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Effects of drip irrigation frequency, fertilizer sources and their interaction on the dry matter and yield components of sweet corn

Mohamed Abdirahmann Muhumed[1], Shamshuddin Jusop[1*], Christopher Teh Boon Sung[1], Puteri Edaroyati Megat Wahab[2] and Qurban Ali Panhwar

[1]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia

***Corresponding author: shamshud@upm.edu.my**

Abstract

Irrigation frequency is one of the most important factors in the management of water in the agriculture sector to sustain crop productivity, especially in arid and semi-arid regions of the world. Additionally, fertilizers have to be adequately applied. An experiment was carried out under a rain shelter from July to December 2012 in Malaysia to determine the effects of irrigation frequency and fertilizer sources on the growth and yield of sweet corn planted on a limed sandy clay, Ultisol, using a drip-irrigation system. This experiment was conducted using a split-plot design with four drip-irrigation frequencies (daily, once every 2 days, once every 3 days and once every 4 days) and four sources of fertilizers (NPK, goat manure, poultry manure and control). The drip irrigation was the main plot, while fertilizers were the subplot factors. The results of the study indicated that total dry matter and yield components increased with the increase in drip-irrigation frequency with values of 44% and 32% respectively. The highest growth parameters and shoot dry weight were recorded from daily irrigation intervals with goat manure, while the highest yield components were obtained from daily irrigation frequency with NPK fertilizer and poultry manure. In the light of these results, therefore, for optimum biomass of corn, high irrigation frequency with goat and poultry manure is the most viable option while yield was greatly favoured by a high irrigation frequency with NPK.

Keywords: Drip irrigation; Goat manure; Inorganic fertilizer; Poultry manure; Sweet corn; Ultisols.
Abbreviations: DAS_Days after sowing; GM_Goat manure; GML_Ground magnesium limestone; PM_Poultry manure.

Introduction

Sweet corn (*Zea mays* L) is a popular multi-purpose cereal crop belonging to the family *Poaceae* and is cultivated as an annual field crop all over the world (Remison, 2005). Corn is one of the important staple crops in semi-arid regions, particularly in sub-Saharan Africa due to its short maturity period, high yielding capacity, and easy management and processing compared to other crops. Corn ranks second to wheat based on the world's cereal production (Jaliya et al., 2008). Globally, the United States leads corn production (39%), followed by China and Brazil (Shultz, 2008). Initially, corn was produced for human consumption as both a fresh and processed product; however, corn is also produced for livestock feeding and industrial uses such as production of ethanol, starch and cooking oil (Remison, 2005). In both arid and semi-arid regions, water scarcity is the major problem limiting the overall growth and yield of corn. Water shortages can also occur in the tropics due to its uneven distribution; water is unavailable when it is required the most. El-Hendawy et al. (2008) reported that reduction of corn yield exceeded 90% due to water stress particularly at tasseling and the pollination stage. Irrigation (especially drip irrigation) is therefore necessary to supply water for corn production during the dry season, even in the tropics (El-Hendawy et al., 2008). Irrigation frequency is an important factor in drip-irrigation management because it influences the soil moisture regime, water root distribution around the emitter, amount of water percolating on the root zone and the amount of water uptake by roots (Assouline, 2002). Unavailability of water is an important factor that can limit corn production throughout the growth stages. Payero et al. (2006) reported that soil moisture stress during any of the plant growth cycle can cause reduction in the yield and growth. Water unavailability limits corn growth by way of reducing the uptake of macronutrients (Gutierrez et al., 2008). In countries with limited water resources, improvements are needed in order to overcome the reduction of production and to increase the efficiency and adequate use of the available water. One approach is the development of irrigation scheduling techniques such as deficit irrigation (Salemi et al., 2011). Demand for water increases as the plants grow, and a high amount of water is needed during and after flowering. However, the maximum interval allowed between irrigation depends on the soil type, even though the soil structure can be improved by adding organic matter as it helps to increase water-holding capacity to prevent the damage caused by water stress during the crop development stages (Kara and Biber, 2008). To sustain the quality and the quantity of the crop production, maintaining and improving soil fertility is important, which can be accomplished by applying fertilizers either in inorganic or organic form (Efthimiadou et al., 2010). Applying organic fertilizers in combination with inorganic fertilizers can contribute to increased crop productivity (Pan et al., 2009). Adenyan (2006) believed that the main purpose of fertilizer application to any crop is to obtain a high yield and to improve soil fertility. However, chemical fertilizers are expensive, and so farmers turn to organic fertilizers as alternative sources for supplying plant nutrients. In Malaysia, corn is grown partly on highly weathered acidic soils. The yield of corn planted in these soils is low due to the low pH and low exchangeable Ca and Mg, but high exchangeable Al (Shamshuddin and Fuaziah, 2010). These soils (among the most widespread soil type in the tropics) are taxonomically classified as Ultisols and Oxisols (Soil Survey Staff, 2010). It was reported that the critical pH for corn production in Malaysia is pH 4.7 (Shamshuddin and Fuaziah, 2010), while the critical Al concentration is 22 µM (Shamshuddin et al., 1991). With a low pH of about 4.5, Al concentration in the soil solution under field conditions exceeds the critical level for corn growth. To alleviate Al toxicity for corn production, ground magnesium limestone (GML) has to be applied at the appropriate rate. However, the effect of lime application is confined to the zone of incorporation (Shamshuddin and Ismail, 1995; Shamshuddin et al., 2010). Acording to Shamshuddin et al. (1991), the amount of GML required for corn production on Ultisol in Malaysia is 2 t GML ha^{-1}. Applying GML on Ultisol in Malaysia at this rate would effectively last more than 4 years. This study was conducted to determine the effects of drip-irrigation frequencies and fertilizer sources on the growth and yield of sweet corn planted on an Ultisol soil that had been limed to eliminate Al toxicity.

