Article

Depth of irrigation tape and solarized manure in the production and quality of forage corn

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Abstract

The use of organic fertilizers such as bovine manure and subsurface drip irrigation are alternatives that minimize the use of fertilizers and improve water use efficiency. The objective of the research was to evaluate the depth of drip irrigation tape at 0.3, 0.15 and 0.05 m and doses of solarized bovine manure at 50, 75 and 100 t ha^{-1} and a control with traditional fertilization in the production and bromatological quality in forage corn. The application of manure and the depth of the irrigation tape showed significant differences compared to traditional fertilization. The highest forage yield was for the treatment with a depth of irrigation tape of 0.3 m and 50 t ha^{-1}, on the contrary, the lowest was for irrigation tape with a depth of 0.05 m and traditional fertilization. The manure dose with 75 t ha^{-1} achieved the highest dry forage production with 22.43 t ha^{-1}. The highest efficiency in water use occurred with the tape depth at 0.15 m. Regarding the bromatological quality, this was higher in the treatments where manure and irrigation tape at depths of 0.15 and 0.3 m were applied. With the use of bovine manure and subsurface drip irrigation, fertilization is decreased and the efficient use of water in the production of forage corn is improved.

Keywords: bromatological quality, solarized bovine manure, water productivity.

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Introduction

The main source of food for housed cattle in the Comarca Lagunera are forages (corn, alfalfa, sorghum and oats), which occupy more than 70% of the cultivated area (SADER, 2021). Forage corn occupies the largest cultivated area in the region with 48 793 ha under gravity irrigation (13 834 ha) and pumping (34 595 ha) (SADER, 2021).

To increase the productivity of forages, excessive amounts of fertilizers and water are used (Reyes *et al*., 2020), which is limited and scarce in arid and semiarid regions of the world, in this agroecological zone, the prevailing irrigation system for the cultivation of forage corn is the gravity irrigation system (SADER, 2021), which is very inefficient in water use (Reyes *et al*., 2020).

Subsurface drip irrigation (SDI) improves water use efficiency and decreases the volume applied by up to 44% with respect to the gravity irrigation system (Gutiérrez *et al*., 2017). SDI increases yield and water use efficiency in forage crops, since it reduces losses due to evaporation and deep soil percolation (Sandhu *et al*., 2019).

The use of fertilizers increases crop yields; however, overfertilization and poor soil management accelerate its deterioration. Given this situation, the use of organic fertilizers is a sustainable agricultural practice, since it contributes to maintaining the natural fertility of the soil (Bonanomi *et al*., 2020), as it is a source of nutrients and an improver of soil (Cai *et al*., 2019). In the Comarca Lagunera, about one million tonnes of bovine manure are produced (Ramírez *et al*., 2016), which can be used to reduce or replace inorganic fertilization, as it is an organic source of nutrients for crops (Figueroa *et al*., 2010).

Various studies have been conducted separately to evaluate different SDI systems at different depths of irrigation tape (Salomó *et al*., 2019), or different doses of bovine manure (Salazar *et al*., 2010). However, studies that evaluate the depth of irrigation tape and solarized manure in forage corn in the Comarca Lagunera have not been carried out. For this reason, the objective of the research was: to evaluate the effect of three depths of drip irrigation tape and different doses of solarized bovine manure on the production and bromatological quality in forage corn (*Zea mays* L.).

Materials and methods

The study was carried out in the La Laguna Experimental Field (CELALA), of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), located at 25° 32’ north latitude and 103° 14’ west longitude, at 1 150 masl. The texture of the soil is loamy-clayey (28% sand, 40% clay, 32% silt). The climate of the region is classified as dry semi-warm, (Bwh) (García, 2004), with an average temperature of 22.6 °C, average annual rainfall of 227 mm and evapotranspiration (ET) of 2 000 mm (Villa *et al*., 2005).

The solarization of bovine manure was carried out on mounds 5 m long by 1 m wide with a height of 0.8 m for 90 days. The plastic used was transparent polyethylene 30 microns thick. The mounds were covered in such a way that the edges were sealed, and the plastic was in full contact with the manure, to avoid loss of humidity and temperature.

At the end of the solarization period, the manure was analyzed in chemical form, yielding the following results: pH: 7.79, electrical conductivity (EC): 6.8 dS m^{-1}, OM: 5.35%, total nitrogen: 0.86%, NH_4: 0.084%.

