Optimization of the animal production system based on the selection of corn cultivars for silage

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Introduction

Originally from the tropics, specifically Mexico and Guatemala, corn belongs to the C4 plants group, and is traditionally the most used plant for silage production. There are several aspects that can contribute for this, such as, high dry matter production, optimum dry matter content at harvesting, at least 3% of soluble carbohydrates on an as-is basis, lower buffering capacity, and besides that, adequate microbial fermentation.

The use of modern corn cultivars which are more productive, environmentally adapted, structural and physiologically more efficient, are considered the characteristics responsible for the effective gains in production of these plants. However, despite corn silage is extensively known, still is common miss concepts related to cultivars selection, cultural managements, harvesting time, and ensilaging steps, where the quality of final product usually is impaired.

The structural composition has direct influence in the quality of corn plant. Its fraction variations, due to genotypic and phenotypic factors, have direct consequences on production and plant composition. Thus, to produce good corn silage, beside the amount of grains on the ensiled mass and the high productivity, the proportion of other plant fractions and their fiber digestibility are also very important.

To target elevated dry matter production and adequate quality, it is necessary to know, through the maturation period, the improvements in nutritive value due to the higher grain participation in the plant, and the losses accounted for the reduction in stem digestibility, pondering up to get positive balance on the digestible nutrients production. The main idea of these aspects is to achieve high quality final products, which could be responsible for improvements on animal performance on several production systems, independent if they are based on milk or beef production, and its economic feasibility, as well.

Thomison (2008) consider five steps in the selection of corn hybrids:

1) Select hybrids with maturity ratings appropriate for your geographic area or circumstances;
2) Choose hybrids that have produced consistently high yields across a number of locations. Hybrids will perform differently based on region, soils, and environmental conditions;
3) Minimize stalk lodging, choosing plant hybrids with good standability;
4) Select hybrids with resistance and/or tolerance to stalk rots, foliar diseases and ear rots;
5) Never purchase a hybrid without consulting performance data;

1. Corn hybrids

The current market shows great diversity of materials, with specific characteristics to attempt regional requirements, taking in to account the environmental conditions, soil type, expected productivity, and resistance to pests and diseases.

The corn plant shows different vegetative cycles, with genotypes extremely early, where the pollination can occur 30 days after emergence, or genotypes which cycle can target up to 300 days. In Brazilian conditions, the cycle varies between 130 and 150 days for normal materials, 120 days on early materials, and between 105 and 110 for those that are the earliest (Fancelli & Dourado Neto, 2000).

Normal cycle materials usually show higher vegetative development with higher number of leaves below the ear (10 to 12). However, on early materials, this number is between 6 to 8 leaves, which gives to this group higher photosynthetic efficiency, due to the higher light incidence on the lower leaves (Nussio, 1991).

Besides that, they are also more efficient to convert energy into grains, showing higher grain proportion on the mass (50% vs. 38%) compared with normal genotypes (Nussio, 1991;

Penati, 1995). According to some studies (Cruz & Pereira Filho, 2001), the maturity stage where the grains are on the hard farinaceous point, considered the ideal moment for the ensilage process, early materials show higher dry matter content than normal cycle genotypes.

Ettle & Schwarz (2003), comparing normal cycle material with stay green characteristic and an early cycle hybrid, observed that the normal cycle hybrid showed lower stem dry matter content (26 vs. 31%), and higher ear dry matter content (61.9 vs. 58.4%) for plants harvested at the same age, comprising 38 to 42% plant DM.

The type of cross is also important on corn hybrids selection. Single hybrids are uniform in plant and ear height, ear size, and disease tolerance, while the double crosses are the most variable for all traits. Single crosses have the maximum hybrid vigor, and thus the greatest yield potential, followed by modified single crosses, three-way crosses, and double crosses. Although some double crosses may yield better than some single crosses under certain circumstances, most modern single crosses can outperform double crosses even under unfavorable growing conditions (Carter, 1992). Pixley & Bjarnason (2002) did not observe differences in grain production of single-cross, three-way and double cross corn hybrids.