Results and Discussion

Characteristics of the untreated topsoil

The study was carried out using sandy clay soil classified as Ultisol, which is a common soil for sweet corn in Malaysia. The pH of the untreated soil was 4.8, while the exchangeable Al was 1.79 $cmol_c$ kg^{-1} (Table 1). According to the sweet corn's requirements, a suitable pH of the soil should be more than pH 5; therefore, the soil for this study was limed at 2 t ha^{-1} with ground magnesium limestone (GML) to raise the pH to the required level. Due to lime application, the soil pH was increased from 4.8 to 6.9 (Table 3). When pH was increased to a level above 5.2, Al in the soil solution was completely precipitated as inert Al hydroxides and hence the exchangeable Al was reduced to a very low value or zero (Table 3). The conditions were then good for sweet corn growth. Moreover, the organic fertilizers improved the soil fertility by increasing the nutrient contents in the soil. It was observed that more plant nutrients were supplied by the organic fertilizers compared to those of the inorganic fertilizers as shown by N, Ca, Mg and organic C, which were higher in goat manure (GM) and poultry manure (PM) treatments (Table 3). These results are in agreement with those of Herencia et al. (2009).

Effects and interactions of irrigation frequency and fertilizer sources on total dry matter

Interactions of irrigation frequency and fertilizer sources on total dry matter yield (shoot and root dry weight) and leaf chlorophyll contents are presented in Fig 1, 2, and 3, respectively. Statistical analysis of variance indicated that irrigation frequency and fertilizer sources significantly ($P<0.01$) affected the total shoot dry weight (all above ground except grains) where the highest weight was recorded from the daily irrigation frequency with GM (Fig 1). In daily irrigation (Ir_1), GM was significantly greater (160.01 g^{-1} plant) than the NPK (84.9 g $plant^{-1}$) and PM treatment (115.8 g $plant^{-1}$). However, there were no significant differences between NPK and PM although they were significantly higher than the control. When irrigating once every 2 days (Ir_2) and once every 4 days (Ir_4), NPK, GM and PM were significantly greater than the control (without fertilizer). When irrigating once every 3 days (Ir_3), goat and poultry manure significantly affected shoot dry weight compared to NPK and control (Fig 1). Interaction of irrigation frequencies and fertilizer sources significantly ($P<0.05$) affected root dry weight as shown in Fig 2. Highest root dry weight was achieved from Ir_2 with poultry manure. With daily irrigation, GM significantly affected root dry weight. However, there was no significant difference between NPK and goat manure though both were higher than the control (without fertilizer). In Ir_2, the PM enhanced the root dry weight, while the control recorded the least root dry weight. In Ir_3, GM significantly affected the root dry weight compared with NPK and PM. Poultry manure influenced root dry weight more than NPK and control treatments. The reason why goat and poultry manure increased more shoot and root dry weight compared to NPK is that organic fertilizers have the ability to enhance soil fertility. In Ir_4, GM recorded the highest root dry weight. However, there was no significant difference between NPK and PM treatment. The shoot and root dry weights were significantly increased with increased irrigation frequency; this means that high irrigation frequency has a positive effect on the growth of the sweet corn because of the longer period of water retention in the root zone compared to low irrigation frequency. High irrigation frequency encourages root hairs to develop since the root zone is wet most of the time throughout the growing season. The reduction of the dry matter yield with lower irrigation frequency, especially in Ir_4, might be due to water deficit that occurred at the critical growth stage of the corn growth. On the other hand, the results indicated that inorganic fertilizers have a lower effect on the biomass of the sweet corn especially in the low irrigation frequency compared to the organic fertilizer. This might be caused by the N leaching effect due to the continuous availability of soil moisture. Moreover, organic fertilizers improve the soil structures and retain more soil moisture compared to the inorganic fertilizers. Irrigation frequency and fertilizer sources had a significant ($P<0.05$) effect on leaf chlorophyll contents of sweet corn (Fig 3). The highest chlorophyll content was obtained in Ir_3 with NPK treatment. However, no significant differences were observed among the fertilizers in terms of chlorophyll content with regard to other irrigation frequencies Ir_1, Ir_2 and Ir_4. Chlorophyll contents as shown in Fig 3 showed that NPK treatment gave significant values under 3-day irrigation intervals compared to other organic fertilizers – the reason was that NPK released nutrients faster than organic fertilizers and can be seen directly at the leaf surface by its dark green colour. The second reason might be that, under 3-day irrigation frequencies, the leaching of NPK was very slow as there was no more water around the root areas. The growth and yield of cereal crops in water-limited regions in the world is low, particularly for sweet corn crops due to water stress constraints as well as low soil fertility (El-Hendawy et al., 2008), thus water management and soil enrichment become necessary to enhance the growth and yield of cereal crops. The results of the current study revealed that the total dry mass of sweet corn in both shoots and roots were significantly affected by drip-irrigation frequencies and fertilizer sources (Fig 1 and 2). Shoot dry matter was observed to be higher in high irrigation frequencies Ir_1 (160.01 g $plant^{-1}$) and Ir2 (132.36 g $plant^{-1}$) with goat manure fertilizer compared to lower irrigation frequencies. Similarly,