The preparation of the land consisted of subsoiling, fallow, incorporation of solarized manure (SM), harrowing, leveling and placement of the irrigation tape. The sowing was carried out dry, the distance between plants was 12 cm and 76 cm of separation between furrows to have a population density of 105 000 plants ha^{-1}. The commercial hybrid 20W41 (Syngenta) was used, which is of intermediate cycle, under conventional sowing, tolerant to lodging, with good plant and cob health.

An experimental design of split plots in random blocks with three repetitions was used. The different doses of solarized manure were considered as large plot (50, 75 and 100 t ha^{-1}) and a control with inorganic fertilization (200-100-00 kg ha^{-1} of N-P_2O_5-K_2O), while the depth of the irrigation tape (0.3, 0.15 and 0.05 m) was the small plot, each small plot was made up of four furrows of 5 m in length and a distance between furrows of 0.76 m (15 m^2). One hundred percent of the phosphorus and 50% of the nitrogen dose corresponding to each treatment were applied at the time of sowing to later apply the establishment irrigation. At 34 days after sowing (DAS), a cultivation and hilling work were carried out with a moldboard plow, to break the ‘crust’ of the soil, remove weeds and apply the rest of the nitrogen.

The irrigation tape used was RO-DRIP 8 000 (Rivulis Irrigation Inc., San Diego, CA, USA) with a wall thickness of 0.2 mm, inner diameter of 16 mm, with emitters 0.2 m apart and an expenditure of 0.5 L h^{-1} per dripper. The operating pressure of the irrigation system was 8 PSI with a frequency of irrigation every third day. The irrigation time was the same for the three depths. The reference ET was taken from an atmometer (ETgage, model A, marketed by ETgage Company Loveland, Colorado, USA) that was 20 m from the experimental plot.

The leaf area index (LAI) was determined each week using the PAR/LAI ceptometer, model Lp-80 of ACcuPAR (Decagon Devices, Inc. Pullman, WA, USA). The bar of the ceptometer was placed at an angle of 45° through the crop furrow to measure the interception of photosynthetically active radiation (PAR) along the bar. The interception of photosynthetically active radiation PAR was measured between 12:00 and 14:00 h in each treatment and in each repetition, taking three readings above and below the crop canopy (Reyes *et al*., 2019).

The readings with the SPAD (Soil Plant Analytical Development) equipment were taken weekly in two plants of each experimental unit. The measurements were made on the youngest completely expanded leaves, in the middle part between the base and the apex of the leaf, at the end the average of three readings per plant was recorded. The final height of the plant was taken at the time of harvest. Two plants per treatment were measured from the base of the stem to the ear with a tape measure. The harvest was carried out manually, at 105 DAS when the maturation of the grain had a third of advance of the milk line.

The production of green forage was estimated by weighing the biomass of three linear meters in the two central furrows of each treatment (4.56 m^2), then a sample of 500 g was taken and dried in a forced-air oven at a temperature of 65 ° C for 72 h, to then determine the production of dry forage, by the percentage of dry matter and the production of green forage.

Water use efficiency (WUE) was obtained by dividing the yield of harvested dry forage (kg) by the total volume of water used (m^3) in each treatment. For bromatological quality, samples of 200 g of each treatment per repetition, previously ground, were taken, deposited in plastic bags, to be sent to the laboratory and determine the nutritional content by near-infrared reflectance spectroscopy (NIRS).

For this, subsamples of 100 g were taken and ground in a laboratory mill (Arthur H. Thomas Co. Philadelphia, PA) to pass through a 1 mm mesh and obtain the results in the NIRS equipment using preset correlations with wet chemistry analysis (Valenciaga and Simoes, 2006). The parameters evaluated were: neutral detergent fiber of organic matter (NDFom), crude protein (CP), lignin, starch, net energy of lactation (NEL) and neutral detergent fiber digestibility at 30 h of incubation (NDFD-30 h).

The determination of crude protein (CP) was performed following the official methods of the AOAC (2005). The CP was quantified with the microKjeldhal method, while the fat content was by means of the Soxhlet method using a Goldfish extractor (Labconco, USA). The percentages of acid and neutral detergent fibers (ADF and NDF) were quantified with the method of fractionation with detergent and subsequent filtration (Van Soest *et al*., 1978).

To determine if there were significant differences in the response variables, an analysis of variance was performed on each variable using the GLM procedure of SAS, when statistical differences were detected ($p\leq 0.05$), the Tukey mean separation test ($p\leq 0.05$) was applied, using the SAS 9.3 statistical package (SAS Institute Inc., Cary, Nc. USA).

