Animal Feed Science and Technology 172 (2012) 125–135

Contents lists available at SciVerse ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Effects of irrigation and rates and timing of nitrogen fertilizer on dry matter yield, proportions of plant fractions of maize and nutritive value and *in vitro* gas production characteristics of whole crop maize silage

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A R T I C L E I N F O

Article history:
Received 8 March 2011
Received in revised form
24 November 2011
Accepted 29 November 2011

Keywords:
Maize silage
Water
Nitrogen fertilizer
Grain
Stover
Metabolizable energy

A B S T R A C T

The objective of this study was to investigate the effects of contrasting levels of irrigation water and rates and timing of N fertilizer on yield, different fractions of maize plant and their subsequent effects on nutritive value of maize silage. Hybrid forage maize (Pioneer 31H50) was grown at Camden, Australia with two rates of pre-sown (0, 135 kg/ha), three post-sown (0, 79, 158 kg/ha) N fertilizer and four levels of irrigation (0, 153, 305, 480 mm). Each treatment was replicated four times (blocks) with *n* equals 96 (2 × 3 × 4 × 4 plots of 3.5 m × 3.5 m). Maize was harvested at physiological maturity, chopped at a particle length of 2.5 cm and ensiled in micro-silos. Silage samples were analyzed for dry matter (DM), pH, chemical composition, and metabolizable energy (ME) content. Gas production was measured up to 48 h of incubation and then pH of *in vitro* fermented end products was recorded. Additional plant samples from each replication were fractionated into leaf blade, leaf sheath, stem, cob structure and grain. Increase in irrigation water (0–480 mm) increased DM yield from 9.3 to 23.8 t/ha. Increase in irrigation also increased grain from 92 to 315 g/kg DM but decreased stover of plants from 907 to 685 g/kg DM. For silage, increase in irrigation increased neutral detergent fiber (NDF) from 524 to 555 g/kg DM, but decreased crude protein (CP) from 78 to 52 g/kg DM and water soluble carbohydrate (WSC) from 88 to 31 g/kg DM, which resulted in a decrease in ME from 9.82 to 8.81 MJ/kg DM. In contrast to irrigation, application of post-sown N fertilizer increased CP from 57 to 67 g/kg DM and ME from 9.03 to 9.47 MJ/kg DM. There was also an irrigation × pre-sown N fertilizer interaction for NDF and ME contents, but effects of these interactions were minimal compared to the main effects. Overall, increasing irrigation water had a negative effect on the nutritive value of silage by increasing NDF and decreasing CP and WSC and therefore, ME content. This was despite a substantial increase in grain in irrigated treatments. In contrast, application of N fertilizer, in general, increased ME content of silage, due mainly to an increase in CP content. Results indicate that maximization of forage maize yield through increased application of N and water may be compromised by a decreased nutritive value of the subsequent silage.

Abbreviations: ADF, acid detergent fiber; NDF, neutral detergent fiber; CFR, complementary forage rotation; CP, crude protein; DM, dry matter; DMD, dry matter digestibility; ME, metabolizable energy; MJ, mega joule; ML, mega liter; N, nitrogen; WSC, water soluble carbohydrate.

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doi:10.1016/j.anifeedsci.2011.11.013

1. Introduction

Water and nitrogen (N) are widely considered the two most important nutrients that limit production of pasture and crops. Maize crop requires a high amount of water and N inputs for optimum production because of the large amount of dry matter (DM) produced. Garcia et al. (2008) reported a total of 27 t DM/ha from maize in spring–summer (late October – mid February) using 4 mega liter (ML) of irrigation water compared to 17 t DM/ha from pastures for the whole year using ∼8 ML of irrigation water. In many Australian dairy farms, maize is grown for silage which in turn is used to complement cow's diets at times when pasture quality is low (autumn–winter mainly). However, despite the high potential forage yield, the problem of growing maize for silage in many key dairy regions is that high water and N inputs are needed to maximize forage yield. Current predictions of global climate change impact suggest that irrigation water availability may decline in the future globally (World Water Assessment Program, 2009). This situation of declining water availability may impact on future price and availability of irrigation water.

