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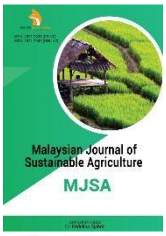

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RESEARCH ARTICLE

RESPONSES OF CORN SILAGE TO SOWING PATTERN UNDER SUBSURFACE DRIP IRRIGATION IN A SANDY SOIL

Abdel Aziz Hassane Sidikou[a], Saad Drissi[b*], Ahmed Bouaziz[a], Ahmed Bamouh[a], Khalid Dhassi[c], Yousra El-Mejjaouy[d], Hicham El Hajli[e], Abdelhadi Ait Houssa[c]

[a] *Department of Plant Production, Protection, and Biotechnology, Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco.*
[b] *Department of Agronomy and Plant Breeding, National School of Agriculture, Meknes, Morocco.*
[c] *Agricultural Training and Research Center, Providence Verte company, Rabat, Morocco.*
[d] *AgroBiosciences program, University Mohamed VI Polytechnic.*
[e] *Moroccan agricultural cooperative, Taroudant, Morocco*
**Corresponding author email: sdrissi@enameknes.ac.ma*

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ABSTRACT

The subsurface drip irrigation technique is introduced in many agricultural areas of Morocco, particularly in the forage production systems. This study aims to determine the optimal sowing pattern of forage corn equipped with a subsurface drip irrigation system. A field experiment was carried out on sandy soil. Five rows spacing were evaluated: 40 cm, 55 cm, 70 cm, 85 cm, and 100 cm. The sowing rate was around 120000 plants ha^{-1}. The subsurface irrigation system consisted of drip lines buried at 30 cm and separated by 100 cm with 1 L h^{-1} emitters and 50 cm as emitters spacing. The results revealed that the fraction of PARi and the accumulated PARi were not influenced by the sowing pattern. The highest corn dry biomass was recorded at 40 cm, 70 cm, and 85 cm row spacing. The biomass increase was mainly attributed to grain yield. The lowest irrigation water use efficiency was recorded at 100 cm row spacing (4.3 kg m^{-3}). Concerning the forage quality, the sowing pattern did not influence the net energy for lactation and other forage quality parameters.

KEYWORDS

corn, sowing pattern, subsurface drip irrigation, productivity, forage quality

1. Introduction

Corn is one of the most produced cereal species in the world (Wrigley, 2017). It is a major forage for ruminants due to its high dry matter yields and low-cost production (Allen et al., 2003). The optimization of corn yielding was related to reasonable irrigation using an efficient technic (Henry and Krutz, 2016). In Morocco, the program of economy and valorization of irrigation water launched in 2009 resulted in large-scale use of the drip irrigation techniques. Therefore, surface drip irrigation became commonly used for corn production. Also, some producers are introducing subsurface drip irrigation for corn silage. Many authors reported that subsurface water supply enhances crop yield and water use efficiency (Miguel et al., 2003; Najafi and Tabatabaei, 2007; Vories et al., 2009). The yield increase due to subsurface drip irrigation was mainly related to the adequate nutrient supply around the root system (Badr, 2007; Elhindi et al., 2016). Also, the in-depth development of roots limits crop exposure to water and mineral stresses (Bar-Yosef, 1999).

However, subsurface drip irrigation requires optimization of specific agronomic factors such as sowing rate and sowing pattern according to driplines spacing (Lamm, 2016). Indeed, the effects of row spacing on corn yield, silage quality, and radiation use efficiency have been reported by many authors (Cox and Cherney, 2001; Gobeze et al., 2012; Sharratt and McWilliams, 2005). The efficiency of the light conversion into biomass can be improved by the canopy architecture (Long et al., 2006). The optimal sowing pattern for subsurface drip irrigation was mainly related to the soil type. On clay loam soil, 76 cm between planting rows for subsurface drip lines of 152 cm was reported as an adequate sowing pattern for corn (Murley et al., 2018). However, sowing rows of 38 cm for drip lines spaced 100 or 200 cm was suggested for corn grown on a loam sandy soil (Stone et al., 2008).

