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Effects of Deficit Drip Irrigation and Rice Straw Mulch on Flowering, Fruiting and Yield of Tomato (*Lycopersicon Esculentus* L.) Varieties

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Abstract: Tomato (*Lycopersicon esculentum* L.) is one of the most important vegetables in the world and its demand has increased making factors affecting its production very key for evaluation. The yields of tomato in Ghana are generally low, as such being supplemented by imports from neighbouring countries. This study investigated the effects of deficit drip irrigation and mulch on flowering, flower abortion, fruiting and yield of two tomato varieties. The experiment was carried out at Savannah Agricultural Research Institute (SARI) experimental field at Nyankpala, Tamale in Ghana from November 2020 to March 2021, laid out in a split-split plot design. The output of the CROPWAT model indicated highest seasonal water requirement of tomato was 564 mm at ET_{100} whilst the lowest of 282 mm at ET_{50}. Soil analysis revealed that the soil textural class was sandy loam. The top-soil had a field capacity of 18.2%, whilst the subsurface soil was 18%. Significant ($p < 0.05$) differences in flower count, flower abortion, fruiting and total fruit yield as influenced by irrigation regime and mulch were observed. Highest total fruit yield of 13.46 t/ha was obtained with combined use of Mongal F1 and of ET_{100}, whilst the lowest of 2.04 t/ha was recorded from Pectomech tomato and ET_{50}.

Key words: deficit irrigation, straw mulching, total fruit yield

1. Introduction

Tomato (*Lycopersicon esculentum* L.) is considered a very important vegetable in the world [1]. The tomato fruit can be consumed fully cooked, half-cooked, fresh in salad, as paste in soups and stews all over the world [1]. Tomatoes are packed with health benefits [2, 3]. Lycopene is a powerful antioxidant found in tomato fruits, it helps in resisting cancerous cell formation and also prevents other diseases [3, 4]. Tomato is moderately tolerant to soil pH of 5.5-6.8 and it is a deep-rooted plant with its roots reaching up to 160 cm [1]. The crop is moderately sensitive to salinity, requires about 350-800 mm of water from the transplanting stage to the harvest, the amount of water required depends on climate, soil type and crop management. The type of soil required is usually one with good aeration, well drained, deep and an adequate water holding capacity, of which sandy loam soils are preferred [5].

Water is fast becoming an increasingly scarce resource, with droughts becoming serious due to changing climate conditions, especially in the arid and semi-arid regions. Agriculture is the world's largest water user, accounting for 70% of all freshwater withdrawals [6, 7]. Production of tomato is limited by several factors like soil infertility, over or under application of fertilizers and mis-management of water

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[8] especially in the northern region of Ghana. In terms of the expected yield of tomatoes, the farmers in Ghana have failed to reach their potential of producing 20 t/ha of tomato (MoFA, 2020). Average yields remain low at 2-5 t/ha [9, 10] because of the one seasonal production, high perishability of the fruit, poor access to markets, and competition from imports. From the 2000s, production of tomato appears to be slowly declining so domestic production is supplemented by imports from neighboring countries like Burkina Faso during the December to May harvest season, estimated to be as high as 100,000 tons per year [11].

The use of drip irrigation systems has the potential to increase crop production even at reduced irrigation water application [12]. Drip irrigation systems have an application efficiency of 90% and above especially for vegetable crops in the semi and arid regions [13]. Agronomic practices like mulching have the potential to reduce the demand for irrigation water by conserving moisture [14]. Accurate assessments of specific growth stage stress tolerances like vegetative and reproductive stages for vegetable crops are very necessary to establish deficit irrigation levels [15] and be able to deal effectively with the crop water requirement at sensitive and precise stages with support from modern irrigation systems for optimal water management [16].

The objective of the study was to identify the best bet irrigation and mulch strategies that allows water saving in drip irrigated tomato with reduced effect on yield under the Guinea savannah Agro-ecological zone of Ghana. The expectation was to enable tomato growers to incorporate more appropriate deficit irrigation methods and mulching into their usual production practices.