Results and discussion

Leaf area index

The values of LAI were affected by the treatments under study (Figure 1a), in general at the beginning it presents a slow growth, followed by a greater increase in the vegetative stage, until reaching a maximum value and then gradually decreasing due to the senescence of the leaves when the crop reaches its physiological maturity.

The highest LAI was 6.56 for the treatment with 50 t ha^{-1} of solarized manure and a depth of the irrigation tape of 0.3 m, exceeding the LAI obtained by the control treatment by 20%, the above is probably due to the fact that in this treatment there was a greater water stress in the plant which induces less transpiration, less CO_2 absorption and reduction in photosynthesis, Montemayor *et al*. (2012), due to lower soil moisture; these same authors report similar LAI values, obtaining maximum LAI values of five and six in corn production with subsurface drip irrigation. Reyes *et al*. (2019) found low LAI values in the treatments where there was low soil moisture in a corn sown in South Dakota, USA.

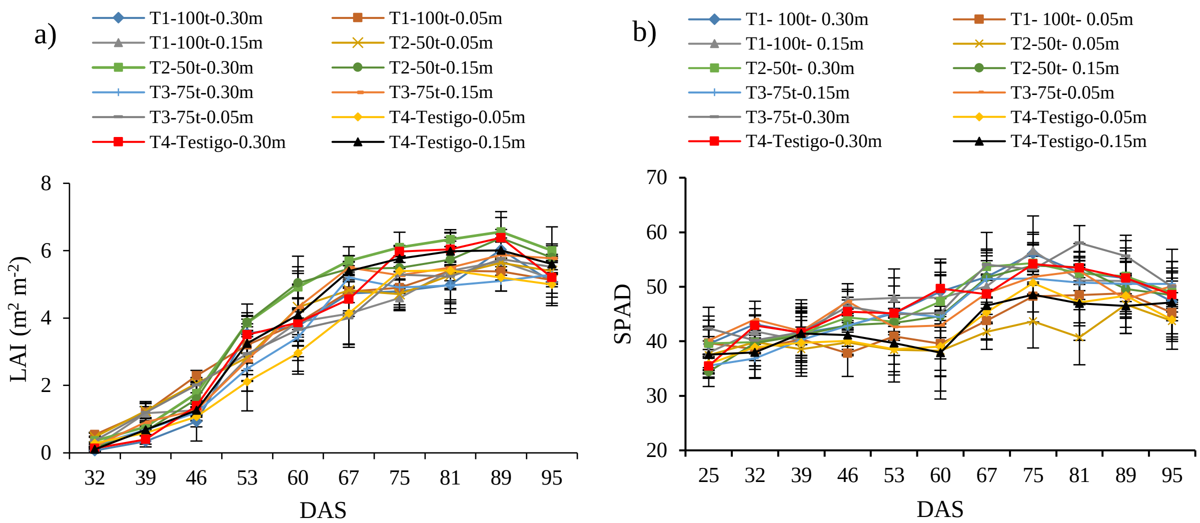

Figure 1. Behavior of LAI (a) and SPAD values (b) in three doses of manure and one chemical fertilization and three depths of irrigation tape. The vertical bars indicate the standard deviation of each of the treatments.

Chlorophyll index

SPAD values in corn leaves were different for manure and chemical fertilization (Figure 1b). In the initial stages, the SPAD values showed a similar behavior, because in the initial development stages of the corn crop, there is little demand for nutrients by the plant, so the use of SM allows nutrients to be available. At this stage, SPAD values below 35.3 are equivalent to an N content of 1.83% in the leaves, which indicates that it is necessary to apply N (Castellanos *et al*., 2017); however, after the 46 DAS, there were differences between the treatments. The lowest values were for those of 50 t ha^{-1} of manure and the control with 37.43 and 48.55 SPAD units, respectively, on the contrary, the treatment with 75 t ha^{-1} and a depth of 0.3 m of irrigation tape had the highest values with a range of 40.17 to 58.02 SPAD units.

These values are considered suitable for the cultivation of corn since, according to Castellanos *et al*. (2017), greenness index values above 50 SPAD units are decisive for a good yield of the forage corn crop because the greenness index is related to the nitrogen content, therefore it has an impact on the yield of the crop. Ávalos *et al*. (2018) obtained similar results, obtaining higher results with similar applications of bovine manure (80 t ha^{-1}) compared to chemical fertilization in the production of forage corn.

