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THE INFLUENCE OF IRRIGATION MANAGEMENT AND GENOTYPE ON FIBER CONTENT AND *IN VITRO* DIGESTIBILITY OF NDF IN CORN PART PLANT

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Abstract

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In several Italian regions climatic conditions are often not adequate to produce corn (Zea Mays) without an efficient irrigation strategy. Considering that forages quality is strictly related to fiber digestibility, it becomes more important to understand how the irrigation system affects fiber characteristic of the plants and it's in vitro NDF digestibility (dNDF). The objective of this study was to investigate the effect of irrigation system on fiber characteristic of corn part plants. Two genetics were selected to have high (HD) and low (LD) digestibility of NDF and were subjected to 2 different irrigation systems, furrow (F) and sprinkler (S). Eight whole plants per each treatment were harvested at 33% of dry matter. Immediately after harvesting, the plants were divided into five fractions consisting of stalk, leaves and ears. The ears were then splitted into grain, cob and husk. All the samples were analyzed for fiber fraction (NDF, ADF, ADL) and digestibility of NDF (dNDF). NDF and ADF were not different between genotype and irrigation management in leaves, while ADL was influenced both genotype ($P < 0.01$) and irrigation management ($P < 0.05$). NDF digestibility and kD showed significant differences for genotype ($P < 0.01$) and for irrigation system effect ($P < 0.05$). ADL of HD genotype in stalks was lower (respectively 4.24% in sprinkler and 5.16% in furrow irrigation system) than in stalks of LD (respectively 5.75% in sprinkler and 5.84% in furrow irrigation system) ($P < 0.001$), while dNDF ($P < 0.001$) and kd ($P < 0.05$) were influenced only by genotype showing the higher digestibility of dNDF in HD genotype. Cobs were not different in NDF, ADF and ADL, while DM ($P < 0.05$) and dNDF ($P < 0.001$) were influenced by irrigation system.

We can conclude that higher fiber digestibility of the plant is mainly due to the genotype effect, even if is possible to obtain better results combining appropriate genetic and irrigation system.

Key words: corn silage, digestible NDF, genetic, irrigation system

Introduction

Improving the nutritive value of forage is an important goal for dairy cow breeders. The use of forages with higher fiber digestibility allows higher dry matter intake and milk production (Oba and Allen, 1999) and could reduce the use of concentrates with a positive impact on animal welfare, health and milk composition. The rate (kd) and extent of NDF digestion is also important because it impacts the available energy from fiber, the passage of particles out of the rumen and the physical fill of the rumen. According to Casler (2000), the main criteria for improving forage nu-

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tritional value must include reduced content of lignin and increased NDF digestibility. These conditions may be promoted by plants selection, choosing the optimal stage for harvest and improving growth factors, such as appropriate fertilization and irrigation strategy. Genotype and weather conditions are known to influence the neutral detergent fiber (NDF) content and the cell wall structure and digestibility (Struik, 1985; Raffrenato et al, 2007). Struik et al. (1985) documented the impact of temperature on cell wall content in different developmental phases of corn. Lower cell wall concentrations were consistently reported for hot and/or dry growing seasons compared to cool and/or wet conditions (Cox et al., 1994; Van Soest, 1994), which may be due to the accumulation of water-soluble carbohydrates (Aydinsakira et al., 2013).

The relationship between climate condition, genetic characteristic and irrigation management with fiber digestibility in corn is poorly investigated. Van Soest (1996) suggested that factors such temperature, light intensity and water availability affected forage lignin content and dNDF. Raffrenato et al. (2007) reported that dNDF is significantly improved when corn plants were obtained under sprinkler irrigation system with less water. The effect of water and temperature to reduce digestibility operates through increased lignifications of the plants cell wall (Van Soest et al., 1994).

The objective of this study was to investigate the effect of two irrigation system (furrow or sprinkler) and two corn genotype selected to have low vs high digestibility NDF, on fiber of corn part plants in North region of Italy.

Materials and Methods

Experimental details and site description

The experiment was conducted in four farm located in the Po Valley, Northern Italy (Mantova), during the growing season of the year 2007. Two corn genotype (G) provided by the Long Island Cauliflower Association (LICA, NY) were selected to have high (HD) and low (LD) NDF digestibility. The digestibility was calculated in vitro for all the genotypes. The LD was selected to have 40-45% of dNDF at 24 h while the predicted digestibility of NDF for HD genotype was about 55%. The two genotypes were seeded at the end of March. All the experimental sites were close and subject to the same climatic and atmosphere conditions. In each farms the experimental field were divided in its length into 8 plots. Each plot was 15 square meter with a final plant density of 7.5 plants/m^2. The land of each farms received a nitrogen fertilizer partitioned into one preplanting application and two post-planting applications. Weeds, pests and diseases were controlled.