The availability of water can affect not only forage and grain yield but also nutritive value of the maize plant and therefore, the silage made from it. Philipp et al. (2005) reported that the increase in levels of irrigation increases fiber concentration in the plant and reduces ME content of bluestem forages. These researchers concluded that water available for plant use has profound effects on growth and chemical composition of forages due largely to effects on plant maturity, leaf blade: stem plus sheath ratios and rate of senescence. Kiziloglu et al. (2009) reported that the yield of leaf, stem and cob of maize decreased with decreasing levels of irrigation, where grain yield could be nil with zero irrigation depending on the year. These differences in yield of plant fractions due to the differences in levels of available water may also affect the nutritive value of maize silage. Thus, irrigation strategies designed to improve both nutritive value and nutrient yield without compromising each other may be more important than emphasizing either yield or nutritive value of maize alone.

Timing and amount of N fertilizer application to maximize both yield and nutritive value of maize silage are also not unequivocal in the literature. Cox and Charney (2005) found that N fertilizer consistently increases N content of maize forage but its effect on fiber and ME contents were less consistent. Sheaffer et al. (2006) reported that N content of maize forage increased in one site with the increase in N fertilizer, but remained similar in another site. Cheetham et al. (2006) reported no increase in N content of maize grain with the increase in N fertilizer from 0 to 250 kg N/ha. It is possible that responses to N are conditioned by water availability highlighting the need of studying both nutrients together. Kim et al. (2008) reported that water and N fertilizer work synergistically to increase yield and nutrient use efficiency of maize. However, there is no clear information on how combined effects of irrigation water and pre- and post-sown N fertilizer may affect yield, plant fractions and nutritive value of maize silage.

Due to these equivocal results on the effect of N fertilizer and the lack of information on the effect of irrigation water on nutritive value of maize silage, it is necessary to investigate the effect of irrigation water and timing and rates of N fertilizer (and their interactions) on nutritive value and nutrient yield of maize silage. This study therefore investigated the effects of different levels of irrigation water and rates of pre- and post-sown N fertilizer on different plant fractions of maize before ensiling and on the nutritive value of maize silage. It was hypothesized that as irrigation water increased, the expected increase in plant structure (fiber) will be compensated by the increased proportion of maize grain, particularly when N was not limiting.

2. Materials and methods

2.1. Experimental site, soil, climate and treatments

The experiment was carried out during the 2009–2010 growing season at May Farm research site of the University of Sydney, Camden, NSW, Australia (34°04′S; 150°69′E). The climate of Camden is warm-temperate with mild to cool winters and warm to hot summers. Mean total annual rainfall is 738 mm, which is distributed over the autumn and winter seasons. The texture of Camden soil has been characterized (Isbell, 2002) as loamy topsoil resting in a clay subsoil which is slightly acidic (pH 6.3) on the top, but alkalinity increases with the increase in depth. The plots used for this trial were part of a larger study comprising a complementary forage rotation of maize–forage rape-field pea from October 2008 to October 2010.

The experiment was carried out using a 2 × 3 × 4 split-plot design, which consisted of 24 treatments and four blocks. Treatments were two pre-sowing N fertilizer (0, 135 kg/ha) applied a day before sowing, three post-sowing N fertilizer (0, 79, 158 kg/ha) applied at the six-leaf stage (six-leaves with visible collar) and four levels of irrigation water (0.00, 0.33, 0.66 and 1.00 water; *i.e.*, 0, 153, 305, 480 mm). Rainfall during the growing season was 235 mm. Pre-sowing N treatments were assigned to the main plots (half of each block), and irrigation water and post-sowing N fertilizer were randomly allocated to the sub-plots within each main plot.

2.2. Crop management, harvesting, measurement and plant partitioning

Glyphosate (Roundup CT®, glyphosate 450 g a.i./L, Victoria, Australia) herbicide was applied at the rate of 3 L/ha and then the land was ploughed by a manually driven rotary hoe. Pre-sown N fertilizer (0 or 135 kg/ha), phosphorous (P, 70 kg/ha; as sulfur-coated triple super phosphate, 18.5 g P/100 g; Gold Phos 10, Hi-Fert, Victoria, Australia) and potash (K, 200 kg/ha; as muriate of potash, potassium chloride, 50 g K/100 g, Hi-Fert, Melbourne, Australia) were applied to all plots a day before