2. Materials and Methods

2.1 Study Area and Experimental Site

The experiment was conducted at the on-station research field of the Council for Scientific and Industrial Research (CSIR) — Savanna Agricultural Research Institute (SARI), Nyankpala located on N 9°023.321’, W 01°000.140 in Tolon district of the Northern region of Ghana. The Guinea Savanna Agro-ecological Zone includes Ghana’s Northern Region. It is associated with an annual rainfall total of 1000-1300 mm. Every dry season, the rainy season lasts roughly 140-190 days, whereas the projected reference evaporation, ETo, is around 2000 mm/year, resulting in a significant seasonal shortfall. August and early September are frequently the wettest months of the year. Approximately 60% of the rainfall falls in three months (July to September), with severe storms causing serious drainage issues. The soil texture was sandy loam with 70.12% sand, 21.2% silt and 8.6% clay (Table 1).

Table 1 Soil physical and chemical properties of the experimental site.

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil Texture	FC (%)	PWP (%)	AWC (%)	Bulk density (g/cm³)	EC (µs/cm)	pH (1:2.5)	O.C (%)	N (%)	P (mg/kg)	K (mg/kg)
0-20	70.12	21.2	8.68	Sandy loam	0.182	0.091	0.091	1.48	13.06	5.45	0.98	0.09	3.68	78
20-40	60.24	29.24	10.52	Sandy loam	0.18	0.069	0.111	1.66	8.32	5.42	0.74	0.07	2.35	56
40-60	59.35	30.02	10.63	Sandy loam	0.204	0.096	0.108	1.69	6.98	5.42	0.53	0.05	2.31	44

2.2 Experimental Design and Treatments

This was a 2 × 3 × 3 factorial experiment laid out in a split-split-plot design replicated four times. Variety was the main-plot factor with drip irrigation regimes as sub-plot factor and levels of rice straw mulch as a sub-sub-plot factor.

2.3 Nursery Preparations and Cultural Practices

Nursery beds of dimension 1 m × 6 m were constructed and 50 g of tomato seeds of two varieties, Pectomech and Mongal F1 were sowed. The surface of the nursery bed was covered with a thin layer of rice straw mulch to help retain soil moisture and regulate soil temperature within the root zone for effective and uniform seed germination and emergence. Healthy and vigorous seedlings of 12-15 cm height were carefully uprooted from the seedbed and transplanted with a pot of soil placed in holes of 10 cm deep and the soil hardened to maintain an erect posture. Fertisol was applied as soil amendment across the whole field at the rate of 6 t/ha before tomato seedlings were transplanted. Inorganic fertilizer was applied at a rate of 75 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} to the crop in a split manner. Basal dose at 2WATP (weeks after transplanting) and top dressed at 5 WATP to the treatments. Standard pest management procedures were adopted in order to control pests and weeds.