Considering the endosperm type, there are two mainly genetic groups: Flint (*Zea mays* ssp. Indentura) and Dent (*Zea mays* ssp. Indentata). On the Flint corn, the external endosperm layers are completely connected by the zein protein forming vitreous and extremely hard layers, while the more internal layers have a small proportion of farinaceous endosperm, showing non dented and rounded core.

The Dent group is characterized by the presence of certain amounts of zein, however, the corneous layers do not cover the whole endosperm surface, that gives vitreous aspect only on the lateral of the grain, and at the inner grain, shows farinaceous texture. When dehydrated, the central part of the grain hardens to get dented conformation (Brieger & Blumenschein, 1966). The Dent group represents the highest part of USA corn cultivars, while in Brazil, the Flint materials are predominant.

Pereira et al. (2004), evaluating the proportion of vitreous endosperm on Flint and Dent materials in three maturity stages (doughy, ½ milk line, and physiologic maturity), observed values around 59.9; 67, and 72.4%, for the Flint materials, and 38.2; 46.9, and 47.9%, for the Dent hybrids, respectively. \

2. Maturity

Corn silage quality is dependent of several production system steps, which can be divided in 3 mainly stages: pre culture establishment; plant establishment and growth; and ensilage. During the plant establishment and development, special attention should be given to the culture tracts, such as: fertilization, pest, diseases, and weeds control. Besides that, the harvest point determination is essential for appropriate forage fermentation in the silo.

The harvest point of corn plants for silage production directly affects forage production per area, quality, and silage intake. So it is responsible to determine the production levels to be reached and consequently economic results in each animal production system.

As the corn plant matures and reaches the blooming stage, nutrients are stocked in the grain, primary as sugars and later as starch. The plant maturation process is associated with dry matter content increase, starting with less than 20% at blooming to more than 40% when plant reaches physiologic maturity (Wilkinson et al., 1998). Although, corn plants show maturation gradient with variable rates and it is dependent of cultivars and edafoclimatic conditions (Oliveira et al., 2002 cited by Possenti et al., 2004).

The results have suggested the hard-farinaceous point as a reference to harvest plants, because it conciliates an adequate dry matter content to ensile the plants (32-35%), and permits a potential grain filling (6,000 kg/ha) and total plant dry matter accumulation (12,000 - 14,000 kg/ha). Moreover, the animal intake also is improved (Nussio et al., 2001)

According to Wilkinson et al. (1998), the intake of silages harvested with dry matter content higher than 35%, is reduced in 25% when compared to plants harvested with 30% DM.

The advantages of harvesting corn plants with dry matter content between 32 and 35% are: considerable increases in dry matter production per area; storage losses reduction, mainly by runoff production; and animal dry matter intake improvements (Cruz & Pereira Filho, 2001).

Actually, the scientific community has shown variable results, due to the large number of hybrids offered in the market. On this wise, the decision by the harvesting moment, should consider that the plant need to be harvested in a physiological stage where the NDF content is diluted by the progressive starch increase due to the grain filling. Grain filling and stem digestible losses are concomitants events, so historically, minimum dry matter digestibility variation had been observed with the plant dry matter content increase, since the milky up to the hard grain stage.

To sum up, the ideal harvest point recommendation always suggested advanced plant physiological stage, where was possible to conciliate higher liquid biomass accumulation both in grain and in the whole plant; higher percentage of grain/ear, that suggests higher NDF dilution by starch, maintaining the TDN unaltered; higher dry matter content, favoring the fermentative process and potential intake by the animals (Nussio et al., 2001). Planting several hybrid maturities each year spreads the harvest season and reduces the weather risks and is optimum for timely harvest management (Carter, 1992). The author recommends a hybrid maturity mix of 25% short-season, 50% medium season, and 25% full-season hybrids.

3. Productivity

Corn shows maximum dry matter production before the highest grain dry matter accumulation. The greatest dry matter production occurs when grains are at the semi-hard stage, while maximum grain dry matter accumulation occurs when the black layer is formed, which often occurs with grain hardening (Ferreira, 2001).