Table 1. Original physico-chemical characteristics of the topsoil.

Chemical parameters	Values	Physical parameters	Values
pH	4.8	Particle size distribution (%)	
EC (mS cm^{-1})	0.14	Sand	56.13
CEC ($cmol_c$ kg^{-1})	16.9	Silt	8.24
Total N (%)	0.84	Clay	35.54
Total C (%)	1.23	Bulk density (Mgm^{-3})	1.3
Available P (mg kg^{-1})	54.80	Porosity (%)	52.3
Exchangeable ($cmol_c$ kg^{-1})		Soil moisture content (mc)	12.5
Ca	0.22	Field capacity (%)	18.2
Mg	0.55	Wilting point %	12.7
K	0.24		
Al	1.79		

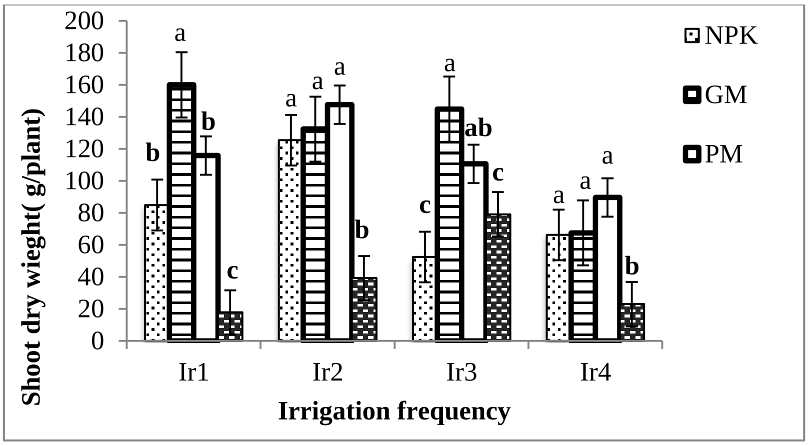

Fig 1. Interaction between irrigation frequencies and fertilizer source on corn shoot dry weight. Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

Table 2. Nutrient contents of fertilizer sources for the current study.

Fertilizers	N (%)	P_2O_5 (%)	K_2O
NPK (Urea, TSP and MOP)	46	46	60
Goat manure (GM)	4	1	3
Poultry manure (PM)	4.5	2	2

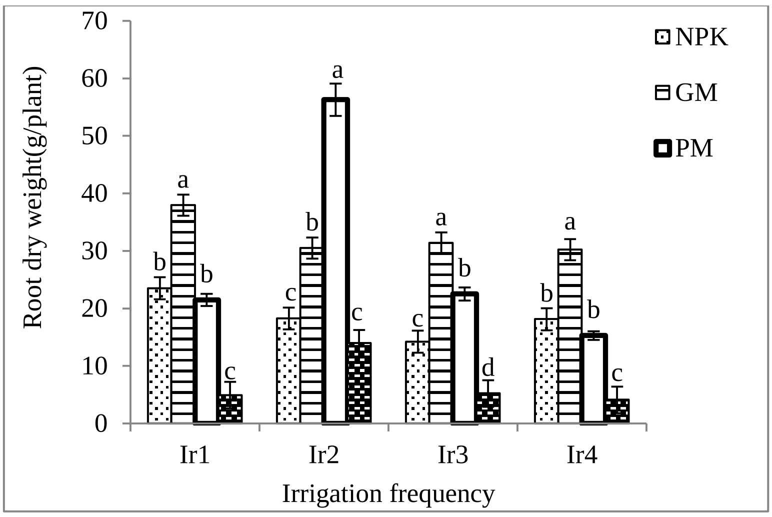

Fig 2. Interaction between irrigation frequencies and fertilizer source on corn Root dry weight. Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

