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Productive characteristics of maize hybrids at different cutting heights for silage and organic matter and mineral rates in post-harvest residues

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ABSTRACT. Current trial evaluated yield, organic matter and mineral composition of the residual harvest of five maize hybrids at three cutting heights (15, 35 and 55 cm). The experimental design consisted of a randomized block split plot with three replications. Concentrations of N, P, K, Ca, MS, MM and MO in the samples were evaluated. No difference among hybrids occurred in stem diameter (22.4 mm), ear production (8.0 ton DM ha^{-1}), grain harvest index (37.3%) and total forage yield (15.0 ton DM ha^{-1}). Hybrid effect occurred for variables of mineral composition of harvest residues. With the exception of calcium, a rise in cutting height from 15 to 55 cm failed to increase the concentration of minerals in the residue. The amount of organic matter and mineral residues that remained in the field increased in proportion to crop height.

Keywords: nutrients, recycling, corn silage.

Características produtivas de híbridos de milho em diferentes alturas de corte para silagem e teor de matéria orgânica e minerais no resíduo após a colheita

RESUMO. O objetivo do estudo foi avaliar características produtivas e os teores de matéria orgânica e composição mineral do resíduo remanescente da colheita de híbridos de milho em três alturas. Cinco híbridos de milho foram avaliados em três alturas de corte (15, 35 e 55 cm). O delineamento experimental foi em blocos casualizados com parcelas subdivididas e três repetições. Nas amostras foram determinadas as concentrações de N, P, K, Ca, MS, MM e MO. O diâmetro do colmo (22,4 mm), produção de espigas (8,0 t MS ha^{-1}), índice de colheita de grãos (37,3%), e produtividade total de forragem (15,0 t MS ha^{-1}) não diferiram entre híbridos. Houve efeito de híbrido para as variáveis de composição mineral do resíduo remanescente da colheita. Com exceção do cálcio, a elevação da altura de colheita de 15 para 55 cm não aumenta a concentração dos minerais no resíduo. A quantidade de matéria orgânica e mineral de resíduo que permanece na lavoura aumenta com a elevação da altura de colheita.

Palavras-chave: nutrientes, reciclagem, silagem de milho.

Introduction

Owing to its quality and productivity, corn silage is a widely used option for animal feeding where the crop is adapted to the climate. An alternative for high quality corn silage would be to increase the cutting height while leaving part of the stem and old leaves, or rather, the less digestible fractions, in the field. According to review by Wu and Roth (2005), an increase in harvest height from 15 to 45 cm triggered a reduction in dry matter production (7.3%), increase in milk production per ton of silage (4.9%) and reduction in milk production per hectare (1.8%). Furthermore, cutting height increased the quantity of residues in the field, with benefits for nutrient recycling. Lauer (2002) studied the relationship between corn-harvest height, post-harvest residue and soil cover percentage and reported that, on average, for every 15 cm of increase in harvest height there was an increase of 1.3 tons of dry matter (DM) that remained in the field. DM increased the soil cover percentage from 13 to 55%. Further, according to Lauer (2002), residue production was influenced by plant population, hybrid, production level and soil cover and also by factors including space, orientation and residue distribution. Grande et al. (2005 a and b) found that greater quantities of residues from high corn harvesting for silage, associated with manure application, substantially reduced sediment and phosphorus losses in erosion-susceptible soils.

Current trial evaluated the effect of different cutting height son the productivity and mineral composition of residues (stems and remaining leaves) from five corn hybrids harvested at three heights.