Plant height

The treatments evaluated showed significant differences for plant height (PH), green forage (GF), dry forage (DF) and water use efficiency (WUE) (Table 1). The treatment with 100 t ha^{-1} of SM and an irrigation tape depth of 0.3 m had the highest height with 2.04 m, followed by the treatment of 50 t ha^{-1} with depth of 0.3 m; however, this treatment but with an irrigation tape depth of 0.05 m had the lowest height with 1.56 m, this is because the irrigation tape is on the surface, therefore evaporation is greater and the moisture in the root system of the crop is lower, which affects the good development of the crop. Reyes *et al*. (2020) comment that the highest heights are obtained with SDI, since, with this system, moisture is always available in the root zone of the crop compared to the surface drip irrigation system.

The plant height obtained in this research paper is similar to those reported by López *et al*. (2015), who obtained taller plants with the application of bovine manure due to the nutritional contributions provided by manure as it increases the production of biomass in plants. Similar results were observed by Ávalos *et al*. (2018), who obtained the highest heights in the treatments where organic fertilizers were applied.

Biomass production

The production of green and dry forage was affected by the different treatments evaluated (Table 1), the use of SM promoted the highest average yields of green and dry forage, with 75.29 and 24.21 t ha^{-1}, with manure doses of 50 t ha^{-1} and with an irrigation tape depth of 0.3 m. This is attributed to the fact that there is practically no moisture on the surface of the soil, therefore, the evaporation process decreases and allows preserving the moisture content in the soil directly in the root zone of the plant (Montemayor *et al*., 2012).

Table 1. Effect of solarized manure and irrigation tape depths on plant height (PH), yield of green forage (GF), dry forage (DF) and water efficient use (WUE) in forage corn.

Treatments		Variables			
Dose (t)	Depth (m)	PH (m)	GF (t ha^{-1})	DF (t ha^{-1})	WUE (kg DF m^{-3})
100	0.3	2.04 a*	65.16 abc	22.48 ab	3.27 ab
100	0.15	1.93 a	65.71 abc	22.85 ab	3.75 ab
100	0.05	1.77 ab	54.9 c	18.86 abc	3.44 ab
75	0.3	1.85 ab	67.68 ab	23.55 ab	3.43 ab
75	0.15	1.91 a	64.10 bc	22.54 ab	3.69 ab
75	0.05	1.78 ab	60.81 bc	21.2 abc	3.87 a
50	0.3	1.96 a	75.29 a	24.21 a	3.52 ab
50	0.15	1.9 a	66.88 ab	22.01 abc	3.61 ab
50	0.05	1.56 b	55.19 c	19.55 abc	3.56 ab
Chemical	0.3	1.94 a	67.47 ab	20.7 abc	3.02 ab
Chemical	0.15	1.8 ab	64.1 bc	18.01 bc	2.95 b
Chemical	0.05	1.74 ab	56.72 bc	16.64 c	3.03 ab

*= different letters are significantly different according to the Tukey test ($p \leq 0.05$).

In contrast to treatments in which the irrigation tape was on the surface (0.05 m), the production of green and dry forage was lower 27 and 22%, respectively. The yields obtained in this research exceed those reported by Yescas *et al*. (2015), who had an average green forage yield of 52.30 t ha^{-1} in forage corn irrigated with drip irrigation without the use of manure, hence the importance of using an organic fertilizer such as solarized bovine manure, its addition modifies the water-soil-plant system by providing nutrients and decreasing the negative effects of moisture deficit stress, which could be observed due to the positive effects on plant height and production of green and dry forage (Santoyo *et al*., 2017).

Water use efficiency

WUE was superior with the use of SM in relation to traditional fertilization (Table 1). The greater WUE corresponds to the treatment with 75 t ha^{-1} of manure and with the irrigation tape on the surface (0.05 m) (3.87 kg DF m^{-3}), surpassing the WUE achieved by the treatment with chemical fertilization (2.95 kg DF m^{-3}) by 24%. These values were different from those reported by Reyes *et al*. (2018), who found no significant difference between the use of manure and chemical fertilization in corn with drip irrigation. On the other hand, Conde *et al*. (2021) found a statistically significant difference between WUE values at three different depths of irrigation tape (0.1, 0.2 and 0.3 m), being different from what was reported in the present work. However, similar WUE values have been reported in forage corn under different levels of drip irrigation, finding values from 2.98 to 3.24 kg DF m^{-3} (Montemayor *et al*., 2007).