In sandy soil of the Loukkos area (Northern Morocco), corn is usually sown in twin lines (90*45 cm) at a density of 120000 plants ha^{-1} (Aït Houssa et al., 2008). For the subsurface drip irrigation, the driplines are buried at 30 cm as suggested by Douh et al. (2013) with a lateral spacing of 100 cm. However, the adequate sowing pattern is still not yet determined for this southern Mediterranean area. The objective of this study was to determine the appropriate planting row spacing for corn silage equipped with subsurface drip irrigation. This study will investigate the effect of the sowing structure on the forage quality and the uses efficiencies of radiation and irrigation water in the sandy soil.

2. Materials and Methods

2.1 Experimental Site

Field experiment of corn silage was conducted in 2017 (July to October). The experimental site was located in the Loukkos area (Northern Morocco, 35°00'N, 6°12'W, 30 m from the sea level). The soil was sandy (86.4% sand). It contains a low organic matter level (1.1%). The other soil properties are reported in Table 1.

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Table 1: Soil properties (0-30 cm)

Soil properties	
Sand (%)	86.40
Silt (%)	4.20
Clay (%)	9.20
pH[a]	8.00
Cation exchangeable capacity (meq 100 g^{-1})[b]	8.30
Electrical conductivity (ds m^{-1})[a]	0.25
Organic matter (%)[c]	1.10
P_2O_5 (mg kg^{-1})[d]	186.00
K2O (mg kg^{-1})[e]	405.00
Zinc (mg kg^{-1})[f]	2.13
Copper (mg kg^{-1})[f]	0.64
Manganese (mg kg^{-1})[f]	3.69
Iron (mg kg^{-1})[f]	18.16

a. Determined in a soil: water ratio of 1/5.
b. Determined using Cobaltihexamine Chloride method.
c. Determined using Walkey-Black method.
d. Olsen extraction method.
e. Ammonium acetate extraction.
f. DTPA extraction.

2.2 Crop management and Experimental Design

The land was prepared for planting by cultivator tillage. A subsurface drip irrigation system was installed before sowing. The driplines were separated by 100 cm with 1 L h^{-1} emitters and 50 cm as emitters spacing. The drip lines were buried at 30 cm depth. The sprinklers were installed to ensure an adequate plant emergence. The sowing was done manually. The common sowing rate was 120000 seeds ha^{-1}. Five rows spacing were tested: 40 cm, 55 cm, 70 cm, 85 cm, and 100 cm. The experimental design was a randomized complete block with five replications. The experimental plot size was 56 m^2 (8 m*7 m). The number of sowing rows was 18 for the 40 cm row spacing and 8 for the 100 cm row spacing. For each plot, the first sowing line was close to the subsurface drip line (Figure 1). The distribution of crop rows and subsurface drip lines according to different sowing patterns was reported in Figure 1.