root dry yield was affected by irrigation frequencies and fertilizer sources. Irrigation once every 2 days with PM gave the highest root dry yield values (56.30 g plant^{-1}) compared to NPK fertilizer, this is due to that PM improves soil structure and increases moisture-retention capacity by increasing the number of storage pores in the soil (Bhatacharyya et al., 2008). At low irrigation frequencies, water stress occurred and the amount of stored water in the root zone was less than the rate at which the plants take up water (Coelho, 1999; Assouline et al., 2002). These results are in agreement with those of Moster et al. (2006) who found a reduction in the dry yield of sweet corn with water stress. On the other hand, in terms of fertilizer sources, goat and poultry manure gave the most significant total dry yield values compared to the NPK fertilizer – the reason was that organic fertilizers have the ability to enhance soil fertility and improve its structure. This is reflected in the fact that GM and PM fertilizers provided more N, Ca, Mg and organic C compared to that provided by NPK fertilizes, as shown in Table 3. Adeniyan et al. (2006) reported that organic manure produced higher values compared to NPK fertilizers due to availability of essential nutrient, particularly N and organic matter that are important for the plant growth, which ultimately leads to higher grain yields. Organic fertilizers enrich the soil structures, improve aggregate stability and increase moisture-retention capacity by increasing the number of storage pores in the soil (Bhatacharyya et al., 2008).

Yield components

The yield components of the study – namely cob weight, ear weight (Fig 4 and 5), ear length, ear diameter and 100-grain weight – are presented in Table 5. Statistical analysis of variance indicated that interaction between irrigation frequencies and fertilizer sources significantly ($P<0.05$) affected the plant cob weight. Daily (Ir_1) and once every 2 days (Ir_2) irrigation frequency together with NPK, GM and PM significantly enhanced cob weight. This means that NPK, GM and PM treatments increased the cob weight in the same way. However, Ir_3 and Ir_4 NPK treatments gave a higher yield than the rest of the fertilizer treatments, while there were no significant differences between GM and PM in both irrigations, but they were significantly greater than that of the control. The interaction effect of irrigation frequency and fertilizer sources on ear weight of sweet corn is presented in Fig 5. The results show that interaction of irrigation frequency and fertilizer sources significantly ($P<0.001$) affected the ear weight of the plant. In daily irrigation (Ir1), PM showed a higher ear weight compared to GM and control treatments. However, all of the fertilizer treatments produced a better yield than the control. In Ir_2, the highest ear weight was recorded from the NPK treatment, while the control treatment had the lowest (189.43 g plant^{-1} and 57.95 g plant^{-1}, respectively). In Ir_3, all the fertilizer treatments significantly affected the ear weight. In Ir_4, NPK treatment produced a greater ear weight compared to poultry manure; however, all the fertilizer treatments produced significantly more weight than that of the control. Irrigation frequencies and fertilizer sources significantly ($P<0.05$) affected 100-grain weight and the highest weight was obtained from Ir_1 and Ir_2 treatments. Irrigation frequencies did not affect ear length and ear diameter; however, fertilizer source significantly ($P<0.05$) influenced ear length and ear diameter. Previous studies showed that the yield parameters affected by water stress at the tasseling stage were the number of ears and grains per plant, while after pollination; water stress highly decreased the size of the grain (El-Hendawy et al., 2008). This might explain why Ir_3 and Ir_4 of the current study had a lower grain weight compared to that of Ir_1 and Ir_2 treatments (Table 5). In the case of the fertilizer sources, NPK and GM significantly affected the 100-grain weight compared to PM; PM treatment gave a significantly higher yield than that of the control. The highest 100-grain weight was recorded from NPK (21.99 g) and GM (21.55 g), followed by PM (15.08 g) and the lowest 100-grain weight was found from the control (14.4g) (Table 5). Similar findings have been reported by Jaliya et al. (2008) in which organic manures had a significant effect on grain yield. Organic manures produced higher values of yields compared to NPK fertilizers due to the availability of essential nutrients, particularly N, and organic matter that are important for the growth of the plants, which ultimately leads to higher grain yields (Ojeniyi and Adejobi, 2002; Ojeniyi, 2000). The current results show that the yield components increased with increased irrigation frequency, especially Ir_1 and Ir_2 due to the optimum availability of soil moisture; sandy clay soil encouraged the growth of the plants when the root zone was wet. However, in low irrigation frequency, sandy clay soil has no ability to store soil moisture for a long time without irrigation and plants did not have enough water to proceed with normal growth (Table 5). Therefore, the reduction of the yield parameters in low irrigation intervals were caused by the water deficit occurring during the critical growth stage, especially during the tasseling and filling grain stages (Sinclair et al., 1990; Traore et al., 2000; Stone et al., 2001). Fertilizer sources and irrigation frequencies significantly influenced the yield components of sweet corn. High irrigation frequencies (Ir_1 and Ir_2) gave a highly significant yield value due to water availability (Table 3). Oktem (2008) reported that ear weight was significantly ($P<0.01$) affected by irrigation frequencies and the yield was found to be less under water stress conditions. In terms of fertilizer sources, sweet corn yield – especially ear and cob weights – were found to be higher with NPK treatments (183.20 g and 125.9 g respectively) compared to GM and PM manure. However, in 100-grain weight there was no significant difference between NPK and GM manure. The reason why NPK fertilizer was higher than GM and PM in terms of yield components (ear and cob) was that NPK fertilizers released nutrients at a faster rate compared to organic fertilizers. This is reflected by the high N and P in the roots and leaves of NPK treatments compared to those of GM and PM treatments as shown in Table 4. Therefore the high leaf N content encouraged the photosynthesis of the plants to be higher and the higher photosynthesis is an indication of high plant yield.