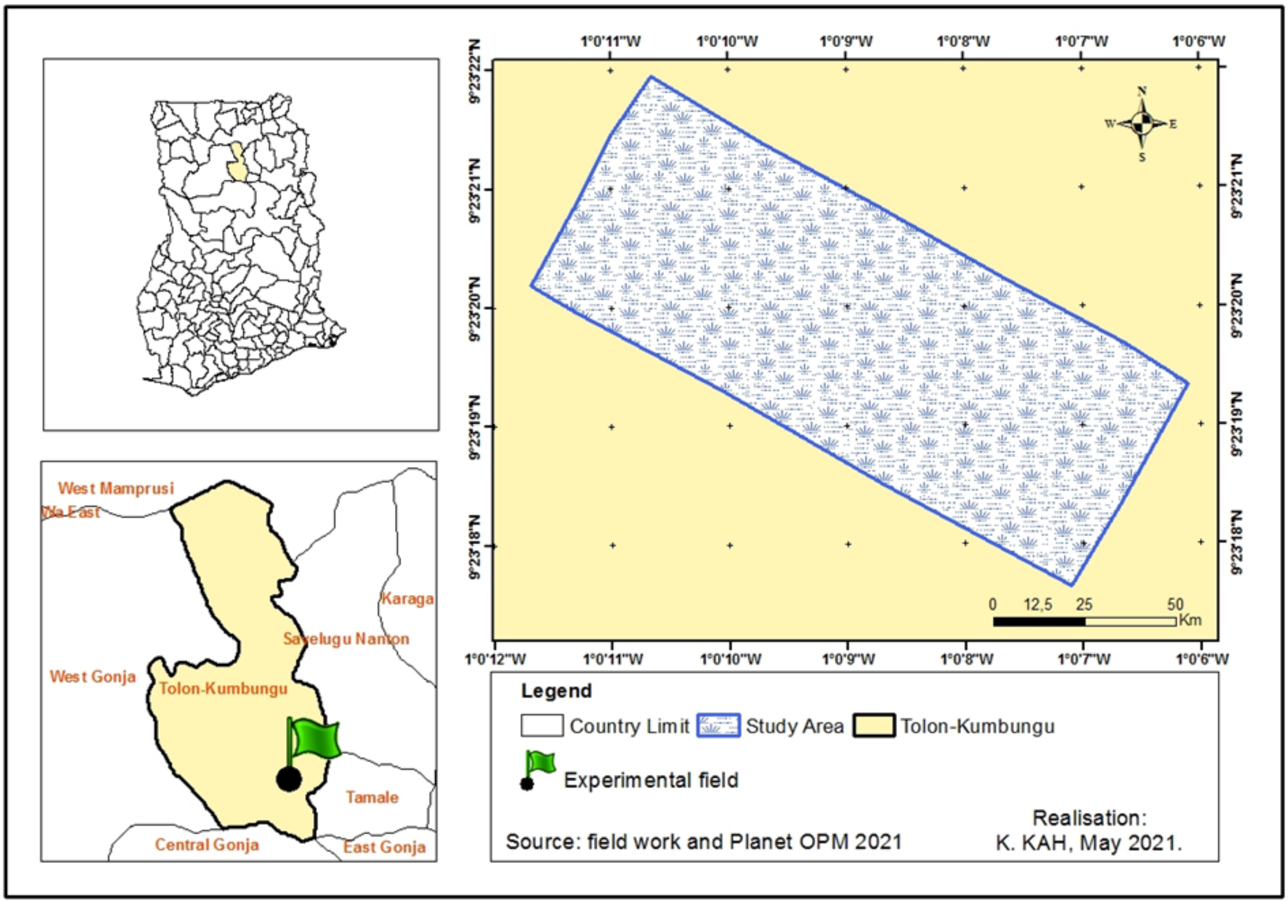

Fig. 1 Map showing location of study area.

Table 2 Factor and factor levels used in the experiment.

Variety	Irrigation Regime	Rate of Rice Straw Mulch (t/ha)
Pectomech	ET_{50}	0
Mongal F1	ET_{75}	3
	ET_{100}	6

2.3.1 Land Preparation and Field Layout

The experimental field was harrowed and hand leveled and layout for planting. Plot size consisted of three rows of 4.5 m long and 1.8 m wide, with alleys of 1 m separating plots and blocks. The drip irrigation system was gravity-fed with the water source located 22 km away from the field. The water was pumped via a subsurface pipe network to the facility and stored in a

30,000 liters capacity tank as night storage.

2.3.2 Soil Sampling and Analysis

The composite soil sample was analyzed for physical and chemical properties, using standard procedures. The samples were analyzed at the laboratory in Savannah Agricultural Research Institute (SARI) at Nyankpala, Tamale. The soil properties analyzed included: soil texture, organic matter content, electrical conductivity and bulk density, water retention at field capacity (FC) and permanent wilting point (PWP), pH, organic carbon, soil texture, total nitrogen, available phosphorous, potassium, calcium and magnesium.

2.3.3 Irrigation Water Requirement

Reference Evapotranspiration (ETo): Long term (1970-2019) daily weather data was used to calculate ETo. Climatic parameters considered were: maximum and minimum temperatures, relative humidity, wind speed and sunshine hour. The ETo was estimated by the CROPWAT software (FAO, version 8.0) using the FAO Penman-Monteith approach [17]. Crop water requirement was calculated as:

$$ETc = ETo \times Kc \quad (1)$$

Where: ETo = Reference evapotranspiration (mm); Kc = crop constant.

For localized (drip) irrigation, the equation by Keller and Bliesner (1990) was used to adjust the ETc to ETcrop-loc for localized irrigation systems with a ground cover (Pd) of 95%. The adjusted ETc was calculated using the formula:

$$Td = Ud \times [0.1\ (Pd)^{0.5}] \quad (2)$$

Where, Td = $ETc_{\text{-localised}}$,

$ETc_{\text{-localised}}$ = estimated ETcrop at peak demand for localized irrigation,

Ud = conventionally estimated peak ETcrop,

Pd = percentage ground cover.