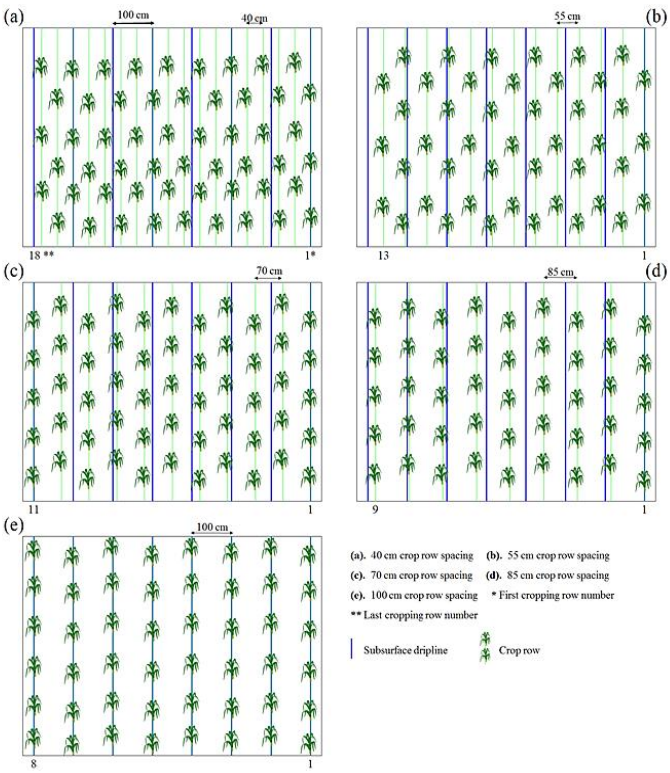

Figure 1: Studied sowing patterns on the experimental plot (7 m*8 m). For all the sowing patterns, the subsurface driplines are separated by 100 cm.

The soil was supplied with 220 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5, and 240 kg ha^{-1} of K_2O. Ammonitrate, diammonium phosphorus, and sulfate of potassium were used as sources of nutrients. 34% of nutrients were applied at sowing and 66% was applied by fertigation using the subsurface drip irrigation system. Concerning micronutrients, 35 kg ha^{-1} of zinc sulfate, 5 kg ha^{-1} manganese sulfate, and 1 kg ha^{-1} copper sulfate were applied. Weeds were controlled using a mixture of pre-emergence herbicides. Also, the fungal disease (*Setosphaeria turcica)* was controlled with Epoxiconazole. During the growing season (July to October), the average minimum and maximum temperatures were around 16.7 °C and 28.9 °C. From emergence to harvest, the accumulated global radiation was 1874 MJ m^{-2}. The rainfall amount was around 62.2 mm (Figure 2) and the irrigation amount was 423 mm.

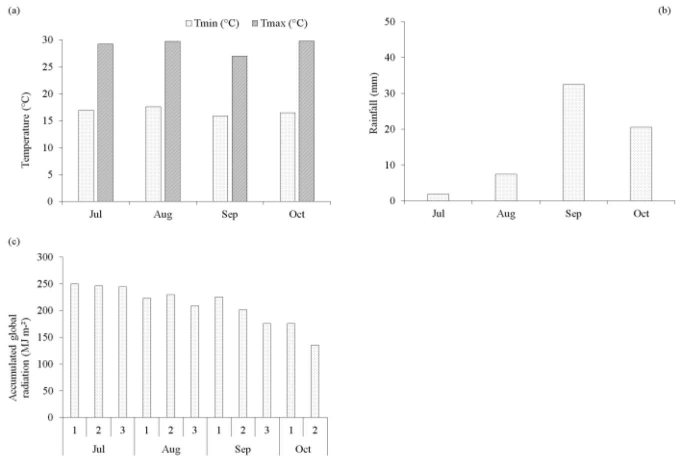

Figure 2: Temperatures, rainfall, and accumulated global radiation of the studied area.

2.3 Measurements

2.3.1 Solar Radiation

Global radiation (Rg) was measured each 10 days using a pyranometer (*Solar Radiation Sensor, SN. 8519*). Measurements were made between 12h and 14h GMT at the ground level. On each plot, solar radiation was recorded outside canopy and under canopy between 3 successive crop rows spacing. Thereafter, photosynthetically active radiation (PAR) was calculated using formula (1) (Szeicz, 1974).

$$FPARi\ (\%) = (PAR - PARs)/PAR \quad (1)$$

The fraction of PARi was calculated using formula (2) (Monteith, 1981).

$$Fraction\ of\ PARi\ (\%) = (PAR - PARs)/PAR \quad (2)$$

Where PARs is the photosynthetically active radiation at the ground level of canopy.
The accumulated PARi was calculated using formula (3).

$$Accumulated\ PARi\ (MJ\ m^{-2}) = FPARi * (accumulated\ PAR) \quad (3)$$

Where the accumulated PAR was recorded from a weather station (iMetos 3.3).