Root and leaves nutrient contents

Nitrogen contents in the leaves and roots are presented in Table 7. Statistical analysis of variance indicated that irrigation frequencies and fertilizer sources significantly ($P<0.05$) affected N contents in the leaves and roots. N contents in the roots and leaves increased with decreasing irrigation frequencies as Ir_3 and Ir_4 showed higher N contents compared to Ir_1 and Ir_2 (Table 7). The reason is that N was leached out more in daily and once every 2 days irrigation due to high water drainage in the soil. In terms of fertilizer, NPK significantly affected root and leaf N contents more than goat and poultry manure because inorganic fertilizers released the nutrients faster compared to organic fertilizers (Table 7). Irrigation frequency and fertilizer sources significantly ($P<0.05$) affected P contents in the roots and leaves. P contents in the roots and leaves increased with

Table 3. Selected chemical properties of the soil at harvest.

Treatments	pH	EC ($mS\ cm^{-1}$)	Exchangeable ($cmol_c\ kg^{-1}$)					Available P ($mg\ kg^{-1}$)	Total N (%)	Total C (%)
			Ca	K	Mg	Al	CEC			
Irrigation frequency										
Ir_1	6.2	0.08	4.66	0.04	0.91	0	9.4	8.12	0.112	1.34
Ir_2	6.9	0.15	4.94	0.04	1.58	0	10.6	7.28	0.105	1.58
Ir_3	6.0	0.27	6.03	0.04	1.12	0	11.1	12.6	0.117	1.67
Ir_4	6.7	0.12	3.36	0.03	1.60	0	11.2	6.79	0.116	1.25
Fertilizer sources										
NPK	6.5	0.11	3.20	0.02	1.19	0	10.8	16.24	0.09	1.42
GM	6.9	0.24	3.11	0.05	1.41	0	11.2	14.77	0.12	1.65
PM	7.2	0.18	5.20	0.05	1.28	0	10.7	12.67	0.10	1.50
Control	5.8	0.27	6.05	0.04	0.91	0	11.1	12.60	0.12	1.34

Note: NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure, Ir1: daily irrigation.

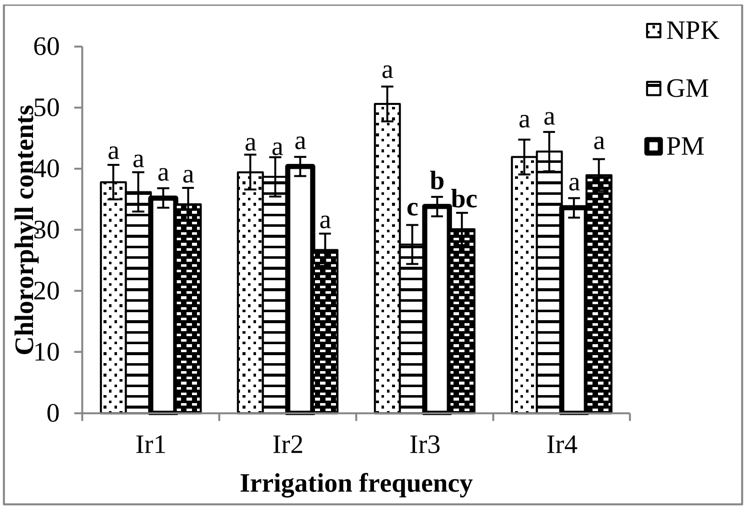

Fig 3. Interaction between irrigation frequencies and fertilizer sources on chlorophyll contents. Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

