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Effect of Irrigation Volume on Biomass and Nutritional Value of *Zea mays* L. as Green Hydroponic Forage

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ABSTRACT

Objective: To evaluate the effect of irrigation water volume on biomass production and to quantify the nutritional value of green hydroponic maize forage (GHMF) for sheep.

Design/Methodology/Approach: Three treatments were used to evaluate water irrigation volume: T1) 9.48 L m^2 day^{-1}; T2) 18.95 L m^2 day^{-1}; and T3) 28.43 L m^2 day^{-1}, employing a completely randomized statistical block design. To determine nutritional value, four inclusion levels of GHMF were used (0, 20, 40, 60% DM) in the diet of 16 sheep. A completely randomized statistical design was used as well as a linear regression model.

Results: A greater weight in fresh biomass of GHMF was observed with T3 ($P<0.01$). The values of apparent digestibility of DM, OM, CP, NDF, and ADF of GHMF oscillate between 80 and 89%. The estimated digestible energy was 3.9 megacalories/kg DM.

Study Limitations/Implications: Forage production in the dry tropics is characterized by being markedly seasonal; however, GHMF represents a viable alternative for the rapid and sustainable production of forage with high nutritional value for animals.

Findings/Conclusions: The greatest yields in fresh biomass of green hydroponic maize forage are obtained by using a greater volume of irrigation water. Likewise, the forage has high nutritional value for sheep, with considerable delivery of digestible energy, thus it can be used as an excellent source of forage in animal feeding.

Keywords: Forage, hydroponic, maize, biomass, digestibility.

INTRODUCTION

Green hydroponic maize (*Zea mays* L.) forage (GHMF) is a technology for producing plant biomass from the growth of seedlings from viable seeds, cultivated under controlled environmental conditions (light, temperature, and humidity) in the absence of soil (FAO, 2002). It is a fast-paced (10 to 15 days) forage production system with high safety and nutritional quality, and it can be employed any time of year and in any geographic location, as long as the conditions for it are established (Juárez *et al*., 2013). It has been shown to be an efficient production system because it saves and controls water usage and nutrients, and because of the minimum space requirements from cultivation in vertical modules, it optimizes usable space (Müller *et al*., 2006; Salazar *et al*., 2014; Zagal *et al*., 2016).

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Forage production in the dry tropics is characterized by being markedly seasonal, such that the highest production and the best quality are obtained during the rainy season (Muñoz *et al*., 2016; Merlo *et al*., 2017). This variability in forage quantity and quality throughout the year causes grazing animals to gain and lose weight (Castro *et al*., 2017; Coleman *et al*., 2018), which results in economic losses for farmers. Therefore, GHMF represents a viable alternative for rapid production of clean and sustainable plant biomass with nutritional quality for animal feeding. Some authors, such as Herrera *et al*. (2007) and Acosta *et al*. (2016), mention that it is a food with high protein and energy that can be used for grazing animals in substitution of concentrated feed. However, little is known about the production conditions and nutritional quality of hydroponic forage in the Mexican tropic. Based on the former, this study evaluated the effect of irrigation water volume on the production of biomass using green hydroponic maize forage for sheep, quantifying its nutritional value.

MATERIALS AND METHODOLOGY

The study was conducted in Chiná, Campeche, Mexico (19° 44′ N and 90° 26′ W, at 15 m altitude). The climate is Aw subhumid tropical according to the Köppen classification modified by García (1973), with 1200 mm in annual precipitation distributed between June and November (Duch, 2002). The maximum, mean, and minimum temperatures are, respectively, 36, 26, and 18 °C. The photoperiod is less than 11 h in December and above 13 h in July (UNAM, 1991).

Evaluation of Irrigation Water Volume

Forage production was carried out in 13 d cycles in a production module located within a greenhouse equipped with metal racks and tray holders, and completely protected by a bicolor, anti-aphid mesh. Maize seeds (*Zea mays* L.) were used with a 95% germination rate, free of impurities and agrochemicals. The seeds underwent a pre-germination stage, they were washed and disinfected with 3% NaClO for 20 min and soaked in water for 24 h. Later, they were placed in plastic trays measuring 60×37×7 cm, with a planting density of 45 kg m^{2-1}. For germination and to inhibit the development of fungi and phytopathogens, the trays were left for 48 h in a completely sealed dark chamber or area. Once the seeds germinated, the trays were fitted into the metal racks two levels high (top and bottom), with a distance of 0.50 cm between each level. Irrigation was carried out using an automated system equipped with sprayers and a potential output of 31.8 L h^{-1}. To evaluate the volume of irrigation water, three treatments were used: T1) 9.48 L m^2 day^{-1}; T2) 18.95 L m^2 day^{-1}, and T3) 28.43 L m^2 day^{-1}. Each treatment was applied in five waterings per day with a duration of two to three minutes and with two-hour intervals, from 9:00 a.m. to 5:00 p.m., for a period of 8 d starting on day four of plant development. Per treatment, 24 repetitions were carried out, where each tray represented one experimental unit. The plants were fertilized on days 7, 9, and 11 of the cycle in a single morning application, using a solution of 0.1 mg KNO_3, 0.2 mg phosphonitrate (33-3-0), and 0.02 mL H_3PO_4/L water using a Venturi system. Starting on day five, daily recordings were made of the plant's root layer height, plant height (from the root neck), and fresh biomass weight (seeds, roots, and plants). The plants were harvested on day 13 of the production cycle. A completely randomized statistical block design was applied (Montgomery, 2004), using the level of the tray holder in the rack as the block criterion, and the results were analyzed using a linear model with the Proc GLM procedure of the SAS statistical package (SAS Inst. Inc., 2003).