In the present work, the greater WUE on average was achieved with the depth of irrigation tape at 0.15 m, since it obtained yields similar to the treatment with depth of 0.3 m, but with less irrigation sheet (61 cm). These results coincide with Reyes *et al*. (2020), who report that applying greater irrigation sheets will not always result in greater efficiencies in water use. In general, with the use of solarized bovine manure and subsurface drip irrigation, it is possible to replace traditional chemical fertilization and improve the WUE in forage corn production.

Bromatological quality

Crude protein

Forage CP is one of the best indicators of nutritional quality, as it regulates digestibility and, therefore, production in ruminants (Mejía, 2002). The results obtained showed that the use of manure in general improved CP yield (Table 2). The application of 75 t ha^{-1} of SM and a depth of the irrigation tape at 0.3 m achieved the highest CP yields (1 891 kg ha^{-1}); on the other hand, the lowest yield of this nutrient corresponded to traditional fertilization and irrigation tape on the soil surface (0.05 m) (1 407 kg ha^{-1}).

Although nitrogen fertilization increases the content of CP (Barrios and Basso, 2018), the results of this study may be due to the fact that nitrogen fertilization causes a high content of inorganic nitrogen in the soil, which is probably not required and used by the plant at that time, so it begins to be lost by leaching or volatilization, thus decreasing the accumulated nitrogen (Larios *et al*., 2021). This explains why in the treatments with manure, CP yields are superior to treatments with chemical fertilization, because the mineralization of manure is gradual and prolonged during the crop cycle, unlike chemical fertilization. Larios *et al*. (2021) mention that nitrogen losses occurred from 24 h after application. Similar results were obtained by García *et al*. (2019), who evaluated different doses of fertilizers in forage corn in the Comarca Lagunera, although higher than those found by Osuna and Martínez (2017), who evaluated forage yield and quality in rainfed corn and sorghum.

Table 2. Yield of neutral detergent fiber (NDF), crude protein (CP), acid detergent fiber (ADF), lignin, starch, net energy of lactation (NEL), *in vitro* digestibility of NDF at 30 h of incubation (NDFD30h) of corn forage.

Treatments		Nutrient yield						
Dose (t)	Depth (m)	Y-NDFom (kg ha^{-1})	Y-CP (kg ha^{-1})	Y-ADF (kg ha^{-1})	Y-lignin (kg ha^{-1})	Y-starch (kg ha^{-1})	Y-NEL (Mcal kg)	Y-NDFD30h (kg ha^{-1})
100	0.3	8 448 abcd	1 728 ab	5 319 abc	1 079 abcd	8 507 a	3 6195 a	4 623 abcd
100	0.15	9 948 abc	1 808 ab	6 160 ab	1 129 abc	6 684 ab	3 4517 ab	5 505 abc
100	0.05	7687 cd	1 612 ab	4 681 c	860 cde	5 923 bc	29 799 abc	4 367 cd
75	0.3	10 084 ab	1 891 a	6 126 abc	1 137 ab	7 003 ab	36 275 a	5 801 a
75	0.15	9 601 abcd	1 846 ab	6 077 abc	1 134 abc	6 375 b	34 041 ab	5 309 abcd
75	0.05	8 805 abcd	1 732 ab	5 444 abc	1 026 abcde	6 984 ab	32 872 abc	4 859 abcd
50	0.3	10 296 a*	1 823 ab	6 433 a	1 196 a	7 608 ab	37 048 a	5 643 ab
50	0.15	9 573 abcd	1 829 ab	5 903 abc	1 094 abcd	6 189 bc	33 467 ab	5 127 abcd
50	0.05	7 606 d	1 632 ab	4 775 bc	909 bcde	6 521 b	31 090 abc	4 172 d
Chemical	0.3	9 131 abcd	1 638 ab	5 715 abc	1 084 abcd	5 830 bc	30 851 abc	5 011 abcd
Chemical	0.15	7 886 bcd	1 598 ab	4 944 bc	836 de	4 412 cd	27 028 bc	4 399 bcd
Chemical	0.05	7 680 cd	1 407 b	4 709 c	794 e	3 742 d	24 630 c	4 414 bcd

*= different letters are significantly different according to the Tukey test ($p \leq 0.05$).