decreasing irrigation frequency and Ir_3 and Ir_4 gave significantly higher values than that of Ir_1 and Ir_2. NPK treatment significantly ($P<0.05$) increased P in the roots and leaves. However, there was no significant difference between GM and PM treatment. Statistical analysis of variance indicated that there were no significant differences among the irrigation for K contents in the root and leaves. However, fertilizer sources significantly ($P<0.05$) affected the amount of K in the roots where NPK and GM treatments gave higher values than PM or control treatment. Calcium and magnesium contents in the leaves and roots are presented in Table 7. Irrigation frequency did not affect the amount Ca in the roots and leaves. However, in terms of fertilizer sources, the control treatment had higher Ca contents in the roots and leaves than the fertilizer treatments, GM and PM. Analysis of variance indicated that irrigation frequency and fertilizer sources significantly affected the Mg contents in the roots and leaves as shown in Table 7. Ir_4 resulted in the highest Mg contents in roots compared to the other irrigations, which means that Mg contents in the roots increased with decreasing irrigation frequencies. In terms of tissue analysis of the sweet corn, irrigation frequencies and fertilizer sources significantly affected the amount of N and P in the roots and leaves; however, irrigation did not influence the K contents in the root and leaves (Table 7). The results indicate that N and P contents in the roots and leaves increased with decreasing irrigation intervals. This could be due to low irrigation frequencies meaning the leaching level of N is slow or zero and this might have made it possible for the roots to absorb essential nutrients from the soil with the help of the moisture content in the soil, though the moisture is slow due to low irrigation intervals. The contents of Ca and Mg in the roots also increased with the decrease in irrigation frequency. However, there were no significant differences between the irrigation treatments for Ca contents in the leaves. In terms of fertilizer treatments, the highest Ca and Mg contents were recorded from the control treatments (without fertilizer) due to antagonism effects between the fertilizer treatments, i.e. the Ca and Mg in the fertilized soil were low because the amounts of N and K in the treatments were high (Table 7). Malvi (2011) reported that excessive N in the plants reduces the uptake of Ca, Mg and K while excessive P reduces the uptake of Mg and Ca.

Material and Methods

Plant materials

Sweet corn seeds were sown in 230 poly bags each containing sandy clay soil (27 kg) at a rate of three seeds per bag. The emerging seedlings were later thinned to one seedling per bag.

Experimental site and conditions

This study was conducted at Field 2, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Malaysia. The experimental site was located at an altitude of 30 m above sea

Table 4. Mean square of total dry matter and yield components traits.

Treatments	Shoot weight(g)	Root weight (g)	Leaf Chlorophyll	Ear weight (g)	Cob weight (g)	Ear length (cm)	Ear diameter (cm)	100-grain weight (g)
Irrigation frequencies (I)	**	**	ns	*	**	ns	ns	**
Fertilizer sources (F)	**	**	*	**	*	*	**	**
I*F	**	**	*	*	**	ns	ns	ns
CV	23.6	24.83	17.87	17.8	14.27	17.1	15.2	21.22

Note: CV = coefficient of variation. * = significant at 0.05 level; ** = significant at 0.01 level; ns = not significant.

Table 5. Effects of irrigation frequency and fertilizer sources on yield components.

Treatments	Ear length (cm)	Ear diameter (mm)	100-grain weight (g)
Irrigation frequency (I)			
Ir_1	28.31a	40.20a	17.25a
Ir_2	30.13a	43.91a	17.18a
Ir_3	29.50a	39.89a	11.55b
Ir_4	27.34a	38.97a	14.43ab
Fertilizer sources			
NPK	31.94a	46.11a	21.99a
GM (goat manure)	29.63a	43.05a	21.57a
PM (poultry manure)	29.31a	42.79a	15.08b
Control	24.44b	31.02b	3.77c

Means within same column with similar letters are not significantly different. Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

Table 6. Mean square of nutrient contents in the root and leaves traits

Treatments	Root N	Root P	Root K	Root Ca	Root Mg	Leaf N	Leaf P	Leaf K	Leaf Ca	Leaf Mg
Irrigation frequencies (I)	*	**	ns	ns	*	**	ns	ns	ns	*
Fertilizer sources (F)	**	**	**	*	**	**	*	ns	**	*
I*F	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV	22.0	27.1	24.0	61.0	17.2	13.0	20.0	10.9	14.0	12.5

* = significant at 0.05 level; ** = significant at 0.01 level; ns = not significant

Table 7. Effects of irrigation frequency and fertilizer sources on nutrient contents in the root and leaves.

