox and Cherney, 2002) have failed to demonstrate consistent yield advantages of narrow-row corn silage, suggesting that in some situations the competition for nutrients and light may not occur at levels that are sufficient to reduce crop yield.

According to Argenta et al. (2001), the increased productivity by reducing the spacing between rows is attributed to greater efficiency in radiation interception and decreased competition for light, water, and nutrients between plants in the row, due to their more equidistant distribution. However, this is dependent on various characteristics such as hybrid/variety, density of plants, and water and nutrients in the soil, with more pronounced differences when the plants suffer from higher stress (Barbieri et al., 2000).

In the present experiment, the competition between plants was probably very low, as parameters such as plant height, stem circumference, and ear height were not affected ($P>0.05$) by treatments. This suggests that the lack of differences in this experiment and others may be explained by low competition between plants. For this reason, protocols for this kind of experiment should be tested in extreme stress conditions for specific requirements of crop production (e.g., nitrogen, plant density, water deficit).

As differences in DM and grain proportion were not detected, a lack of differences in fermentation parameters could be expected. On the other hand, the small increase in DM (2%) for a smaller space between rows is in accordance with Cox et al. (2006) and Widdicombe and Thelen (2002), suggesting faster DM accumulation and the possibility of anticipating harvest in 3–4 days.

Narrow row spacing reduced CP ($P<0.05$) content in silage, with the lowest CP content (5.4% of DM) for 40 cm row space (Table 3). This effect can be partly attributed to the higher TC content ($P<0.05$), as there was a higher carbon/nitrogen ratio for this treatment. This shows the changes in plant physiology and synthesis of compounds.

Also, CP fractions A, B_1, and B_2 were affected ($P<0.05$) by treatments (Table 3). Fraction B_1 was negatively related to the reduction of space between plant rows, showing the lowest value (6.4% of CP) at 40 cm, while the same treatment showed the highest levels for fractions A and B_2. However, the B fraction (B_1+B_2+B_3) showed no significant difference between 40 and 60 cm row spacing, with 43.8 and 42.5% contents, respectively. In vegetal metabolic routes, true

Table 1 - Yield and morphological characteristics of corn plants grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Plants/hectare	64,375	65,384	65,312	65,164	6.14
Yield (kg/ha of DM)	14,834	16,853	15,398	15,695	13.0
Height (m)	2.0	2.2	2.1	2.1	6.28
Ear height (m)	1.2	1.3	1.2	1.2	9.58
Stem circumference (cm)	6.7	6.9	6.7	6.8	3.82
Dry leaf (% DM)	4.5	4.1	3.9	4.2	37.1
Green leaf (% DM)	19.5	20.4	21.0	20.3	11.9
Total leaf (% DM)	24.0	24.5	24.9	24.5	12.4
Stem (% DM)	27.0	29.2	27.3	27.8	13.6
Grain (% DM)	24.4	22.4	24.1	23.7	35.4
Cob (% DM)	10.1	9.4	9.7	9.7	6.5
Ear husks (% DM)	14.4	14.4	14.0	14.3	18.55
Ear (% DM)	49.0	46.2	47.8	47.7	13.8

CV - coefficient of variation.

Table 2 - Fermentation characteristics of corn plants grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Dry matter (%)	41.8	41.0	39.8	40.9	3.8
Ammonium (N-NH_3/% TN)	2.2	2.4	2.7	2.4	14.2
pH	3.5	3.5	3.5	3.5	0.8

CV - coefficient of variation; TN - total nitrogen.

protein synthesis begins with non-protein nitrogen (NPN) and is dependent on ATP and soluble carbohydrates. Phosphorus is necessary for ATP synthesis. However, no significant difference was observed for the values of P and SS. Another hypothesis is that the ATP required for amino acid synthesis had been used for cell wall formation, especially lignin.

A higher CP value and superior protein quality were observed in the 80 cm treatment. This row spacing had lower NPN and higher values for B fractions (B_1+B_2+B_3) (51.1%). These differences may have occurred through better silage protein use for microorganism growth, due to better synchronism between protein and carbohydrate degradation, as evidenced by higher OA contents (P<0.05) at 80 cm. These CP values have an advantage in the rumen microorganism metabolic route, when a carbonated chain is available as an energy source after deamination occurs. This is especially interesting for feedlot ruminants receiving high urea levels in diets.