Neutral detergent fiber and acid detergent fiber

The different treatments showed significant differences in NDFom (Table 2). The treatment of 50 t ha^{-1} with a depth of 0.3 m had the highest yield of NDFom with 10 296 kg ha^{-1}, surpassing the rest of the treatments, with the same treatment, but with a depth of irrigation tape of 0.05 m, being the one with the lowest yield (7 606 kg ha^{-1}). Similarly, the treatment of 50 t ha^{-1} with an irrigation tape depth of 0.3 m was the one that had the maximum value (6 433 kg ha^{-1}) of ADF. The minimum ADF value was with the treatment of 100 t ha^{-1} with tape depth of 0.05 m.

The higher fiber yields may be associated with a better development of the crop in the treatment where 50 t ha^{-1} of N and a tape depth of 0.3 m were applied, obtaining the highest yield of forage in this treatment. It is possible that the crop in this treatment developed a higher proportion of stems compared to the other treatments and consequently, the fiber yield in general was increased. This is specifically considering that fiber is found mainly in the stem of forages (Van Soest, 1994). (Olague *et al*., 2006); (Yescas *et al*., 2015) found significant differences between NDF and ADF values in corns established under subsurface drip irrigation.

Lignin

Significant differences in lignin were observed between the treatments, the treatment of 50 t ha^{-1} with tape depth of 0.3 m was the one that had the highest yield (1 196 kg ha^{-1}) of lignin, while the minimum value was for the treatment with chemical fertilization (794 kg ha^{-1}). Lignin yields in this study were similar (806 kg ha^{-1}) to those reported by Ochoa *et al*. (2012), who tested two sources of nitrogen and two irrigation systems in the production and quality in forage corn.

In vitro digestibility of neutral detergent fiber at 30 h incubation

NDFD30h yields fluctuated between 4 172 and 5 801 kg ha^{-1}, with significant differences between treatments. The highest yield of NDFD30h was for the treatment with a dose of 75 t ha^{-1} and tape depth of 0.3 m. Zaragoza *et al*. (2019) mention that the digestibility of NDF is positively correlated with feed consumption. That is, as the digestibility of NDF in a forage increases, feed consumption in animals increases, and therefore milk or meat production is improved. Therefore, the results with higher yield of NDFD30h, as is the case of the treatment of 75 t ha^{-1} with tape depth of 0.3 m, can contribute mostly to improve consumption in animals when using this forage. Fortis *et al*. (2009) report similar results with the application of organic fertilizers and underground drip irrigation, as well as Salazar *et al*. (2007), who applied bovine manure in forage corn.

Starch

Significant differences in starch yield were observed between treatments (Table 2). The range fluctuated from 3 742 to 8 507 kg ha^{-1}. The lowest value corresponded to the treatment with chemical fertilization with tape depth of 0.05 m and the highest value to the treatment with manure of 100 t ha^{-1} with tape depth of 0.3 m. The highest starch yields occurred in the treatments where 100 and 75 t of manure with buried tape were applied, while the lowest occurred in chemical fertilization. It is possible that the low mineralization of the N of manure with respect to chemical fertilizer led to a greater availability of N for the plant when it was in the grain filling stage (Castellanos *et al*., 2017). Therefore, the crop in the treatment with manure had higher grain production.

Net energy of lactation

Regarding the yield of NEL, there were significant differences between the treatments. The treatment with dose of 50 t ha^{-1} of manure and a depth of 0.3 m obtained the best yield (37 048 Mcal kg^{-1}), unlike that of chemical fertilization with depth 0.05 m (24 630 Mcal kg^{-1}), which obtained the lowest yield. Fortis *et al*. (2009) evaluated the application of organic fertilizers and chemical fertilization in the production of forage corn with drip irrigation and obtained better results in the treatments with chemical fertilization.

Conclusions

The highest production of dry forage occurred in the treatments with tape buried at 0.15 and 0.3 m deep, this because the water reaches directly to the root area of the crop and the loss of water by evaporation is less than in the surface stratum. The efficiency in the use of water in general was greater in the treatment where the tape was buried at 0.15 m. Regarding the application of solarized manure, the dose with 75 t ha^{-1} was the one that had a higher average in the production of dry forage (22.43 t ha^{-1}). In general, treatments with doses of manure were higher than the control treatment, exceeding it from 14 to 18%. This means that it is possible to replace the chemical fertilizer with the application of solarized bovine manure. In addition, with the use of manure, the efficiency in the use of water was greater. As for the yield of nutritional quality of forage, the treatments where manure and irrigation tape at depths of 0.15 and 0.3 m were applied were the ones that showed the best results.

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