Treatments	Root N (%)	Root P (%)	Root K (%)	Root Ca (%)	Root Mg (%)	Leaf N (%)	leaf P (%)	Leaf K (%)	Leaf Ca (%)	Leaf Mg (%)
Irrigation frequency (I)										
Ir_1	0.75b	0.04b	2.31a	0.02ab	0.17bc	1.82c	0.12a	2.42a	0.29a	0.19b
Ir_2	0.81ab	0.05b	2.00a	0.016b	0.18ab	2.07b	0.13a	2.46a	0.29a	0.22a
Ir_3	0.96ab	0.076a	2.13a	0.02ab	0.17c	2.38a	0.13a	2.30a	0.31a	0.20b
Ir_4	0.97a	0.07a	2.25a	0.024a	0.20a	2.31a	0.12a	2.39a	0.28a	0.18b
Fertilizer sources										
NPK	1.14a	0.10a	2.42a	0.02ab	0.199a	2.40a	0.13a	2.34a	0.28b	0.20ab
GM	0.76b	0.06b	2.54a	0.01b	0.151c	2.12b	0.14a	2.48a	0.27b	0.19b
PM	0.72b	0.05b	2.02b	0.01b	0.17b	1.84c	0.12ab	2.34a	0.27b	0.18b
Control	0.85b	0.04b	1.7b	0.03a	0.198a	2.22ab	0.11b	2.40a	0.33a	0.21a

Means within same column with similar letters are not significantly different. Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

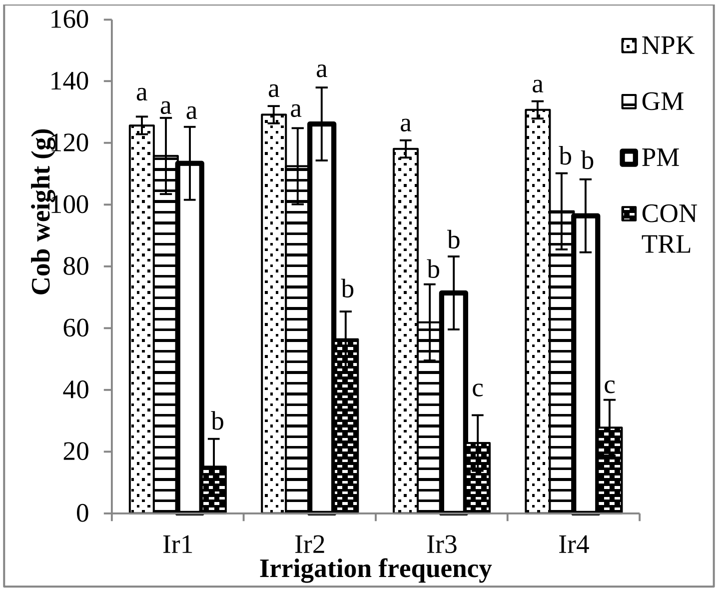

Fig 4. Interaction between irrigation frequencies and fertilizer sources on cob weight.Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM : poultry manure.

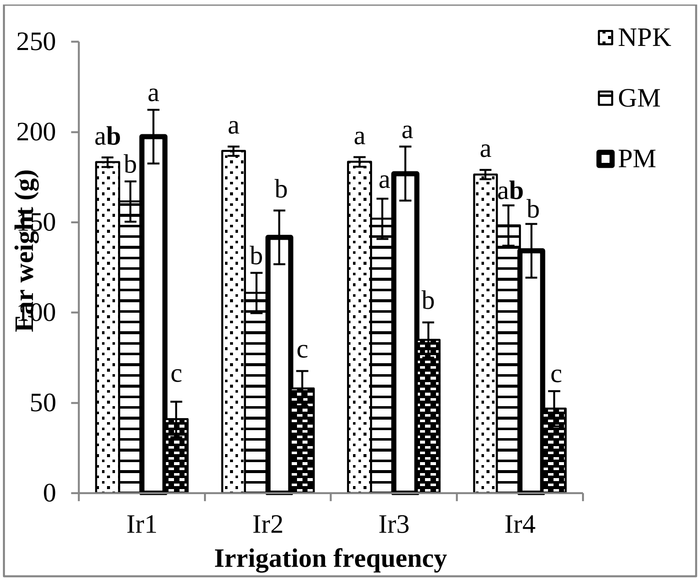

Fig 5. Interaction between irrigation frequencies and fertilizer sources on ear weight.Ir_1: daily irrigation, Ir_2: once every 2 days, Ir_3: once every 3 days, Ir_4: once every 4 days, NPK (urea, triple superphosphate, muriate of potash), GM: goat manure, PM: poultry manure.

level, and at latitude of 30.01°N and longitude of 101°.70E. The plants were sown under a rain shelter to prevent the effect of rainfall on the crop. Bungor Series soil classified as Ultisol was selected for this study (Soil Survey Staff, 2010). The physico-chemical characteristics of the untreated topsoil are given in Table 1.