Corn hybrids, with early cycle, show lower dry matter production (12,270 vs. 14,945 kg/ha) and grain production (5,978 vs. 6,721 kg DM/ha) than normal cycle hybrids (Russel et al., 1992). Furthermore, according to Penati (1995), usually, in adversely environmental conditions, production damages in early hybrids cycle are higher than those in normal cycle materials.

Corn hybrids production varies between 26,000 and 75,300 kg/ha fresh basis (Costa et al., 2000; Beleze et al., 2003; Neumann et al., 2006), while dry matter production reaches values between 8,470 and 35,900 kg/ha, depending on the cultivar and harvesting time (Silva et al., 1999; Filya, 2004; Jaremtchuk et al., 2005; Baron et al., 2006).

Fiber fractions production (stem, leaves and bracts) and grains are also important for the evaluation of corn hybrids for silage production, and varies between 4,700 to 11,750; and 4,000 to 12,700 kg DM/ha, respectively (Tolera et al., 1999; Farinelli et al., 2003; Jaremtchuk et al., 2005; Ferreira et al., 2006). The stem fraction reached productions between 2,380 to 3,620 kg DM/ha in a hybrid evaluation study conducted by Beleze et al. (2003) for plants harvested between 20.74 and 48.27% DM.

Nussio (1997) evaluated the plant fiber fraction influence of different corn cultivars on the dry matter production per hectare, and on the *in situ* digestibility of plant fractions. The author observed that the selection of corn hybrids for silage production, based mainly on the dry matter production, should be revised due to the variable production potential of the available materials, and also due to the wide dispersion between agronomic and qualitative characteristics. Consequently, the importance of information about the genotypic origin of corn hybrids, and the quality of the material to be ensiled as well, is gaining space in this scientific field.

Some hybrids perform at consistently high levels over many sites while others may not perform equally well under variable conditions. Superior hybrid performance over several locations and years is the best prediction of superior future performance (Carter, 1992).

Different participations of plant components can result in similar plant dry matter production (Penati, 1995). Therefore, it is clear the relevance of the analysis of corn plant production and the quality of its fractions on the evaluation programs of corn silage hybrids, aiming to join good production and digestibility of the whole plant.

4. Morphological composition

In despite of being used as a forage source, the factor that is highlighted on the evaluation of corn silage quality is the grain percentage in a dry matter basis (Silva et al., 1999). Grain proportion has been recognized as an adequate criterion on silage material selection because there is a relationship between potential grain and whole plant dry matter production (Nussio & Manzano, 1999).

On the other hand, the importance of grain participation, as the main factor responsible for corn silage quality, was questioned by Hunter (1978), who observed genotypic variation on plant fiber fraction quality, expressed by the dry matter intake and forage digestibility. These values were independent of grain proportion (DM basis) what suggests important contribution of fiber on forage quality.

A study conducted by Lauer et al. (2001) showed that, in the last 70 years, the improvements in corn silage production and quality is due to grain production increase, with small changes in cultivars fiber fraction, moreover, they reinforce the importance of improvement programs based on productivity and quality of this fraction.

The different plant fractions contribute distinctly to the dry matter production, and its variation can be attributed to the genotype as well as plant maturity stage. Santos et al. (2002) observed lower correlation, positive and significant ($P<0.05$) between grain productivity and plant height ($r^2=0.51$), and ear insertion height ($r^2=0.52$). Actually, corn plant has shown height variation between 1.6 to 2.65 m, with ear insertion around 0.78 to 1.43 m (Santos et al., 2002; Farinelli et al., 2003; Jaremtchuk et al., 2005; Neumann et al., 2006).

Additionally to the corn plant fractions participation on the silage production, the quality of these fractions is also a determinant factor on the corn hybrid selection.

5. Nutritive value

The great nutritive value of corn plant, characterized by high digestibility or energy density, determines the excellence of this plant, and generally, this is the attribute that qualifies it as an option for the animal production systems. Whole plant composition can be observed on the summary data showed in Tables 1 and 2.

Actually, modern corn hybrids had reached harvest point early and with higher starch content, one of the main breeders objectives. However, this occurred at the expense of lower cell wall digestibility, and with little effect on the organic matter digestibility (Givens & Deaville, 2001).