According to Barbieri et al. (2008), a reduction in the spacing from 70 to 35 cm increases N availability and the efficiency of its use by plants. Shapiro and Wortmann (2006) argue that regardless of the plant population, reducing spacing from 76 to 51 cm results in higher N uptake and usually in higher plant nitrogen. However, little attention has been dedicated to the quality of this protein, which is related to plant and animal N metabolism.

Protein fractions can be separated into A, B_1, B_2, B_3, and C according to the Cornell Net and Carbohydrate Systems (CNCPS), to better represent the protein quality of feedstuffs. Fraction A consists of NPN, with high degradability; fraction B represents true protein, and is stratified into B_1, B_2, and B_3, with a decreasing rate of degradability from the first to last. According to Sniffen et al. (1992), fractions B_1 and B_2 present rapid rates of ruminal degradation compared with B_3, and tend to be extensively degraded in the rumen. Fraction C is characterized as indigestible along the gastrointestinal tract because it is complexed with the lignin in the cell wall.

For the carbohydrate fractions, differences (P<0.05) were detected only for the A an C fractions. For the A fraction, differences occurred due to the higher (P<0.05) amount of OA in the largest row space (80 cm; Table 4). Conversely, this spacing had the lowest (P<0.05) content of C fraction, which is composed of lignin. This suggests that the plants with less space between rows were more structurally affected than those plants that were closer within rows. Nevertheless, in the present experiment, the higher need for structural components cannot be attributed to greater plant height or thinner stem circumference. More plant deposition of lignin (the C fraction) has been attributed to higher needs for structure by the plant due to growth (Van Soest, 1994).

Table 3 - Protein fractions of corn silage grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Crude protein	5.4b	7.0a	6.8a	6.4	8.4
Fraction A	52.0a	53.0a	45.2b	50.1	6.1
Fraction B_1	6.4c	13.7b	20.0a	13.4	18.4
Fraction B_2	29.4a	20.8b	22.9b	24.3	12.3
Fraction B_3	8.0	8.0	8.2	8.1	10.1
Fraction C	4.1	4.5	3.7	4.1	14.4

Values expressed as a percentage of crude protein.
Means in the same row followed by different letters differ by Tukey's test (P<0.05).
CV - coefficient of variation.

Table 4 - Carbohydrate fractions of corn silage grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Fraction A	12.0ab	11.4b	14.1a	12.5	8.8
Soluble sugar	3.8	3.8	4.1	3.9	13.9
Organic acids	8.2b	7.6b	10.0a	8.6	10.7
Fraction B_1	22.7	22.8	22.8	22.8	10.5
Starch	16.4	17.0	15.5	16.3	7.1
Soluble fiber	6.3	7.7	7.4	7.1	25.4
Fraction B_2	53.3	51.1	50.0	51.4	4.3
Hemicellulose	28.5	25.8	25.7	26.7	6.1
Cellulose	24.8	25.3	24.2	24.8	5.5
Fraction C	3.6a	2.7b	2.3b	2.9	10.0
Non fiber carbohydrates	34.7	36.1	37.0	35.3	3.5
Total carbohydrates	91.6a	89.9ab	89.0b	90.1	0.86

Values expressed as a percentage of dry matter.
Means in the same row followed by different letters differ by Tukey's test (P<0.05).
CV - coefficient of variation.

Similar to the protein fractions, the total carbohydrates are classified into A, B_1, B_2, and C fractions. Fraction A is composed mainly of SS and OA, which are readily fermentable in the rumen. The OA are residues of anaerobic bacteria fermentation that takes place inside the silo, and are dependent on carbohydrates such as sugars. Higher OA levels (P<0.05) were found for greater spaces between rows, suggesting a higher potential for accumulation of sugar and utilization by the microorganisms responsible for silage fermentation. This can result in faster and better conservation of silage. However, these differences were not great enough to be detected by the fermentation parameters tested (pH and N-NH_3).

The TC value was higher for 40 cm row spacing than the other levels of row spacing (Table 4). This effect was due the increase in the NDF content (P<0.05). Total carbohydrates increased due to an increase in SS, which can be indicative of higher efficiency of solar radiation use or other factors related to plant physiology.