Material and methods

The field experiment was carried out at the State University of Maringá in the northwestern region of the state of Paraná, Brazil (23º21'13"S - 52º04'27"O; 550 m altitude). The climate is Cfa (wet subtropical), according to Köppen's classification. The plots were established in soil classified as sandy dystrophic red latisol. Soil analysis indicated pH $CaCl_2$: 4.4; pH water: 5.3; P 0.6 mg dm^{-3} (Mehlich 1); C 3.87 g dm^{-3}; K^+0.07 $cmol_c$ dm^{-3}; Al^{3+}0.5 $cmol_c$ dm^{-3}; Ca^{2+}0.86 mol_c dm^{-3}; Mg^{2+}0.19 $cmol_c$ dm^{-3}; s sum of bases 1.12 $cmol_c$ dm^{-3}; CTC 4.29 $cmol_c$ dm^{-3}; V% 26.11. In conventional harrow tillage, the experimental area received 2 ton ha^{-1} of dolomite limestone. During planting, 530 kg ha^{-1} of fertilizer, formula 4-20-20 (N-P_2O_5-K_2O), were applied and plants were mulched with 200 kg ha^{-1} urea 30 days after emergence. Besides, 4 L ha^{-1} of herbicide, with active ingredient atrazine (370 g L^{-1}) and metolachlor herbicide (290 g L^{-1}) were used, and 250 mL ha^{-1} of insecticide with the active ingredient Lefenurom (50 g L^{-1}) were applied against an infestation of *Spodoptera frugiperda*. Accumulated rainfall from planting to harvest period reached 596 mm. Average air temperature was 25°C and mean relative air humidity was 71%.

Five hybrid corn cultivars (Table 1) were assessed at three cutting heights (15, 35 and 55 cm). A randomized block design was used with split plots and three replications. The hybrids were planted on the 23rd October 2007 in the main plots (2.100 m²) with 0.90 m between-row spacing and 70,000 plants has^{-1} owing ha^{-1} density. The harvest heights were allocated to the split plots (700 m²). Three side rows and 5 m of the ends of the main plot formed the border and were used as sampling area to determine harvest time.

Table 1. Genotype characteristics of the corn hybrids[1].

Corn hybrids[2]	Hybrid type	Cycle	Days-degree[3]	Purpose[4]	Grain texture
AS 32	Hybrid double	Precocious	870	DP	Flint
AG 9090	Hybrid simple	Precocious	830	DP	Dent
CD 308	Hybrid double	Precocious	800	DP	Flint
P 30F87	Hybrid triple	Precocious	….	G	Flint
DKB 747	Hybrid double	Precocious	845	DP	Flint

[1]Source: corn cultivar registry at the Ministry of Agriculture, Livestock and Supply -MAPA. [2]AS 32: Agroeste S/A Monsanto (Xanxerê, Santa Catarina State, Brazil, CP 185); AG 9090: AgroceresBiomatrix Monsanto (Rio ClaroSP Brazil); CD 308: Coodetec – Central Cooperative for Agricultural Research (Cooperativa Central de PesquisaAgrícola) (Cascavel, Paraná State, Brazil CP 301); P 30F87: Pioneer Hi-Bred DuPont (Iowa, USA); DKB 747: DeKalb S/A Monsanto (Illinois, USA). [3]heat sum until male flowering. [4]DP = dual purpose (grain and silage production); G = grain production.

The milk line was used as a visual indicator of the harvest time that occurred at the half milk line stage or at about 34% DM. Agronomic characteristics such as plant height, ear insertion height and stem diameter were measured before cutting by the random sampling of 20 plants per plot. AS 32, AG 9090, CD 308, DKB 747 and P 30 F87 hybrids were cut on the 25, 26, 30th and 31st January and 1st February 2007, respectively. Five one-linear meter random samples were taken in the split plots. The plants were cut manually at the pre-established cutting height, using a measuring stick. The corresponding residues (remaining stems and leaves) were cut at soil level. The samples were grouped and identified to determine forage and residue yields. After weighing, the forage and residue yields were chopped by a stationary chopper and samples were dried at 55°C for 72 hours in a forced air chamber.

The concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), dry matter (DM), ashes (A) and organic matter (OM) were determined for all samples. The grain-cutting index was defined as the proportion of DM grain DM in total DM. DM was determined in a chamber at 105°C for 12 hours and the ash content calculated by burning samples at 550°C for four hours (AOAC, 1990). OM was obtained by the difference (OM (%) = 100 - A), following AOAC (1984). N content was measured by the micro-Kjeldahl method (AOAC, 1990). The mineral constituents, phosphorus, potassium and calcium, were determined according to methodology by Malavolta et al. (1997).

Prior to the statistical analyses, the variables were tested for normality of variance by the Shapiro-Wilk test. Data exploratory analyses showed that all variables presented normal distribution ($p < 0.01$). Data was submitted to analysis of variance by GLM procedures of SAS® statistical program (SAS Institute, 1999). Differences among means were compared by Tukey's test, significant at $p < 0.05$. The mathematical model included the effects of treatment, block, cutting height, and experimental error:

$$Yijk = \mu + ti + bj + eij + sk + tsik + eijk,$$

where:

Y_{ijk} = all dependent variables; μ = mean of observations; t_i= effects of the i-eth corn hybrid; b_j = effect of j-eth block; e_{ij} = random residual variation of hybrid and block (error a); s_k = effect of k-eth cutting height; ts_{ik} = interaction between hybrid and cutting height; e_{ijk} = random residual variation (error b).

Results and discussion

Mean plant height (217 cm) was similar among the hybrids. Only AG 9090 and DKB 747 hybrids were different ($p < 0.05$) when compared to CD 308 (Table 2).

Table 2. Agronomic and productive characteristics of corn hybrids.

Variables	Hybrids[2]					Mean	CV[3]
	AS 32	AG 9090	CD 308	P 30F87	DKB 747		
Plant height (cm)	218[ab]	222[a]	197[b]	219[ab]	232[a]	217	3.9
Ear insertion height (cm)	109[ab]	101[ab]	94[b]	109[ab]	124[a]	107	8.2
Stem diameter (mm)	23.7	24.6	21.2	21.8	20.7	22.4	7.9
Plant population (plants m^{-2})	72.8[c]	81.4[ab]	80.2[abc]	87.9[a]	79.5[bc]	80.3	3.8
Forage productivity (ton ha^{-1})	56.0	55.9	52.0	52.8	51.0	53.6	6.0
Forage productivity (ton DM ha^{-1})	15.6	15.4	14.1	14.9	15.0	15.0	8.2
Ear productivity (ton DM ha^{-1})	8.6	8.5	7.2	7.5	8.1	8.0	9.6
Grain harvest index[4] (%)	32.7	37.2	38.8	38.5	39.5	37.3	11.3

[1]For this data set, the statistical model does not contemplate the harvest height effect. [2]See hybrid details in Table 1. [3]Coefficient of variation (%). [4](Grain production / total forage production) x 100. a, b and c. Means with different letters on the line indicate significant difference by Tukey's test at 5%.

Similar performance was reported for ear insertion height (107 cm) with significant difference ($p < 0.05$) only for CD 308 when compared to DKB 747. The highest cutting height ($p < 0.05$) was registered in DKB 747 and the shortest in CD 308, with 232 and 197 cm, respectively (124 and 94 cm ear insertion height). These results were close to those reported by Jaremtchuk et al. (2006), with 184 cm plant height and 99 cm ear insertion height for corn hybrids.