Assuming no effective rainfall (Pe), no leaching (LR), the net irrigation requirement for this experiment became the adjusted crop water requirement (ETc). The Net Irrigation Requirement (IRn) did not include losses that occurred in the process of applying the water. The gross irrigation requirements accounted for losses of water incurred during conveyance and application in the field. The gross irrigation requirement was computed by adopting a field application efficiency (Ea) of 95%.

2.4 Data Collection

In each plot, ten tomato plants were randomly selected and tagged and monitored throughout the growing season. Thirty plants per block were selected and a total of 720 plants were tagged for the entire field and the following data sets collected:

Flower Count: the number of flowers within each plot were counted and recorded weekly.

Flower abortion Count: the number of aborted flowers were counted and recorded weekly.

Fruit Count per plant: Total fruit number on the tagged plants were counted weekly and averaged.

Fruit Yield: Total fruits per plant per plot were harvested and weighed using an electronic weighing scale and converted to tons per hectare.

2.5 Data Analysis

Data collected was subjected to analysis of variance (ANOVA) model appropriate for split-split-plot using the GenStat software. Where significant differences were observed, means were separated using Least Significant Difference (LSD) at 5% probability.

3. Results and Discussions

3.1 Crop Water Requirement

The highest net irrigation water application was 564 mm obtained from ET_{100} and the minimum was 282 mm from the highly stressed treatment (ET_{50}) (Table 3). The highest gross irrigation seasonal water requirement that was calculated by using 95% field application efficiency was obtained from ET_{100} as 593 mm and the lowest was 297 mm from ET_{50}. The result of tomato seasonal water demand that was obtained from optimal irrigation was in agreement with [18, 19]. As expected, the highest seasonal ETc was recorded in the full irrigation regime (ET_{100}), clearly owing to favorable soil moisture during the growing period, whereas the lowest seasonal ETc was recorded in the treatment with a prolonged water deficit (ET_{50}). The estimated seasonal ETc values for tomato are consistent with the values noted by Doorenbos and Pruitt (1992). These authors stated the water requirements of tomatoes varied from 400 to 600 mm [12, 20-22] depending on the climate and the total length of the growing period.

Table 3 Crop water requirement and deficit irrigation level of tomato.

Month	Kc	ETo (mm/day)	100% ETc (mm/dec)	75% ETc (mm/dec)	50% ETc (mm/dec)
Nov	0.9	4.43	39.87	29.90	19.94
Dec	0.9	4.03	36.27	27.20	18.14
Dec	0.9	4.03	36.27	27.20	18.14
Dec	0.94	4.03	37.88	28.41	18.94
Jan	1	4.46	44.60	33.45	22.30
Jan	1.06	4.46	47.28	35.46	23.64
Jan	1.11	4.46	49.51	37.13	24.75
Feb	1.12	5.16	57.79	43.34	28.90
Feb	1.12	5.16	57.79	43.34	28.90
Feb	1.12	5.16	57.79	43.34	28.90
Mar	1.01	5.36	54.14	40.60	27.07
Mar	0.83	5.36	44.49	33.37	22.24
Total			564	423	282

3.2 Weather Parameters During Crop Growth

During the tomato crop growth period, the temperature ranged from 27.6 to 33.7°C (Fig. 2), relative humidity varied from 14 to 66 percent, likewise, wind speed ranged from 1.74 to 2.43 ms^{-1} (Fig. 3). The stated values are inline with the report by Kumar, 2012, who stated that the crop requires a mean maximum temperature of 29 to 32.8°C, with relative humidity of 24 to 91%. The total rainfall received during the cropping period was only 26.8 mm. Thus it was evident that the moisture was insufficient for the optimum growth of the tomato plant agreeing with the need for irrigation [23].