2.3.2 Growth Parameters and Forage Biomass Production

The harvest was done at 37% of dry biomass. 10 plants per experimental plot were cut to determine biomass production. These plants were separated into leaves, stem, and ears to determine the biomass allocation. At harvest, the stem height, the stem diameter, and leaf area were determined on 10 plants for each plot. The leaf area was determined using formula (4) (Mokhtarpour et al., 2010).

$$Leaf\ area\ (m^2\ plant^{-1}) = \sum_{i=1}^{n}(l_i * w_i * 0.75) \quad (4)$$

Where *l, w*, and *i* are, respectively, leaf length, leaf greatest width, and leaf number.

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2.3.3 *Forage Quality Analysis*

At harvest, plants were cut and shopped to determine forage quality for each experimental plot. Then, the samples were chemically analyzed for mineral matter and fat content. The mineral matter was determined after calcination at 550 °C of the dry sample. The fat content was determined using a Soxhlet extractor. Crude protein, cellulose, starch, dry matter digestibility (DMD), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed using a near-infrared reflectance spectrophotometer (NIRS). Thereafter, the net energy lactation was determined using formula (5) (Harlan et al., 1991).

$$NE_L(Mcal\,kg^{-1}\,DM) = 2.196 - 0.0278 * ADF\ (\%\,DM) \quad (5)$$

2.3.4 *Uses Efficiencies of Radiation and Irrigation Water*

The radiation use efficiency (RUE) was calculated for each plot as the slope of the linear regression between the accumulated biomass and the accumulated PARi determined using formula (3). Irrigation water use efficiency (IWUE) was calculated using formula (6).

$$IWUE\ (kg\,m^{-3}) = Aerial\ dry\ biomass\ (kg)/Irrigation\ water\ amount\ (m^3) \quad (6)$$

2.4 Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA). The comparison of means was carried out at a 5 % level of significance using the Student-Newman-Keuls test. The statistical analyses were performed using the program SPSS (Version 20.0).

3. Results and Discussion

3.1 Solar Radiation Interception and Growth Parameters

The plant emergence rate (88%) was similar for all tested sowing patterns. The final population was around 107000 plants ha^{-1}. The fraction of PARi was not significantly affected by the sowing pattern (Figure 3a). Similarly, the accumulated PARi was not affected by the cropping architecture (Figure 3b). Therefore, the light interception does not seem to be improved by reducing row spacing. In contrast, Sharratt and McWilliams (2005) reported more light interception for reduced row spacing (38 cm) than 76 cm at a plant density of 75000 plant ha^{-1}. At harvest, the accumulated PARi intercepted by corn was around 1703 MJ.

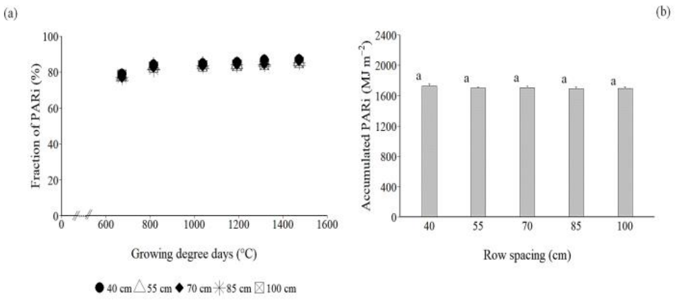

Figure 3: Evolution of the fraction of intercepted PAR and accumulated PARi at harvest. Values with the same letters are not significantly different. Vertical bars are standard deviation (n=15)

Table 2: Plant height, stem diameter, and leaf area at harvest for different row spacing.			
Row spacing (cm)	Stem height (cm)	Stem diameter (cm)	Leaf area (m^2 plant^{-1})
40	266.8 ± 16.3 a	1.98 ± 0.24 a	0.35 ± 0.07 a
55	262.3 ± 10.2 ab	1.96 ± 0.20 a	0.34 ± 0.05 a
70	258.2 ± 10.9 b	1.91 ± 0.19 a	0.36 ± 0.08 a
85	263.1 ± 10.5 ab	1.94 ± 0.19 a	0.35 ± 0.08 a
100	261.1 ± 11.8 ab	1.82 ± 0.17 b	0.31 ± 0.07 a

Values are mean ± standard deviation. For each column and studied season, values with the same letters are not significantly different (n=50)

The stem height and the stem diameter were significantly influenced by the sowing pattern (Table 2). Overall, the height and diameter of the stem at harvest were enhanced by reducing crop row spacing. The highest levels were recorded at 40 cm row spacing. A similar result was reported for corn at a row spacing of 50 cm compared to 75 cm (Gözübenli, 2010). In contrast, the leaf area at harvest was not significantly affected by the cropping arrangement. The leaf area was around 0.34 m^2 plant^{-1} for all tested sowing patterns.