The total digestible nutrient content ranged between 66.2 and 69.9%, with the lowest value for 40 cm row spacing. Furthermore, higher levels of NDF were detected for this treatment (Table 5). The TDN content was affected by NDFacp and CP values, which are used in the calculations. The NDF was directly affected by higher carbohydrate C fraction considering that B_2 fractions, which comprehend the major components of NDF (hemicelluloses and cellulose), were not accompanied by differences between treatments.

In vitro organic matter digestibility values were not affected by treatments (Table 5). The TDN and NDFacp levels were not sufficient to reduce IVOMD. Likewise, despite the higher proportion of lignin in the cell wall for 40 cm row spacing (Table 4), the difference was not great enough to reduce the IVOMD of these materials. Since the C fraction is composed of lignin, higher amounts of this fraction should limit total forage digestibility or NDF digestibility.

Scientific publications have demonstrated differences in the composition of silages using reduced spacing. According to Iptas and Acar (2006), reduced spacing reduced the quality of silage due to higher NDF and lower NDF digestibility. According to Beres et al. (2008), NDF and ADF increased by 4%, while the starch content was 12% lower with reduced row spacing (35 cm). However, Cox et al. (2006) and Widdicombe and Thelen (2002) did not observe differences in silage quality with narrow row spacing. On the other hand, Cox and Cherney (2001) observed that the NDF digestibility was higher by 0.8% when row spacing was reduced to 38 cm; the authors commented that the difference would be sufficient to increase estimated milk production by 6.0%.

There was no effect (P>0.05) of treatment on ash content (Table 6). Calcium was the only mineral affected (P<0.05) by treatments, with the highest content (0.39%) in silage made from corn plants grown at 40 cm row spacing. The most abundant mineral in the silages was K (Table 6).

The results for mineral composition confirm that there is high exportation of soil K by the ensilage process, due to the complete removal of the plants that have a high concentration of this nutrient in their tissues. In this study, multiplying the K and the productivity of corn plants, it can be seen that the average exportation of K was around

Table 5 - Nutritional value of corn silage grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Ether extract	2.0	2.2	2.1	2.1	13.4
NDFacp	55.0a	51.6b	50.8b	52.4	4.7
ADF	28.4	28.0	26.5	27.6	5.5
IVOMD	65.9	62.5	62.2	63.5	6.2
TDN	66.2b	68.9a	69.9a	68.3	1.9

Values expressed as a percentage of dry matter.
Means in the same row followed by different letters differ by Tukey's test (P<0.05).
NDFacp - neutral detergent fiber corrected for ash and crude protein; ADF - acid detergent fiber; IVOMD - *in vitro* organic matter digestibility; TDN - total digestible nutrients; CV - coefficient of variation.

Table 6 - Mineral composition of corn silage grown in different spatial arrangements

Variables	40 cm	60 cm	80 cm	Mean	CV (%)
Ash	2.9	3.0	3.3	3.1	13.9
Phosphorus	0.16	0.16	0.16	0.16	1.1
Calcium	0.38a	0.25b	0.24b	0.29	5.0
Potassium	0.76	0.67	0.64	0.69	11.2
Magnesium	0.23	0.26	0.27	0.25	13.2

Values expressed as a percentage of dry matter.
Means in the same row followed by different letters differ by Tukey's test (P<0.05).
CV - coefficient of variation.

108 kg/ha. The average content of 0.16% P was similar to those found by Fontaneli et al. (2002) in an evaluation of 246 samples of corn silage. As the mineral concentration in silage is important to meet the requirements of ruminants, the K contents observed are likely to be insufficient to meet the requirements of cows in lactation, while the Ca and P contents are insufficient to meet even the requirements of animals in the maintenance phase (NRC, 2001), requiring supplementation of these nutrients when the diet is mostly composed of corn silage.

Conclusions

The production and morphological composition of corn plants are not affected by plant arrangements. The plant arrangement with 80 cm row spacing has higher protein content and silage protein of superior quality, which are especially important for feedlot animals. Silage quality decreases with narrow row spacing, specifically neutral detergent fiber, total digestible nutrients, and lignin compounds.

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