Table 1 – Dry matter content (DM), ether extract (EE), crude protein (CP), starch, and *in vitro* true digestible dry matter (IVTDDM) of corn plants for silage production

Author	DM	EE	CP	Starch	IVTDDM
			%		
Russell et al. (1992)	34.8 - 51.4	-	6.9 - 7.6	-	71.9 - 74.8
Coors et al. (1997)	30.0	-	7.5	-	77.4
Thomas et al. (2001)	36.9 - 41.3	3.5 - 3.6	7.7 - 9.6	15.2 - 18.3	77.8 - 79.9
Ballard et al. (2001)	27.3 - 33.7	2.2 - 2.6	6.6 - 6.8	12.6 - 14	73.7 - 79.2
Filya (2004)	21.1 - 42.0	-	-	-	-
Lewis et al. (2004)	28.0 - 42.0	-	7.1 - 8.4	11 - 22	82.5 - 90.7
Kung et al. (2008)	33.7	-	7.1	29.74	-

Table 2 – Cellulose (CEL); Hemicellulose (HEMI); Neutral detergent fiber (NDF); Acid detergent fiber (ADF), and NDF digestibility (NDF-dig) of corn plants for silage production

Author	CEL	HEMI	NDF	ADF	NDF-dig
			%		
Russell et al. (1992)	-	-	43 – 50	24 - 27	-
Coors et al. (1997)	-	-	48.6	25.6	-
Thomas et al. (2001)	-	-	40 – 42	21 - 25	-
Ballard et al. (2001)	21 - 23	18 - 21	41 – 45	23 - 26	44 – 49
Filya (2004)	20 - 33	19 - 20	44 – 56	24 - 35	-
Lewis et al. (2004)	-	-	39 – 46	-	56 – 79
Kung et al. (2008)	-	-	42.91	25.84	51.7

In despite of the dry matter production increases when plants are sowed with high density, the same behavior is not observed for the *in vitro* true digestible dry matter (IVTDDM). Cusicanqui & Lauer (1999) observed dry matter digestibility decreases of 0.35 g/kg for each increase of 1,000 plants/ha, explained by the improvement of plant NDF and ADF content when the population increases.

Table 3 shows some nutritive value results from plant fractions found by some authors.

Table 3 – Fraction compositions of corn plants for silage production

Plant fraction[1]	DM	CP	NDF	ADF	IVTDDM	NDF-dig
			%			
Stem	22 - 26	3.0 - 6.3	57 - 81	44 - 60	26 - 63	20 – 39
Leaves	25 - 43	8.6 - 14.6	56 - 74	33 - 44	55 - 77	55 - 65
Bract	25 - 40	3.6 - 6.4	72 - 82	-	58 - 71	51 - 62
Cob	32 - 43	2.5 - 3.4	78 - 88	-	42- 63	37 - 56
Grain	41 - 59	10.7 - 12.0	11 - 14	3.3 - 3.5	98 - 99	77 - 90

[1]Russell (1986); Philippeau et al. (1999a); Thomas et al. (2001); Zeoula et al. (2002); Zeoula et al. (2003a); Zeoula et al. (2003b); Rosa et al. (2004); Neumann et al. (2006) and Borstmann et al. (2006)

In the last years, some corn hybrids had been developed specifically for silage production. The focus has been on the fiber digestibility improvement, assuming that this can result in dry matter intake increases, and consequently gains in milk or meat production (Thomas et al., 2001). Weiss (2001) observed that cows consumed more DM when fed diets that contained forages with high *in vitro* NDF digestibility.

Philippeau & Michalet-Doreau (1998), in a corn hybrids study with Dent and Flint endosperm, observed that, for non-ensiled material, effective dry matter degradability did not differ between treatments. On the other hand, the genotypic differences were significant based on starch degradability. For non-ensiled material, the effective starch degradability was 72.3 and 61.6% for Dent and Flint genotypes, respectively. For the ensiled material, effective starch degradability was 78.6 and 67%, respectively.