Determining Nutritional Value of GHMF

At the end of the production cycle (day 13) of the GHMF, samples of approximately 500 g were taken to determine its dry material content (DM), organic material content (OM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF), according to the procedures recommended by the AOAC (2016). The nutritional value of the GHMF was estimated by the *in vivo* digestibility technique (Rodríguez and Llamas, 1990) using 16 adult male Pelibuey sheep with an average live weight ±standard deviation (DE) of 35.2±.4 kg. They were placed in individual metabolic cages made of wood and equipped with a feeder, water dispenser, and collector of feces and urine. The animals were assigned, through a completely randomized statistical design (Montgomery, 2004), four treatments that consisted of different GHMF inclusion levels (0, 20, 40 and 60% BS) in their diet based on commercial feed with 15% crude protein. Each treatment had four repetitions and each of these consisted of one animal in a metabolic cage. Before the start of the trial, the animals were treated for parasites internally (Ivermectin™) and given a 14 d period to adapt to the diets and cages. The commercial feed was provided first in the morning, and the GHMF was provided after 12:00 p.m. A 7 d period of measurements followed, in which the total quantity of feces produced per day was recorded, as well as food and GHMF consumption, weighing daily the amounts offered and rejected. Once the total production of feces was determined, feces samples (10%) were collected as well as samples of feed and GHMF offered and rejected daily, in order to have compound samples at the end of the measurement period. These were preserved frozen at minus 20 °C until their DM, OM, CP, NDF, and ADF content was determined in a laboratory according to procedures described by the AOAC (2016). The apparent digestibility of the different diets was determined and a linear regression analysis was carried out with the different levels of GHMF inclusion in the diet. Based on the presented regression model, an equation was calculated for each of the variables studied to estimate the total apparent digestibility of the GHMF. The results were analyzed using a repeated measurements and linear regression model, using the Proc Mixed and Proc Reg procedures from the SAS statistical package (SAS Inst. Inc., 2003).

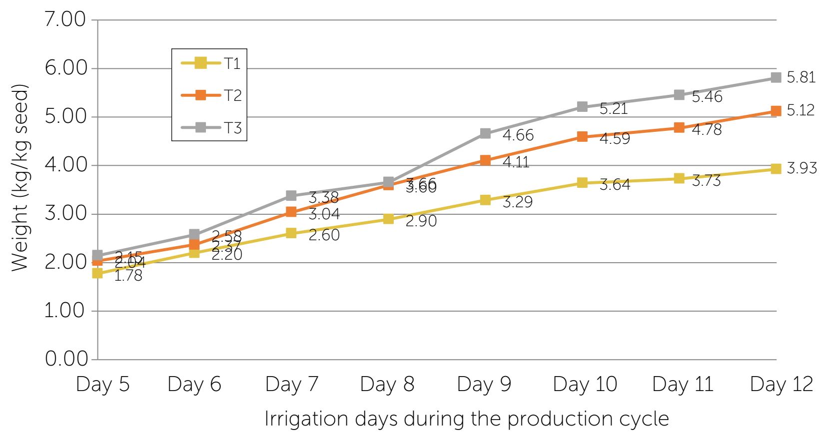

Figure 1. Effect of irrigation water volume on biomass production during the cycle of green hidroponic maize forage (GHMF). (T1=9.48 L/m^2 day^{-1}; T2=18.95 L/m^2 day^{-1}; T3=28.43 L/m^2 day^{-1}).

RESULTS AND DISCUSSION

Effect of Irrigation Water Volume

The irrigation water volume was observed to have a significant effect on the different evaluated variables (Table 1). The highest weight of fresh biomass (5.81 kg for each kg of maize seed) was obtained from the treatment with the most irrigation water volume (T3), higher by 1.9 and 0.7 kg of biomass for each kg of seed in comparison to T1 and T2, respectively ($P<0.01$). This greater production of fresh forage was linearly maintained during crop development, becoming more evident starting on day eight of the production cycle (Figure 1). High quantities of water and high watering frequencies have been reported to improve the agronomic characteristics of the maize plants (Jahanzad *et al*. 2013). Other authors, like Zagal *et al*. (2016), report lower total yields of GHMF (3.5 kg of biomass for every kg of seed) harvested at 13 d. This could be because fertilizer was not used in the crop and they used a conventional irrigation system, at a rate of one liter of water kg^{-1} of maize every 24 h. Authors like Vargas *et al*. (2008) mention that with an irrigation and fertilization system similar to that used in this study, they observed GHMF yields of 4.3 kg of biomass per kg of seed at 10 d of cultivation, which explains in part the differences observed due to reduced time in the production cycle. The differences in the reports found can be attributed also to the quality and variety of the utilized seed, since these are the principal factors that affect maize forage production (Pérez *et al*., 2006; Salas *et al*., 2010). Greater root layer and plant height was detected in T2 and T3 compared to T1 ($P<0.01$).