Experimental design

The treatments were arranged in a split-plot design, with four replicates. Irrigation treatments were assigned as the main plot, while fertilizer sources were sub-plot factors. The types of irrigation used for this study was drip irrigation since it is the most efficient irrigation system in terms of water safety and management. Four drip-irrigation frequencies were used namely: daily irrigation (Ir_1), once every 2 days irrigation (Ir_2), once every 3 days irrigation (Ir_3) and once every 4 days irrigation (Ir_4). The fertilizer treatments were: NPK fertilizer (urea, triple super phosphate and muriate of potash), goat manure, poultry manure and control (without fertilizer). The nutrient contents of NPK, goat manure and poultry manure that were used in this study are presented in Table 2. The fertilizers were applied based on sweet corn's requirements recommended by the Malaysian Agricultural Research and Development Institute (MARDI), which is 120:60:90 kg ha^{-1} of N, P and K, respectively. Both organic and inorganic fertilizers were applied during the planting time except urea (N), which was applied at 50% of the requirement during the planting and another 50% 30 days after sowing (DAS) since the split application of nitrogen fertilizer reduces leaching and volatilization losses of N (Das, 1993).

In this study, water was supplied to the sweet corn at 100, 90, 80 and 70% of soil water field capacity for irrigation Ir_1, Ir_2, Ir_3 and Ir_4, respectively. The drip-irrigation system was divided into the main water source from which the water came through polypipes (32 mm diameter). Then the water was distributed to the poly bags by microtubes that had valves to control water passage, and each plant received the water through a small dripper that was located at the end of the microtubes.

Soil moisture measurement

Soil water content in the soil was measured according to the irrigation schedule before irrigation to determine the volume metric water content (vwc). This was done using a 10HS Soil Moisture Sensor, USA, by which the soil moisture scale was kept under control, i.e. to not reach the permanent wilting point (pwp).

Soil analysis

Soil physical and chemical characteristics were analysed before the plants were planted as well as at harvest and are shown in Table 1 and 3, respectively. At harvest, 200 g soil from the replicates of each treatment was thoroughly mixed (homogenized) and subsequently analysed, and so statistical analysis was not possible. The pH of the soil was determined in water (1:2.5; soil:water), while electrical conductivity was measured by a glass electrode EC meter. CEC was determined by the method of Schollenberger and Simon (1945) in which 1 M NH_4OAc buffered at pH 7.0 was used. Basic cations (Ca, Mg and K) in the NH_4OAc solutions were analysed by an atomic absorption spectrophotometer (AAS). Exchangeable Al was extracted with 1 M KCl and determined colorimetrically (Barnhisel and Bernstch, 1982). Total N was determined by the Kjeldahl method (Bremner, 1960) and available P by Bray and Kurtz method (1945), while organic carbon (C) was determined by the Walkey-Black method (Nelson and Sommers, 1982). Particle-size distribution was determined by the pipette method of Day (1965). Bulk density and porosity were determined by the core ring method, soil field capacity and wilting point by pressure plate, while moisture contents were measured by the gravimetric method.

Plant parameters and analysis

Plants were measured for growth, biomass and yield components such as total dry matter (TDM), chlorophyll and yield components, namely: ear and cob weight per plant, ear diameter, ear length and 100-grain weight. To determine the amount of nutrients in the leaves and roots, plant tissue analysis was done after the leaves and root had been dried and ground. For the tissues analysis, a 0.25-g sample was digested using the wet ash method. The digested sample was used to determine the N, P, K, Ca and Mg contents of the tissues (Wolf, 1982). Nitrogen, phosphorus and potassium were analysed using an auto-analyser (Lachat instrument, USA), while Ca and Mg were determined by AAS (Perkin Elmer 5100, USA). Analysis of variance (ANOVA) of sweet corn yield parameters and nutrient contents are given in Table 4 and Table 6 respectively.

Statistical analysis

All data collected from this study were analysed using ANOVA and the difference between the means was compared by Duncan's Multiple New Range Test (DMNRT) using SAS software version 9.2 (2002, Inc, USA)

Conclusion

The results of this study reveal that total dry matter is significantly ($P<0.05$) increased with increasing drip-irrigation frequency, which means that a higher irrigation frequency (Ir_1 and Ir_2) has a more positive effect on the sweet corn biomass. Similarly, fertilizer (organic and inorganic) sources significantly affected the total dry matter, especially with high drip-irrigation frequency. It was observed that organic fertilizer treatments produced more biomass compared to inorganic fertilizer treatments. Organic fertilizers (goat and poultry manures) had improved soil structures that increased water retention, enabling the roots to absorb the required nutrients from the soil. The yield components were significantly ($P<0.05$) affected by the drip-irrigation frequency and fertilizer sources, especially the ear, cob and 100-grain weight. Based on this study, daily or once every 2 days drip-irrigation frequency is recommended for the sandy clay Ultisols under a tropical environment.

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