Failures during planting caused difference in the plant population (Table 2), with significant difference ($p < 0.05$) in hybrid AS 32 (72.8 plants m^{-2}), when compared to the hybrid P30F87 (87.9 plants m^{-2}). However, the stem diameter (22.4 mm), ear production (8.0 ton DM ha^{-1}), grain harvest index (37.3%) and forage production (15.0 ton DM ha^{-1}) did not differ ($p > 0.05$) among the hybrids. Cusicanqui and Lauer (1999) assessed the influence of plant density and hybrids on corn forage productivity and quality and reported a quadratic response for DM productivity, with plant densities ranging between 44,500 and 104,500 plants ha^{-1}. However, there was no difference in DM or milk yield between 17,000 and 90,000. Average ratio between forage and grain yield was 2.6 tons DM for one ton grain DM, very similar to results by Vasconcellos et al. (1983) where the mean estimate of DM production in the canopy was 14.2 and of 6 ton ha^{-1} for grain (2.5 ton DM corresponded to 1 ton grains). In these studies, the mean values of nutrient extraction by the corn canopy, at maximum accumulation at the end of the crop cycle, were equal to 139, 23 and 120 kg ha^{-1} N, P, and K, respectively.

Table 3 shows the contents of dry matter, organic matter and mineral composition of the post-harvest residue.

Table 3. Dry matter (DM), organic matter (OM) and mineral composition of residue after harvest of corn hybrids harvested at different heights for silage.

Hybrids[1]	DM	OM	N	P	K	Ca
	(%)	(g kg^{-1} DM)				
AS 32	17.95[c]	949[b]	1.351[a]	1.598[b]	23.250[a]	1.908[ab]
AG 9090	18.85[bc]	955[ab]	1.257[ab]	2.319[a]	21.500[a]	2.130[a]
CD 308	20.09[abc]	956[ab]	0.984[c]	1.634[b]	16.874[b]	1.548[b]
P 30F87	21.48[ab]	958[a]	1.014[bc]	1.497[bc]	16.442[b]	1.635[b]
DKB 747	21.99[a]	959[a]	1.060[bc]	1.146[c]	17.503[b]	1.766[ab]
Harvest height[2]						
15	19.58	954	1.090	1.536	18.663	1.598[b]
35	19.66	955	1.156	1.587	19.017	1.857[a]
55	20.99	958	1.155	1.793	19.660	1.938[a]
Means	20.07	956	1.134	1.639	19.113	1.797
CV[3]	9.47	0.54	11.10	17.43	12.40	14.57
Effect[4]	(H)	H. H⋆A	(H)	(H).(H⋆A)	(H). H⋆A	H. A

[1]Values represent mean of different harvest heights of plant. See hybrid details in Table 1. [2]The values represent the mean of the hybrids harvested at different heights (harvest height in cm). [3]Coefficient of variation (%). [4]Probability of significant H effect, H = hybrid, A = harvest height and HxA = hybrid and harvest height interaction, $p \leq 0.05$ or effect between parenthesis, $p \leq 0.001$. [5]Residue dry matter production per hectare (PMSR). [a, b, c]Means with different letters in the column indicate significant difference by Tukey's test at 5%.

There was hybrid x cutting height interaction for OM, P and K contents. This interaction may have occurred because of the different accumulation dynamics and/or nutrient translocation by the hybrid (COORS et al., 1997; DUARTE et al., 2003). The DM contents of the hybrid corn residue after harvest for silage were similar among the hybrids (20%) and no variations were recorded with an increase in cutting height. These results occurred because hybrids were harvested at the same development stage (half milk line stage). However, residue's DM content after harvest was ten percentage units lower than the mean (29.42%) of forage mass at harvest for silage (data not shown).The above difference was sufficient to increase the dry matter content by 2.2% of silage when the cutting height increased from 15 to 55 cm (OLIVEIRA et al., 2011). The above may be explained by a lower residue proportion, with less dry matter content with regard to the role plant height of cutting increase. There was a hybrid effect for the residue mineral composition variables (Table 3). Andrade et al. (1998a) studied silage production and nutrient recycling in seven corn cultivars and reported hybrid effect ($p < 0.05$) for plant mineral composition, albeit not for the stem base mineral composition (50 cm). These authors observed lower contents of DM, N, P and S in the stem base (cutting at 15 or 55 cm) when compared to those of the canopy.