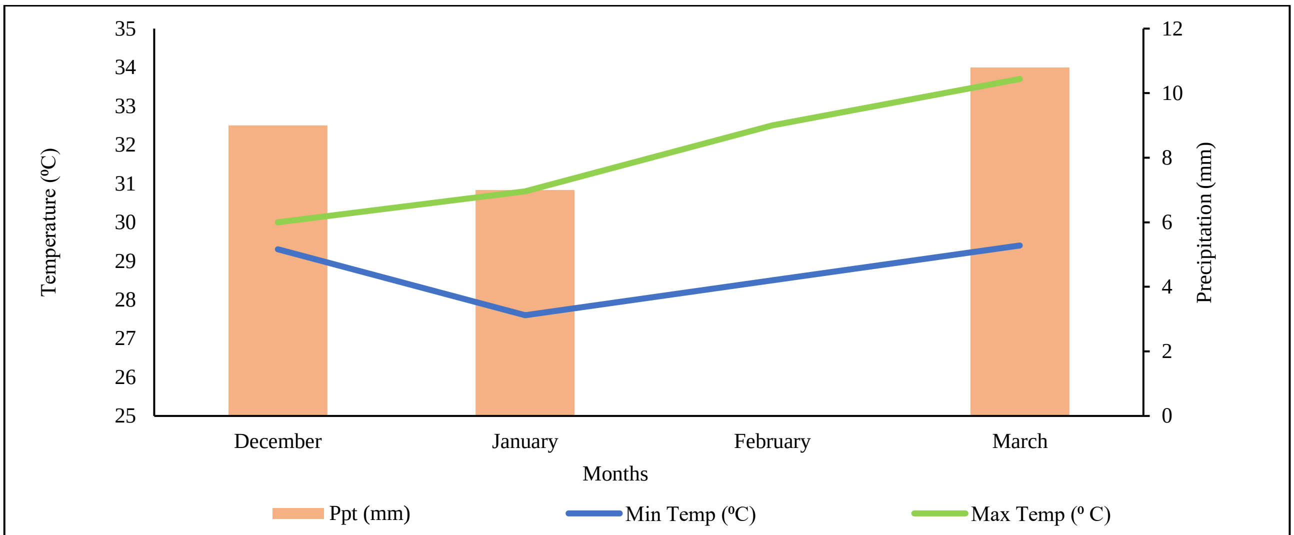

Fig. 2 Monthly temperature and precipitation during the cropping season.

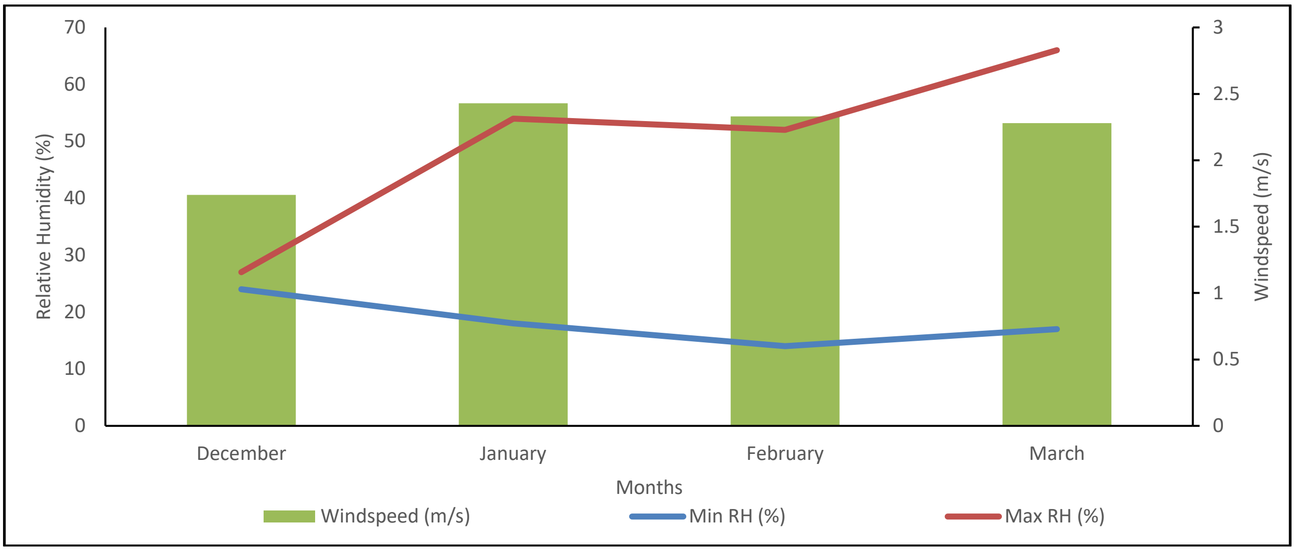

Fig. 3 Relative humidity and windspeed during cropping season.