3.2 Biomass Production and Forage Quality

The biomass yield was significantly influenced by the sowing pattern (Figure 4a). 40 cm, 70 cm, and 85 cm as row spacing resulted in the highest dry biomass production (around 24 T ha^{-1}). At 100 cm, the dry biomass showed a decline of 24% compared to the other crop rows spacing. The biomass increase at reduced row spacing was attributed to the ear biomass enhancement, particularly the kernels' dry weight (Figure 4b and Figure 5a). Indeed, the kernels biomass was significantly increased by 27% for 40 cm and 70 cm row spacing. This kernels biomass increase was mainly attributed to the enhancement of the kernel number per ear (Figure 5b). The low kernel number per ear at 100 cm can be explained by the negative effect of competition, between plants of a crop row, in the pollination rate (Zhang et al., 2018). Concerning the 1000-kernel weight, it was around 240 g for all tested sowing patterns (Figure 5c). The positive impact of narrow row spacing in grain yield was reported by many authors (Baron et al., 2006; Cox and Cherney, 2001; Shapiro and Wortmann, 2006). This advantage can be explained by the high root density and limited soil evaporation at narrow row spacing (Sharratt and McWilliams, 2005). Moreover, the results revealed that the subsurface driplines, separated by 100 cm, did not limit forage corn production, particularly at not adjusted crop rows to driplines (Figure 1). Indeed, for 100 cm row spacing, the reduced distance between plants (8 cm) may increase the intra-row competition, thereby reducing the silage yield even the crop rows followed the driplines.

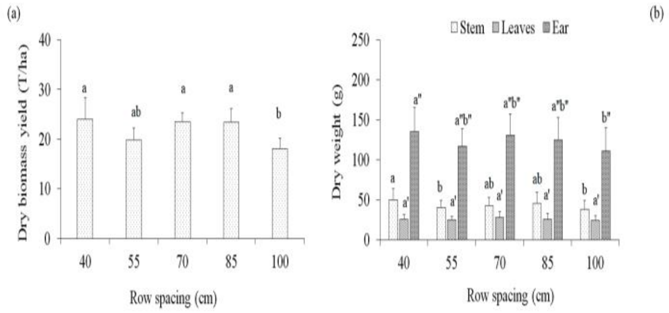

Figure 4: Dry aerial biomass yield and its allocation on stem, leaves, and ear at different row spacing. Values with the same letters are not significantly different. Vertical bars are standard deviation (n=50).

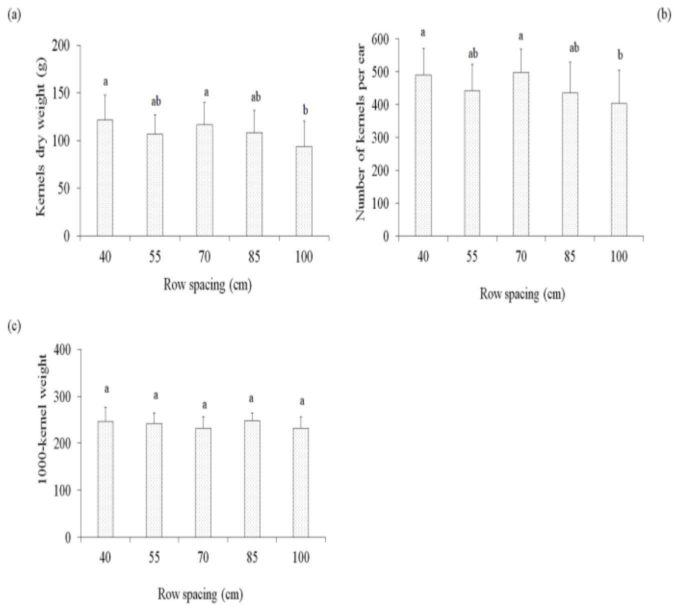

Figure 5: Kernels dry weight, number of kernels per ear and 1000-kernels dry weight at different row spacing. Values with the same letters are not significantly different. Vertical bars are standard deviation (n=50).