The lower starch degradability for Flint genotypes on *in situ* studies was probably due to the lower rapidly degradable fraction proportion, lower degradation rate, or from both effects (Philippeau et al., 1999a). The difference on starch ruminal degradability could be related to the vitreous endosperm content that showed little farinaceous endosperm proportion.

With the lower starch fraction digestibility, the hypothesis of “dilution” may not always be occurring, leading to the lower digestibility of plants harvested on advanced maturity stage.

It is also important to highlight that, in despite of evident starch degradation superiority for the Dent genotype, usually, the same slope is not applied for the vegetative plant portion. Some current studies suggest that whole plant nutritive value should not follow the reduction in starch digestibility, independent of the analyzed material (Dent or Flint), because there is a compensation on the vegetative portion (Nussio et al., 2001).

The variability observed for ruminal starch digestion in corn cultivars with different endosperm, suggests that the genetic selection can manipulate the local and extension of starch digestion in ruminants (Philippeau et al., 1999b). Ruminal and post ruminal starch digestibility can vary widely among feedstuffs. However, intestinal starch digestion is always compensated by reductions in its ruminal digestion, so that total tract digestion variation could be relatively small (Huntington, 1997; Taylor & Allen, 2005).

The site of starch digestion alters the final products nature (volatile fatty acids in the rumen, and glucose in the small intestine), and finally, its metabolic utilization efficiency by the ruminant (Philippeau et al., 1999a). These authors observed effective dry matter and starch degradability, closed to 42.3 and 55.8; 46.2 and 61.9% for Flint and Dent genotypes, respectively. The highest Dent genotype degradability is explained by the higher degradable rate, and higher starch fraction rapidly degradable than those observed in Flint genotypes. As a result, forage and energy intake should be optimized based on the dry matter content and starch concentration as well, without compromising nutrient digestibility.

A study evaluating the influence of corn endosperm type on nutrient digestibility in lactating dairy cows showed that total-tract starch digestibility was greater (+6.3%) for diets that contained floury and opaque corns, compared with vitreous corn diets. In contrast, apparent total-tract NDF digestibility was lower for floury (-8.4%) and opaque (-0.4%) diets (Lopes et al., 2009).

Wolf et al. (1993) observed that ear proportion and plant fiber fraction production have stronger associations on whole plant digestibility and cell wall composition than on grain production. However, they suggested that the improvements on fiber fractions should be targeted without sacrificing grain production.

Penati (1995) observed that cell wall components (NDF, ADF, cellulose, hemicelluloses and lignin) are responsible for negative effects on plant digestibility, highlighting the importance of stem and leaves fractions analysis, when high quality silages are expected.

In this context, Nussio & Manzano (1999) suggested that quality prediction models, for corn cultivars selection programs that aim silage production, should be established based on two mainly factors: grain percentage on the ensiled mass (% DM), and nutritive value of stem-leaves portion (% of the *in vitro* true digestible dry matter) as well.

According to Tovar-Gomez et al. (1997), a considerable share of the animal responses associated with distinct corn genotypes had occurred due to differences in ruminal plant cell wall degradability, highlighting so, the importance of knowing this component quality. As a result, corn silage hybrids improvement programs that aim gains on fiber fraction quality should consider the NDF digestibility as an important criteria for hybrids selection (Lauer, 2003).

6. Cutting height

Increasing the cutting height of corn silage decreases silage yield. Corn plant parts contain different amounts of fiber and digestible energy. Raising the cutter bar on a silage chopper will leave more of the lower corn stalk in the field, which is typically higher in fiber and lower for digestible energy. According to Lauer (2001), corn silage yield decreased 15% as the cutter bar was raised from 15.2 to 45.7 cm above the soil surface. Neylon and Kung (2003) observed reductions of 5-10% in the dry matter production in plants harvested at 45.7 cm height, when compared to plants harvested at 12.7 cm height.

In a study evaluating high (42 cm) and normal height cut (20 cm), Restle et al. (2002) observed reductions in the dry matter (-6,7%), and NDF (13,24%) content, and increases in the IVTDOM (+13,77%), and in the digestible energy (+11,8% - Mcal/kg DM) in the high cutting treatment. However, the dry matter production was reduced in 6,7% (10,945 vs. 10,207), and the dry matter intake, daily weight gain and feed conversion were not affected.