3.3 Reproductive Parameters

3.3.1 Effect of Variety, Irrigation Regimes and Mulch on Flower Number

The interaction of mulch and variety on flower count at 7 WATP was significantly ($p < 0.01$) different. Pectomech variety recorded the highest flower count at 6 t/ha mulch, which was closely followed by 3 t/ha mulch and no mulch gave the lowest count (Fig. 4). In a study carried out on freesia plants, straw mulch produced highest number of flowers per spike as compared to no mulch, the experiment also concluded that straw mulch encouraged flower production [24].

At 9 WATP, there was a statistically significant difference in flower number due to the interaction effect of the variety Pectomech and irrigation at ET_{50} (Fig. 5). There was also a highly significant difference ($p < .001$) in flower number due to the interaction effect of the variety Pectomech and mulch level of 0 t/ha (Fig. 4). This increased flower count under drought conditions might be due to rapid phenological development to complete the life cycle under an unfavorable environmental condition [25]. The results disagree with findings by Younis et al. (2012) [24] who concluded that straw mulch enhanced flower production.

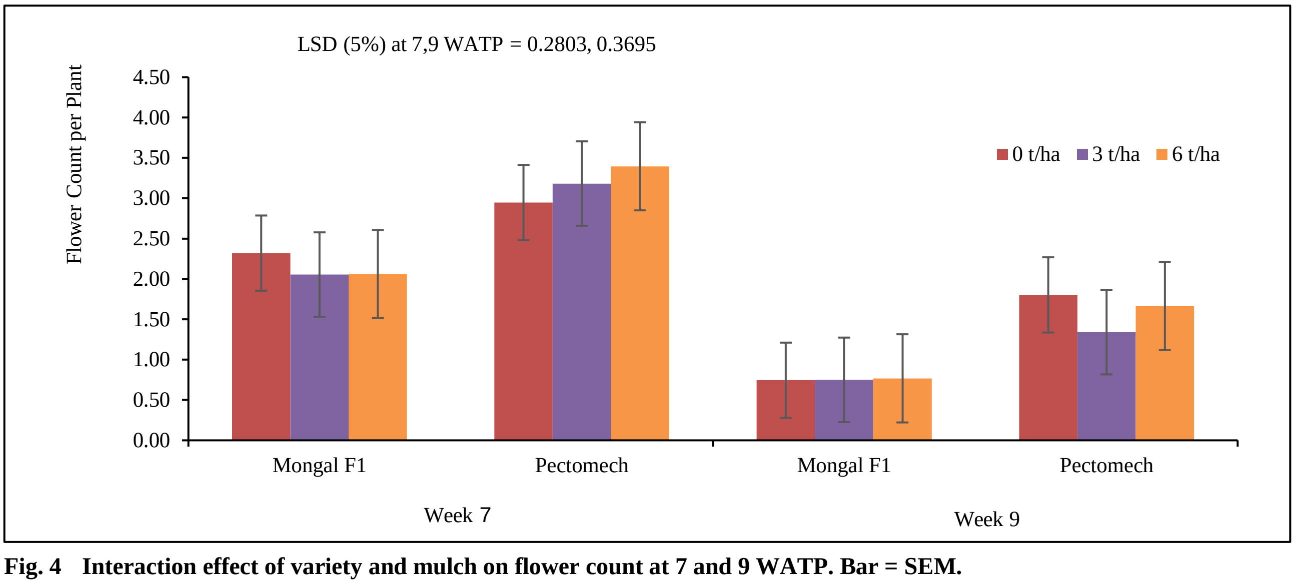

Fig. 4 Interaction effect of variety and mulch on flower count at 7 and 9 WATP. Bar = SEM.