On the other side, the radiation use efficiency was not affected by the sowing pattern (Table 3). It was around 2.1 g MJ^{-1}. Such a result can be explained by the absence of a sowing pattern effect on the fraction of intercepted PAR and accumulated PAR as reported above (Figure 3).

Table 3: Uses efficiencies of radiation and irrigation water at different row.

Row spacing (cm)	Radiation use efficiency (g MJ^{-1})	Irrigation water use efficiency (kg m^{-3})
40	2.3 ± 0.48 a	5.7 ± 1.06 a
55	2.0 ± 0.19 a	4.7 ± 0.57 ab
70	2.0 ± 0.49 a	5.6 ± 0.40 a
85	2.1 ± 0.47 a	5.5 ± 0.63 a
100	2.0 ± 0.15 a	4.3 ± 0.51 b

Values are mean ± standard deviation. For each column and studied growing season, values with the same letters are not significantly different (n=5)

Concerning the irrigation water use efficiency, it was enhanced by around 20% at 40 cm, 70 cm, and 85 cm row spacing compared to 100 cm. For the spring corn (2018), no significant enhancement was observed. The increase of the irrigation water use efficiency was related to the high aerial dry biomass yield recorded at narrow crop row spacing.

Concerning the response of forage quality to sowing patterns, the net energy for lactation was similar for all tested sowing patterns. It was around 6.6 MJ kg^{-1} DM^{-1}. The mineral matter, the fat content, and the crude protein were, respectively, around 3.7 %, 2.9 %, and 6.7 % of dry biomass (Figure 6). On the contrary, other studies reported a decrease of crude protein with reducing row spacing (Baron et al., 2006; Iptas and Acar, 2011). The content of cellulose and starch in the forage were, respectively, 18.9 % and 36.4 %. Similarly, Skonieski et al. (2014) reported no significant effect of row spacing on the mineral matter, the cellulose, the starch, and the fat content of corn forage. Concerning the dry matter digestibility, it was around 67.1 %. The neutral detergent fiber (NDF), the acid detergent fiber (ADF), and the acid detergent lignin (ADL) were, respectively, around 42.4 %, 22.5 %, and 2.1 %. Likewise, no significant effect of row spacing on NDF and ADF of corn forage was reported by Baron et al. (2006). From these results, the forage quality of corn, equipped with a subsurface drip irrigation system, does not seem to be influenced by the sowing pattern.

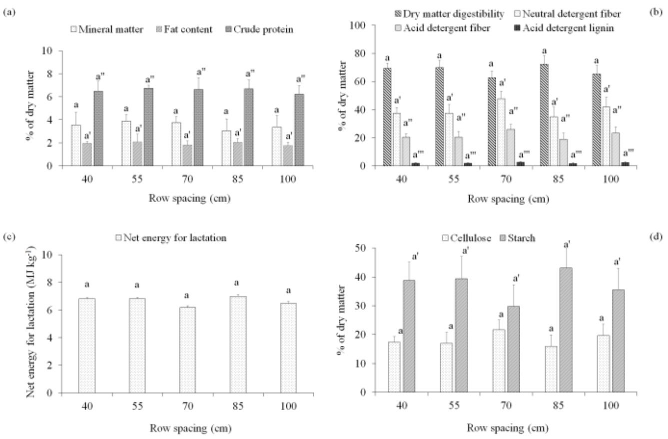

Figure 6: Forage quality parameters at different row. Vertical bars are standard deviation (n = 5)

4. Conclusion

The results of this study have revealed that the production of corn silage, grown in the sandy Mediterranean soil and equipped with 100 cm subsurface driplines spacing, requires an appropriate sowing pattern. The highest biomass yield was achieved at crop row spacing lower than or equal to 85 cm. However, the forage quality parameters were not affected by the sowing pattern. It would be interesting to confirm these results for the spring corn in this region. Also, more research is needed to identify the appropriate sowing pattern for other crops commonly sown in rotation with forage corn, particularly soybean and fodder beet.