N contents varied ($p < 0.05$) between hybrids AS 32 (8.44 g kg^{-1} DM) and CD 308 (6.15 g kg^{-1} DM). Similar values were obtained by Andrade et al. (1998b) in the stem base fraction of corn hybrids (7.10 g kg^{-1} DM). AG 9090 had the highest P content (2.31 g kg^{-1} DM), whereas DKB 747 had the lowest (1.14 g kg^{-1} DM), with no difference for the hybrid P30F87. Hybrids AS 32 and AG 9090 had a higher concentration of K contents and results were similar to those by Andrade et al. (1998b). These authors also reported that K had higher contents at the stem base when compared to the canopy at the two cutting heights (15 and 50 cm). According to Duarte et al. (2003), practically all the potassium is accumulated before flowering, regardless of the cultivar, and the greater part of the N, P S and Zn accumulated in the plant, excepting calcium, is exported to the ear. The latter nutrient accumulated less in the ear when compared to the whole plant.

Current study showed that calcium contents were similar among the hybrids and ranged from 1.63 to 2.13 g kg^{-1} DM. Only AG 9090 provided greater calcium content when compared to hybrids CD 308 and P 30F87. Andrade et al. (1998a) reported that calcium concentration in the residue of corn hybrids ranged between 1.9 and 3.7 g kg^{-1} DM. The effect of cutting height was only observed for calcium concentration. In fact, it was higher for the residue obtained with cutting at35 cm rather than at 15 cm (1.85 vs 1.59 g kg^{-1} DM). This may have occurred because of the greater quantity of leaves present in the residue harvested at a greater height and the greater calcium concentration in the leaves when compared to that in other parts of the plant (DUARTE et al., 2003). The concentration of the other nutrients (N, P and K) did not vary ($p < 0.05$) with an increase in cutting height.

The hybrids presented similar yield for residue organic matter and mineral nutrients, with means 1.515 and 76.88 kg ha^{-1}, respectively (Table 4), except for AG 9090 that had greater P amounts in the residues than those of the others (4,010 vs 2,338 kg ha^{-1}) and calcium when compared to hybrid CD 308 (3,519 vs 2,633 kg ha^{-1}).

Table 4. Organic matter and mineral nutrients of residues of corn hybrids cutting at different heights.

Hybrids[1]	OM	Ash	N	P	K	Ca
			kg ha^{-1}			
AS 32	1320	66.19	11.91	2.344^{b}	31.899	2.836^{ab}
AG 9090	1507	69.82	12.53	4.010^{a}	36.877	3.519^{a}
CD 308	1607	69.53	10.26	2.755^{b}	27.514	2.633^{b}
P 30F87	1627	70.07	10.76	2.524^{b}	27.964	2.843^{ab}
DKB 747	1513	63.78	11.04	1.900^{b}	28.519	2.800^{ab}
Pr > F[2]	ns	Ns	ns	**	ns	*
			Harvest height[3]			
15	727^{c}	34.66^{c}	5.120^{c}	1.1844^{c}	14.151^{c}	1.203^{c}
35	1427^{b}	66.04^{b}	10.682^{b}	2.3888^{b}	27.896^{b}	2.743^{b}
55	2391^{a}	102.94^{a}	18.109^{a}	4.5482^{a}	49.616^{a}	4.833^{a}
Pr > F	**	**	**	**	**	**
Means	1515	76.88	11.304	2.707	30.554	2.926
CV[4]	13.43	14.42	20.10	26.77	24.76	18.99

[1]The values represent mean of different harvest heights of the plants. See hybrid details in Table 1. [2]Probability of significant effect; * and ** represent level of significance of 0.05 and $p \leq 0.001$ respectively; ns = not significant $p > 0.05$. [3]The values represent the mean of the hybrids harvested at different heights (harvest height in cm). [4]Coefficient of variation (%). [a, b, c]Means with different letters in the column indicate significant difference by Tukey's test at 5%.