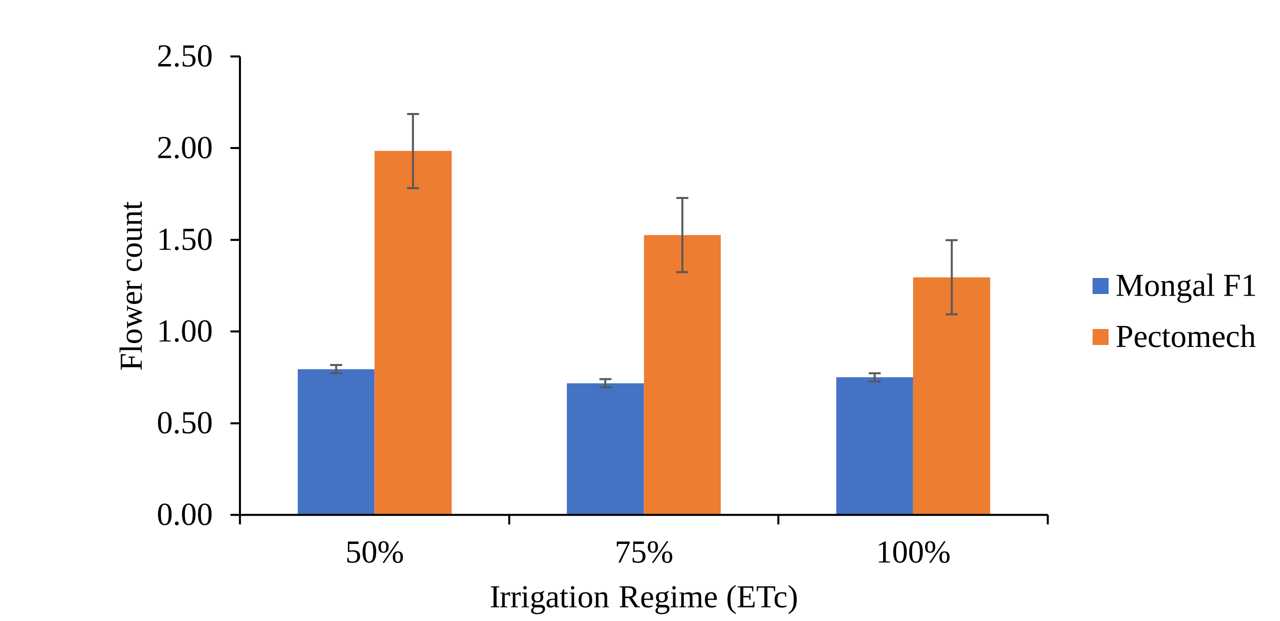

Fig. 5 Interaction effect of variety and irrigation regimes on flower count at 9 WATP. Bar = SEM.

The possible reason for increased flower number, under higher rate of irrigation and straw mulch, was that optimal irrigation and higher levels of straw mulch helped to create a more conducive soil micro-environment for reproductive growth of tomato plant development over an extended time [26].

3.3.2 Effect of Variety, Irrigation Regimes and Mulch on Flower Abortion Count

The interaction of variety, irrigation regimes and mulch at 7 and 8 WATP was significantly ($p < 0.01$) different and also significant ($p < 0.05$) at 9 WATP. Pectomech at ET_{50} without mulch recorded maximum flower abortion count (38.5) at 7 WATP followed by Pectomech at ET_{50} without mulch (35.3) at 8 WATP and 32.3 from Pectomech at ET_{50} without mulch at 9 WATP. The least abortion counts were 10.8, 6.0, and 4.8 which were observed with Mongal F1 at ET_{100} at 6 t/ha at 7, 8 and 9 WATP respectively (Table 4). Pectomech flowers aborted more than that of Mongal F1 and could be as a result of differences in adaptability of the varieties to the environment and tolerance to high temperatures [27]. These results are in harmony with the results of Mends-Cole et al. (2019) [28] who reported that environmental conditions and genotype significantly affected flower abortion. The results also were in consensus with studies by Melomey et al. (2019) [29], who reported some tomato varieties currently cultivated in Ghana have poor performances such as susceptibility to blossom endrot, tomato yellow leaf curl virus, and intolerance to heat. The highly stressed irrigation regime (ET_{50}) significantly aborted more than ET_{100} and this could be attributed to stress levels. This results agreed with Ragab et al. (2019) [30] who reported the irrigation regime of ET_{55} significantly reduced flower number and increased abortion of flowers as compared to the irrigation regime of ET_{100}. The abortion rate indicated that increased deficit water increased abortion which is in agreement with previous studies [25, 31-33]. According to studies carried out by Ganeva et al. [34], the combination of deficit irrigation and high temperatures has adverse influence on flowering of tomato. Even though they might produce flowers, all of them may not translate to fruits due to abortion because the flowers wither and dry up, after which they fall off the plant preventing the flower from fruiting and also environmental causes like temperature, heat and humidity. high temperatures can lead to a reduction in the number of flowers and an increase of blossom drop and fruit abortion [5]. While extremely high temperatures essentially cause tomato plants to give up on producing fruit, and focus instead on survival. High humidity impedes pollination, which could cause the flowers to wither and drop off the plants [35].