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References

Aït Houssa, A., Moutia, S., Belbasri, M., Hsayni, M., Loultiti, M.R., 2008. Productivité et rentabilité du maïs ensilage conduit au goutte à goutte sur les sols sableux de Larache. H. T. E. 139, 65–72.

Allen, M.S., Coors, J.G., Roth, G.W., 2003. Corn Silage, in: Buxton, D.R., Muck, R.E., Harrison, J.H. (Eds.), Silage science and technology. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Madison, Inc., pp. 547-608. https://doi.org/10.2134/agronmonogr42.c12.

Badr, M.A., 2007. Spatial distribution of water and nutrients in root zone under surface and subsurface drip irrigation and cantaloupe yield. World J. Agric. Res. 3 (6), 747–756.

Baron, V.S., Najda, H.G., Stevenson, F.C., 2006. Influence of population density, row spacing and hybrid on forage corn yield and nutritive value in a cool-season environment. Can. J. Plant Sc. 86 (4), 1131–1138. https://doi.org/10.4141/P05-136.

Bar-Yosef, B., 1999. Advances in fertigation, in: Sparks, D.L. (Ed.), Advances in Agronomy. Academic Press, San Diego, pp. 1–77. https://doi.org/10.1016/S0065-2113(08)60910-4.

Cox, W.J., Cherney, D.J.R., 2001. Row spacing, plant density, and nitrogen effects on corn silage. Agron. J. 93 (3), 597. https://doi.org/10.2134/agronj2001.933597x.

Douh, B., Boujelben, A., Khila, S., Mguidiche, A., 2013. Effect of subsurface drip irrigation system depth on soil water content distribution at different depths and different times after irrigation. Larhyss J. 13, 7–16.

Elhindi, K., El-Hendawy, S., Abdel-Salam, E., Elgorban, A., Ahmed, M., 2016. Impacts of fertigation via surface and subsurface drip irrigation on growth rate, yield and flower quality of *Zinnia elegans*. Bragantia 75, 96–107. https://doi.org/10.1590/1678-4499.176.

Gobeze, Y.L., Ceronio, G.M., Rensburg, L.D.V., 2012. Effect of row spacing and plant density on yield and yield component of maize (*Zea mays* L.) under irrigation. J. Agric. Sci. Technol. B 2 (2), 263–271.

Gözübenli, H., 2010. Influence of planting patterns and plant density on the performance of maize hybrids in the eastern mediterranean conditions. Int. J. Agric. Biol. 12 (4), 556–560.

Harlan, D.W., Holter, J.B., Hayes, H.H., 1991. Detergent fiber traits to predict productive energy of forages fed free choice to nonlactating dairy cattle. J. Dairy. Sci. 74 (4), 1337–1353. https://doi.org/10.3168/jds.S0022-0302(91)78289-1.

Henry, W.B., Krutz, L.J., 2016. Water in agriculture: improving corn production practices to minimize climate risk and optimize profitability. Curr. Clim. Change Rep. 2 (2), 49–54. https://doi.org/10.1007/s40641-016-0035-9.

Iptas, S., Acar, A.A., 2011. Effects of hybrid and row spacing on maize forage yield and quality. Plant Soil Environ. 52 (11), 515–522. https://doi.org/10.17221/3543-PSE.

Lamm, F.R., 2016. Cotton, tomato, corn, and onion production with subsurface drip irrigation: A review. T. ASABE. 59 (1), 263–278. https://doi.org/10.13031/trans.59.11231.

Long, S.P., Zhu, X.-G., Naidu, S.L., Ort, D.R., 2006. Can improvement in photosynthesis increase crop yields? Plant Cell Environ. 29 (3), 315–330. https://doi.org/10.1111/j.1365-3040.2005.01493.x.