The quantity of organic matter and mineral nutrients that remained in the field was greater as the corn cutting height increased (Table 4). Organic matter increased in the field and reached 1,664 kg ha^{-1} or 228% when cutting height rose from 15 to 55 cm. Increasing cutting height of harvest increased N, P and K potential recycling by 258, 275 and 352% respectively. In absolute terms, more 3.6, 5.2 and 11.7 kg ha^{-1} of N, P and K remained in the crop, respectively. In a 50 cm cutting, a further 2,529 kg DM ha^{-1} remained in the field when compared to that from 15 cm cutting (ANDRADE et al., 1998a).

Increase in field residue and its benefits have been reported in other studies. Bundy et al. (2001) studied the effects of management practices on phosphorous losses in corn production systems and emphasized the need to define management recommendations to minimize losses of the forms of P with great pollution potential. Similarly, Grande et al. (2005a) studied the effects of corn residue level (by the variation in the cutting height between 10 and 60 cm) added to manure application. They reported that the combination of manure application with the highest level of corn residue (harvested at 60 cm) caused a smaller loss of total P, without substantial increase in soluble P losses. These results may have practical applications for nutrient loss management in agricultural areas.

Potassium is usually the most abundant nutrient in plant tissue. Since it predominantly contains K^{+} in the ionic form, waste decomposition releases it quickly and entirely (BORKERT et al., 2003). In the case of rice straw, for example, 80% of the release of this nutrient occurred in approximately 7 weeks, according to Tian et al. (1992). Jaremtchuk et al. (2006) studied potassium extraction by corn plant for silage at two cutting heights and reported that increase in the cutting height (20 to 40 cm) would return to the soil on an average 19.15% of the potassium that was extracted. This would correspond to 21.37 kg potassium chloride to recover the K content in the soil. Andrade et al. (1998b) reported that cutting at 50cm resulted in a return of 78 to 102 kg potassium chloride to the soil. Current analysis showed that potassium had the highest recycling potential at the three cutting heights (14.1, 27.8 and 49.6 kg ha^{-1}). In the case of extraction of potassium of 120 kg ha^{-1} (VASCONCELLOS et al., 1983), the potential for the element's recycling would be about 41.3% when corn is harvested at 55 cm.

Nitrogen was the second nutrient with the highest recycling potential, with 5.1, 10.6 and 18.1 kg ha^{-1}, respectively for heights 15.35 and 55 cm. Corn residues contained large quantities of N (40-

80 kg N ha^{-1}) when harvested for grain. However, C: N ratio is high, so that N is immobilized by the decomposing organisms at some points of the decomposition process (BURGESS et al., 2002). According to these authors, N losses occurred (by lixiviation) and there was a later immobilization phase and residues with low N content, such as stems, cobs and brackets, immobilized N at some point in their decomposition. However, they did not observe net N immobilization for all residues.

Although nutrient extraction was higher in the lower cuts, the low percentage in the stem base also reduced the recycling of such nutrients as N, P, Ca, Mg and S (ANDRADE et al., 1998b). Except for K, the quantity of the other nutrients harvested at 55 cm was four times greater when compared to cuttings at 15 cm, albeit involving small quantities (4.5, 4.8 and 18.1 kg ha^{-1} for P, Ca and N respectively). Potassium, harvested at 55 cm, was three and a half times greater when compared to cuttings at 15 cm, albeit involving great quantities (49.6 kg K ha^{-1}) than other nutrients. Results suggest a significant potential return of K extracted by the corn crop harvested at 55 cm when compared to that harvested at 15 cm.

Conclusion

There was no difference among the hybrids with regard to residue yield (remaining leaves and stem). The hybrids differed in residual mineral composition. Except for calcium, rise in the cutting height from 15 to 55 cm did not increase the residue's mineral concentration. The quantity of organic and mineral material that remained in the field increased considerably with the increase in cutting height.

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