According to Bernard et al. (2004), increasing the cutting height from 10.2 to 30.5 cm, did not improve silage quality or milk yields of cows. Corn silage harvested at 30.5 cm had lower (-5.3%) concentration of ADF, but no differences were observed in concentrations of NDF or digestible NDF.

Wu and Roth (2005) summarized 11 studies that evaluated low (17.8 cm) versus high (48.2 cm) cutting height and observed reductions in ADF (-10.2%), NDF (-7.4%), forage yield (-7.4%), and increases of DM (+6%), CP (+2%), starch (+5.9%), digestible NDF (+4.7%), and DM digestibility (+2.5%).

Kung et al. (2008) observed that high cutting of a normal corn hybrid increased concentrations of DM (+4%), CP (+5%), NE_L (+3%), and starch (+7%), but decreased the concentrations of ADF (-9%), NDF (-8%) and ADL (-13%). The NDF digestibility was not affected by the high harvest height.

7. Cultivars evaluation models

Besides the agronomic characteristics evaluation from current market corn cultivars, animal performance studies are extremely important, and to do it, some productivity indices are created aiming to evaluate these factors together.

Corn hybrids selection based on plant IVTDDM and total dry matter production as well, sounds a reasonable way on the high production and quality hybrids selection (Hunter, 1978). Recent models of corn cultivars for silage consider factors, such as dry matter production per hectare associated with plant dry matter digestibility, or with digestible dry matter production per hectare (DDMP/ha) as a criteria for material selection.

Ballard et al. (2001) found digestible dry matter productions between 11,000 and 11,700 kg/ha for early hybrids (94 to 95-d relative maturity), while in higher spacing (0.9 vs. 0.76 m), Costa et al., (2000) observed DDMP/ha between 5,540 and 8,560 kg/ha.

Plant dry matter content affects total dry matter production (Russell et al., 1992; Ballard et al., 2001; Wilkinson & Hill, 2003; Filya, 2004) and forage digestibility as well (Bal et al., 1997; Zeoula et al., 2003b; Lewis et al., 2004), and therefore, also has influence on plant DDMP. In a study comparing corn hybrids for silage, Thomas et al. (2001) got digestible dry matter productions closed to 11,400 kg/ha for materials harvested with 49.2% DM against 11,000 kg/ha for plants harvested with 53.9% DM. Paziani et al. (2009) observed that the digestible dry matter production (kg/ha) was affected by dry matter and grain production, and plant and stem digestibility as well

Nutrient composition data and *in vitro* NDF digestibility should be used to estimate economic value of the production system. Corn silage is a major source of both NE_L (net energy for lactation) and eNDF (effective NDF) and these components should be part of the hybrid selection process (Undersander et al., 1993; Weiss, 2001)

Therefore, the possibility of knowing silage corn hybrids behavior throughout its development, based on production evaluation and plant nutritive value as well, allows the ideal harvest moment decision for each material. Thus, it guarantees adequate fermentation, which enables a quality feedstuff, and consequently, results in better animal responses allowing technique-economic feasibility on this important production system phase.

8. Conclusions

The optimization of the animal production system based on the selection of corn cultivars for silage is achieved when producers consider the performance of hybrids over multiple sites or multiple years within a given region.

Information of both silage yield and digestibility of the whole plant and fiber, are needed when selecting hybrids. The digestible dry matter production is an effective measure that reaches most of the quality aspects of corn cultivars, because variables such as digestibility of several fractions and productivity of the whole plant are in accordance of this estimation. As a result, it is a versatile tool on the corn cultivars evaluation. However, sometimes companies do not have this information, so the formula below can help in this situation. It also can be used as a tool to evaluate the efficiency and get predictable values for the production system.

✓ Digestible DM production (kg/ha) = Plant digestibility (%) x DM production (kg/ha)

The cultivar evaluation based on productive aspects should be utilized after supplied some basic recommendations, such as the cultivar requirements on determined region, soil type, rainfall, etc. So, the digestible dry matter production should be used as a fine adjustment to figure out or help on the final decision.

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