Miguel, R.G., Ignacio, S.C., Juan, E.A., 2003. Alfalfa production using subsurface drip irrigation. http://irrigationtoolbox.com/ReferenceDocuments/TechnicalPapers/IA/2003/IA03-0419.pdf (accessed 05 July 2021).

Mokhtarpour, H., Teh, C., Saleh, G., Selamat, A., Asadi, M., Kamkar, B., 2010. Non-destructive estimation of maize leaf area, fresh weight, and dry weight using leaf length and leaf width. Commun. Biometry Crop. Sci. 5, 19–26.

Monteith, J.L., 1981. Climatic variation and the growth of crops. Q. J. R. Meteorol. Soc. 107 (454), 749–774. https://doi.org/10.1002/qj.49710745402.

Cite The Article: Abdel Aziz Hassane Sidikou, Saad Drissi, Ahmed Bouaziz, Ahmed Bamouh, Khalid Dhassi, Yousra El-Mejjaouy, Hicham El Hajli, Abdelhadi Ait Houssa (2022). Responses of Corn Silage To Sowing Pattern Under Subsurface Drip Irrigation in A Sandy Soil. *Malaysian Journal of Sustainable Agricultures, 6(1): 12-16.*

Murley, C.B., Sharma, S., Warren, J.G., Arnall, D.B., Raun, W.R., 2018. Yield response of corn and grain sorghum to row offsets on subsurface drip laterals. Agr. Water Manage. 208, 357–362. https://doi.org/10.1016/j.agwat.2018.06.038.

Najafi, P., Tabatabaei, S.-H., 2007. Effect of using subsurface drip irrigation and ET-HS model to increase WUE in irrigation of some crops. Irrig. Drain. 56, 477–486. https://doi.org/10.1002/ird.322.

Shapiro, C.A., Wortmann, C.S., 2006. Corn response to nitrogen rate, row spacing, and plant density in Eastern Nebraska. Agron. J. 98 (3), 529. https://doi.org/10.2134/agronj2005.0137.

Sharratt, B.S., McWilliams, D.A., 2005. Microclimatic and rooting characteristics of narrow-row versus conventional-row corn. Agron. J. 97 (4), 1129. https://doi.org/10.2134/agronj2004.0292.

Skonieski, F.R., Nörnberg, J.L., Kessler, J.D., David, D.B., Azevedo, E.B., Brüning, G., Pimentel, C.M.M., 2014. Corn plant arrangement and its effect on silage quality. Rev. Bras. Zootecn. 43 (3), 114–119. https://doi.org/10.1590/S1516-35982014000300002.

Stone, K.C., Bauer, P.J., Busscher, W.J., Millen, J.A., 2008. Narrow row corn production with subsurface drip irrigation. Appl. Eng. Agric. 24 (4), 455–464. https://doi.org/10.13031/2013.25146.

Szeicz, G., 1974. Solar radiation for plant growth. J. Appl. Ecol. 11 (2), 617. https://doi.org/10.2307/2402214.

Vories, E.D., Tacker, P.L., Lancaster, S.W., Glover, R.E., 2009. Subsurface drip irrigation of corn in the United States Mid-South. Agr. Water Manage. 96 (6), 912–916. https://doi.org/10.1016/j.agwat.2008.12.004.

Wrigley, C., 2017. The cereal grains: providing our food, feed and fuel needs, in: Wrigley, C., Batey, I., Miskelly, D. (Eds.), Cereal Grains. Woodhead Publishing, Duxford, pp. 27–40. https://doi.org/10.1016/B978-0-08-100719-8.00002-4.

Zhang, M., Chen, T., Latifmanesh, H., Feng, X., Cao, T., Qian, C., Deng, A., Song, Z., Zhang, W., 2018. How plant density affects maize spike differentiation, kernel set, and grain yield formation in Northeast China? J. Integr. Agric. 17, 1745–1757. https://doi.org/10.1016/S2095-3119(17)61877-X.