Two farms were irrigated weekly by furrow (F) system, from the last week of May until the first week of August, with 355 mm/m^2 of water each time flowed during the nighttime. The other two farms were irrigated five times by sprinkler (S) irrigation system. The irrigations were repeated every 2 weeks from the last week of May till the end of July and the amount of water used were 50 mm/m^2 each time during the nighttime. The amount of water used is reported in Table 1.

Table 1
Available water in furrow and sprinkler irrigation (mm/m^2)

Month	Furrow	Sprinkler	Rain
May	355	50	132,6
June	1420	100	84,4
July	1420	100	11
August	355	50	115

Sampling and Analysis

At the harvest time, (about 33% of dry matter DM) for each genotype 8 whole plants were collected. In particular, two representative plants from each plot were randomly selected from the two central rows and cut at 15 cm height from the soil. The plants were immediately separated into five fractions consisting of stalk, leaves and ears; the ears were split into grain, cob and husk. The husks were analyzed with leaves while grain was not analyzed. All the samples were immediately carried to the Bologna Veterinary Medicine laboratory. The samples were weighted, dried at 105°C for content of DM (AOAC, 1980) and were ground in a Cyclotec mill (Foss Tecator AB, Hoganas, Sweden) to a 1 mm (AOAC, 1980) to determine NDF; ADF and ADL. In vitro digestible NDF was determined in triplicate using 24 hours fermentations period according to the procedure described by Goering and Van Soest (1970) and modified by Fusaro et al. 2007. Briefly, 0.5 g of sample was weighed in a bottle which was heated, sealed, and placed into water bath for a 24-h incubation with a medium containing buffer, mineral solution (Goering and Van Soest, 1970) and ruminal fluid, mixed in a ratio of approximately 4:1. Ruminal fluid was collected by esophageal probe from 3 non pregnant dry cow fed *ad libitum* with a total mixed ration (TMR) based on corn silage, soy, grass hay, straw, minerals and vitamins. The upper layer of rumen fluid was eliminated. The rumen fluid was strained through four layers of cheesecloth before mixing with buffer. After 24 hours the samples were processed as described by Goering and Van Soest (1970).

Furthermore the rate of digestion (kd) was calculate using the mathematical model describe by Van Amburgh et al. (2003).

Statistical analysis

Experimental data were evaluated using the GLM procedure of SPSS 13.0 statistical package (SPSS, 2006). The model included the fixed effects of irrigation system, genetics and interaction between the main effects, as follows:

$$Y_{ij} = \mu + I_i + G_j + I_i{*}G_j + e_{ijk},$$

where: μ = general mean; I_i = effect of irrigation system; G_j = effect of genetics; $I_i{*}G_j$ = interaction between main effects; e_{ijk} = random error.

When the analysis of variance F-test was significant ($P < 0.05$), differences among means were compared using the Student–Newman–Keuls test. Results are expressed as mean value and standard error of the Least Squares Means (MSE).

Results

Growing conditions

The meteorological data of the experimental site are presented in Table 2. Average values of rainfall registered during the growing period were lower than the last 30 years (of 85.8 mm/m^2 vs. 190 mm/m^2). Data were provided by the Meteorological Centre of Lombardia. During the first phase of the vegetative period, total recorded rainfall was 217 ml/m^2 (137.6 and 84.4 ml/m^2 in May and June, respectively), while 11.4 ml/m^2 were recorded in July during the reproductive growth stage (milk phase). The minimum and the maximum temperatures registered were respectively 8.5°C in May and 38.6 °C in July. The crop did not experience visible drought stress throughout the growing season and was maintained free of weeds by manual control (when necessary). No visual damages from insects and disease were observed.

Corn part plants fiber composition

The leaves characteristics are presented in Table 3. The leaves of HD genotype showed higher dry matter ($P < 0.05$). NDF and ADF were not different between genotype and irrigation management, even though the interaction between genotype and irrigation was correlated ($P < 0.05$). ADL was influenced both genotype ($P < 0.01$) and irrigation management ($P < 0.05$). NDF digestibility and kD showed significant differences for genotype ($P < 0.01$) and for irrigation system ($P < 0.05$) Specifically the dNDF of HD was higher in sprinkler (60.71%) and furrow (58.07%) irrigation system; while LD genotype showed the lower result in sprinkler (54.36%) than furrow irrigation system (56.79%).