No significant differences were found for these variables between T2 and T3 ($P>0.05$). The plants that were on the bottom rack level registered significantly greater ($P<0.01$) height (23, 85 cm) and fresh biomass weight (5.31 kg of biomass per kg of seed), compared to those that were located on the top level (19.70 cm and 4.6 kg of biomass per kg of seed for both variables,

Table 1. Effect of irrigation water volume on growth and biomass production of green hidroponic maize forage (GHMF).

Variable	Treatments			P Value	SEM
	T1	T2	T3		
Root layer height (cm)	4.437a	5.738b	5.925b	0.0001	0.573
Plant height (cm)	18.067a	22.583b	24.675b	0.0001	5.141
Total weight of fresh biomass (kg/kg seed)	3.930a	5.123b	5.809c	0.0001	0.636

Different letters in the same row indicate statistical difference ($P\leq0.01$).
SEM=Standart error of the mean. T1=9.48 L/m^2 día^{-1}; T2=18.95 L/m^2 día^{-1}; T3=28.43 L/m^2 día^{-1}.

respectively). This is due to the fact that the bottom rack level has less sun exposure, which causes more competition and stimulates the vertical development of the plant by effect of cell wall elongation (Montemayor *et al*., 2006; Lambers *et al*., 2008), thus increasing biomass production.

Table 2. Regression equations for estimating the apparent digestibility of green hidroponic maize forage (GHMF).

Component	Regression equations	r	RMS
Dry matter	DDM=92.144−0.0315*X	0.53	2.56
Organic matter	DOM=91.729−0.0292*X	0.54	2.06
Crude protein	DCP=83.074−0.0413*X	0.48	6.33
Neutral detergent fiber	DNDF=78.5057+0.0549*X	0.59	5.41
Acid detergent fiber	DADF=77.6158+0.0464*X	0.54	5.75

RMS=Residual mean square.

Nutritional Value of GHMF

The linear regression equations obtained in order to estimate the apparent digestibility of the different GHMF components are shown in Table 2. The slopes of the straight line for DM, OM, and CP had negative values, that is, for each 1% increment of GHMF in the diet, digestibility decreased 0.03, 0.03 and 0.04% for these components, respectively. In contrast, an increase of 0.05% in the digestibility of NDF and ADF was observed for each unit of change in the ration's GHMF level. Correlation coefficients above r=0.50 were observed in the majority of the components evaluated, with the exception of CP digestibility, which had r=0.48, considered to be moderate ($P>0.05$). The residual values (RMS) ranged between 2 and 5.7%, which indicated low data variability.

The estimated digestibility percentages of GHMF (Table 3) showed 89% digestibility for DM and OM, while CP, NDF and ADF had percentages above 80%. Other authors (Herrera *et al*., 2007), using *in vivo* digestibility samples in sheep, observed digestibility values for the DM of GHMF of 56%, which is below that reported in this study. However, Acosta *et al*. (2016), using the same method in goats, reported very similar digestibility for DM (93%), OM (85%), and CP (80%) of the GHMF compared to those in this study. It is important to note that the low digestibility percentages of DM obtained by Herrera *et al*. (2007) could be due to the experimental conditions in which the study was conducted and to the characteristics of the plant material used. The digestibility values for NDF and ADF were above those obtained with other conventional forages (Naranjo and Cuartas, 2011; Coblentz *et al*., 2019). This could be because of the physical characteristics of the GHMF, since it is a seedling composed mainly of young leaves with more digestible cell walls. Based on the digestibility of DM, the digestible energy of the GHMF was estimated (NRC, 1984), resulting in a value of 3.9 megacalories kg^{-1} of DM, this being very similar to that reported for maize grain (NRC, 1985).

CONCLUSIONS

The highest yields of fresh biomass in green hydroponic maize forage are obtained by using greater volumes of irrigation water. The forage shows highly nutritional values for sheep, with a considerable availability of digestible energy, thus it can be used as a source of quality forage in animal feeding.

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Table 3. Estimated apparent digestibility values of green hidroponic maize forage (GHMF).

Component	Digestibility (%)
Dry matter	88.99
Organic matter	88.81
Crude protein	79.94
Neutral detergente fiber	83.99
Acid detergent fiber	82.25
Energy (Mcal/kg DM) *	3.91

*Estimated based on the NRC (1984): Digestibility=4.4 (Dry matter digestibility %)/ 100. Mcal=Megacalories.

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