The effect of genotype and irrigation management on the stalks fiber characteristic is reported in Table 4. The stalks showed differences for dNDF ($P < 0.05$) ADL ($P < 0.001$) and kd ($P < 0.05$). In particular ADL of HD was lower (respectively 4.24% in sprinkler and 5.16% in furrow irrigation system) than in stalks of LD (respectively 5.75% in sprinkler and 5.84% in furrow irrigation system) ($P < 0.001$). The dNDF ($P < 0.001$) and kd ($P < 0.05$) were influenced only by genotype showing the higher digestibility of dNDF in HD genotype (60.71% vs 58.07 respectively sprinkler vs furrow) than LD (54.36% vs 56.79 respectively sprinkler vs furrow).The DM of both genotypes was higher using furrow

Table 2
Monthly precipitation, temperature medium and maximum of 2007 growing season

	May	June	July	August
Rain (mm)	132.6	84.4	11.4	114.8
Mean minimum temperature (C°)	8.5	16.4	16.9	16.2
Mean maximum temperature (C°)	23.8	27.4	38.6	30.0

data from CML. Meteorological Centre of Lombardia

Table 3
Leaves fiber characteristics

	Leaves							
	Sprinkler		Furrow					
	HD	LD	HD	LD	G	I	G*I	MSE
DM	29.90^A	28.75^B	31.95^A	27.37^B	*	NS	**	0.64
NDF	66.75^b	67.49^{ab}	69.49^a	66.70^b	NS	NS	*	0.37
ADF	34.71^b	38.42^a	35.95^{ab}	34.98^b	NS	NS	*	0.46
ADL	3.15^b	4.43^a	3.03^b	3.96^a	*	*	*	0.12
dNDF	60.71^A	54.36^C	58.07^{AB}	56.79^{BC}	***	**	**	0.45
Kd	5.72^A	4.79^B	5.27^A	5.23^B	**	**		

HD: high digestibility corn; LD low digestibility corn

Table 4
Stalks fiber characteristics

	Stalks							
	Sprinkler		Furrow					
	HD	LD	HD	LD	G	I	G*I	MSE
DM	21.61^{B}	21.86^{B}	26.72^{A}	24.50^{A}	NS	***	NS	0.40
NDF	65.17^{A}	65.00^{A}	58.85^{B}	61.48^{B}	NS	***	NS	0.65
ADF	39.93^{ab}	42.72^{a}	37.45^{b}	39.63^{b}	*	*	NS	0.55
ADL	4.24^{B}	5.75^{A}	5.16^{B}	5.84^{A}	**	*	NS	0.17
dNDF	37.98^{a}	34.79^{b}	37.81^{a}	35.06^{b}	*	NS	NS	0.57
kd	2.99	2.91	3.26	3.03	*	NS	NS	

HD: high digestibility corn; LD low digestibility corn

Table 5
Cobs fiber characteristics

	Cobs							
	Sprinkler		Furrow					
	HD	LD	HD	LD	G	I	G*I	MSE
DM	36.32^{b}	39.82^{a}	42.75^{a}	41.34^{a}	NS	***	*	0.58
NDF	73.14	72.81	68.43	73.98	NS	NS	NS	0.82
ADF	33.43	35.36	35.96	35.50	NS	NS	NS	0.42
ADL	3.52	4.02	4.10	4.26	NS	NS	NS	0.16
dNDF	53.03^{A}	45.56^{B}	47.93^{B}	47.01^{B}	***	*	***	0.45
Kd	4.58	3.7	4.14	3.94	***	*		

HD: high digestibility corn; LD low digestibility corn

irrigation system ($P < 0.001$); NDF ($P < 0.001$) and ADF($P < 0.05$) were higher value in sprinkler than furrow and ADF was also influenced by genotype ($P < 0.05$).

Cobs (Table 5) were not different in NDF, ADF and ADL, while DM ($P < 0.05$) and dNDF ($P < 0.001$) were influenced by irrigation system. DM of both genotype irrigated by furrow system (42.75% for HD and 41.34% for LD) was higher than the same genotype irrigated by sprinkler (respectively 36.32% and 39.82% for HD and LD). The dNDF of HD genotype was higher in sprinkler than in furrow irrigation system (respectively 53.03 vs 47.93%) and also the irrigation showed the higher value of dNDF in sprinkler than in furrow irrigation management ($P < 0.001$).

Discussion

The Table 1 reported the amount of water used in both irrigation systems. The sprinkler method used 300 mm/m^2 overall of water compared to 3550 mm/m^2 used by furrow system. The low water used by sprinkler method contributed to increase the water application efficiency compared to furrow system. ADL, dNDF and kd of leaves were influenced by genotype and irrigation system, while DM was influenced only by genotype. The HD leaves irrigated by sprinkler system showed higher dNDF than the same genotype irrigated by furrow (respectively 60.71% vs 58.07%). The kd value had similar trend of dNDF confirming that the fiber pool was more digestible in HD than in LD. Comparisons between hybrids containing different NDF digestibility irrigated with different method are not available in the literature. On the contrary, different researchers evaluated the effects of irrigation on corn dry matter digestibility or yield corn production (Dechmi et al., 2003)

Based on our results it is possible to suppose that the sprinkler system mimics the rain effect, in which water is slowly adsorbed and reaches the soil. On the contrary, water provided by furrow irrigation system was rapidly absorbed by roots, moved upwards by capillarity, and immediately evapotranspirated by the corn plant. It is possible to hypothesize that the water flow provided by sprinkler system was constant and uniform, and thus contained the lignin deposition in plants (Salvatori et al., 2014). This effect could have led also to a higher NDF digestibility.

On the contrary furrow irrigation system probably contributed to non uniformity irrigation of the plants, with an impact on the nutritional value of corn part plant. There have been many studies on the impact of non uniformity irrigation on crop yield. Some of these studies have reported a low impact (Allaire-Leung et al., 2001; Li J. Rao, 2000), but others have found the crop yield to be notably influenced by the lack of irrigation uniformity (Dechmi et al., 2003; Yilmaz et al., 2010). Other studies evaluated the redistribution of the irrigation water once the drops are intercepted by the leaves and drip through the canopy, like with sprinkler system. Letey (1985) reported that the soil water is partitioned by the crop canopy in three components: stemflow, throughfall and interception storage (Lamm and Manges, 2000). Consequently, the crop canopy redistributes the irrigation water in a better way when a sprinkler irrigation system was adopted (Paltineanu and Starr, 2000), as observed in the current study. Researchers at Kansas State University (O'Brien, et al., 2000) concluded that converting from furrow to sprinkler irrigation was a profitable undertaking.

The data showed the biggest impact of genotype for stalks fiber characteristic than the irrigation system. According to Verbic et al. (1995), the nutritive value of maize silage can be improved by increasing the proportion of grain and the nutritive value of stalk. Possibilities to enhance the quality of grain are limited because its variability, while, in comparison, variability of stalk is rather small (Deinum, 1988). Our results showed that differences of dNDF and ADL in stalk were due mainly to large differences among genotypes and rather than irrigation.

We hypothesized also that a large supply of water applied by the furrow system contributed to accelerate the aging of the plants. The higher dry matter of corn plants irrigated with furrow system may be a symptom of this fact and it is probably due to an intermittent and inadequate water availability during the time: too much in a short time when water was flowed and drought stress between the irrigation. ADL deposition was also influenced by irrigation method. Increased lignin content associated with higher irrigation was previously observed for sorghum (Amaducci et al., 2000) and for other forage crops. Lignin is generally accepted as the primary responsible for limiting the digestion of fiber in the forages (Besle et al., 1994; Van Soest, 1994). The negative relationship that seems to exist between lignin amount and forage digestibility has been recognized many years ago (Sullivan, 1959; Tomlin et al., 1964). Since lignin is a component of the cell wall, its effect on forage digestibility is assumed to be a direct influence on wall digestibility rather than on digestibility of total forage (Van Soest, 1994). In our trial the irrigation management influenced ADL content of the stalks. These results are in agreement with Van Soest (1996), who demonstrates that many factors such as temperature, light intensity, and water availability could affect forage composition, particularly lignin content. In fact, we hypothesized that the irrigation system associated with low rainfall was not adequate to the high temperature registered during the study.

Data obtained from cobs showed higher DM for both genotype irrigated by furrow system, while dNDF was higher in cobs of HD genotype irrigated by sprinkler method (respectively 53,03 vs 47.93% sprinkler vs furrow) These findings generally agree with the work of Cox et al. (1994), who found that high temperatures can reduce whole-crop fiber concentration. On the contrary are Erteka and Karaba (2013) reported a small but significant contribution of temperature and water level on NDF, ADF, and lignin variability at silage maturity. Results from Farrè and Faci (2006) indicated that in maize grown on a loam soil in the Mediterranean environment of northeast Spain, significate yield penalties were observed when too much days between two consecutive irrigations around flowering was applied. Nevertheless an excess of water available could influence negatively fiber digestibility of the plants (Van Soest, 1996).

Conclusions

Under the conditions of the present experiment, the irrigation management and genotype contributes to modify the fiber quality of corn in different way. The highest dNDF was observed in HD genotype irrigated by sprinkler system in all part plants. Considering these differences in a nutritional perspective, we can affirm that the nutritive value of the plants obtained from HD genotype under sprinkler irrigation system was higher due an increased dNDF.

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