Table 4 Effect of variety, irrigation regimes and mulch on flower abortion at 7, 8 and 9 WATP.

Variety	Irrigation Regimes (% ETc)	7 WATP			8 WATP			9 WATP		
		Mulch Levels (t/ha)								
		0	3	6	0	3	6	0	3	6
Mongal F1	50	25.5	22.3	27.0	21.8	18.3	23.0	18.8	15.8	19.5
	75	27.3	24.5	21.0	23.5	20.8	17.0	20.5	17.8	14.0
	100	19.0	12.0	10.8	14.3	8.3	6.0	11.3	5.8	4.8
Pectomech	50	38.5	31.5	30.8	35.3	27.8	27.0	32.3	24.8	24.0
	75	29.3	25.8	25.3	26.0	21.8	21.3	23.0	19.0	18.3
	100	19.5	16.0	13.5	15.8	12.3	9.8	12.8	9.0	6.8
LSD (5%)		5.172			5.109			5.163		
p-value		0.006			0.005			0.041		

3.4 Yield Parameters

3.4.1 Effect of Variety, Irrigation Regimes and Mulch on Fruit Number

At 7 WATP Irrigation at ET_{100} gave the highest number of fruits (9) with the least from ET_{50} (7), this result was in line with results by Sibomana et al. (2013) [36] who reported the highest number of fruits from ET_{100} (46.03) in the first trial and 48 fruits in the second trial with least recorded by the most stressed regime (ET_{40}) recording 34 .5 fruits and 31.3 in the first and second trial respectively. However, the interaction between irrigation and mulch significantly ($p < 0.05$) influenced the fruit count. The highest number of fruits recorded for the interaction between ET_{100} irrigation regime and 6 t/ha of mulch and the lowest at ET_{50} irrigation regime at 0 t/ha of mulch (Fig. 6). These results were in agreement with results by Al-Suhaibani (2009) who recorded highest fruit count from treatments that were mulched and received high amounts of moisture as compared to treatments that were under deficit conditions. The results also agree with findings by Ayankojo and Morgan (2020) [37] who reported reduced fruit number caused by increased temperatures, no mulched plots were exposed to higher temperatures as compared to the mulched plots. This result was in unison with Kumar (2012) [23] who recorded highest number of fruits per plant (51.22) with mulched treatments as compared to 43.11 from plots with no mulch application. The results are in consensus with Birhanu and Tilahun (2010) [38] who reported a decrease in fruit number from tomato plants that were exposed to moisture stress. The Mongal F1 variety recorded more fruits than Pectomech, this results are in harmony with Ochar et al. (2019) [27] who recorded Mongal F1 to be a high performing genotype suitable for both greenhouse and open field trials. There is a clear indication in the results that deficit irrigation plays a key role in the fruit count of tomato plants. The highest fruit number might be due to optimum water and mulch application.

3.4.2 Effect of Variety, Irrigation Regimes and Mulch on Total Fruit Yield

There was a significant difference in total fruit yield due to the interaction effect of variety by irrigation regime with a maximum fruit yield of 13.46 t/ha from treatments s that received Mongal F1 variety with ET_{100} and minimum from the Pectomech variety and ET_{50} (2.04 t/ha). The analysis of variance results revealed that total fruit yield was significantly affected by the interaction effect of variety and mulch with a maximum total fruit yield of 11.8 t/ha from the Mongal F1 variety and 6 t/ha mulch and a minimum of 1.98 t/ha from the Pectomech variety without mulch. The results

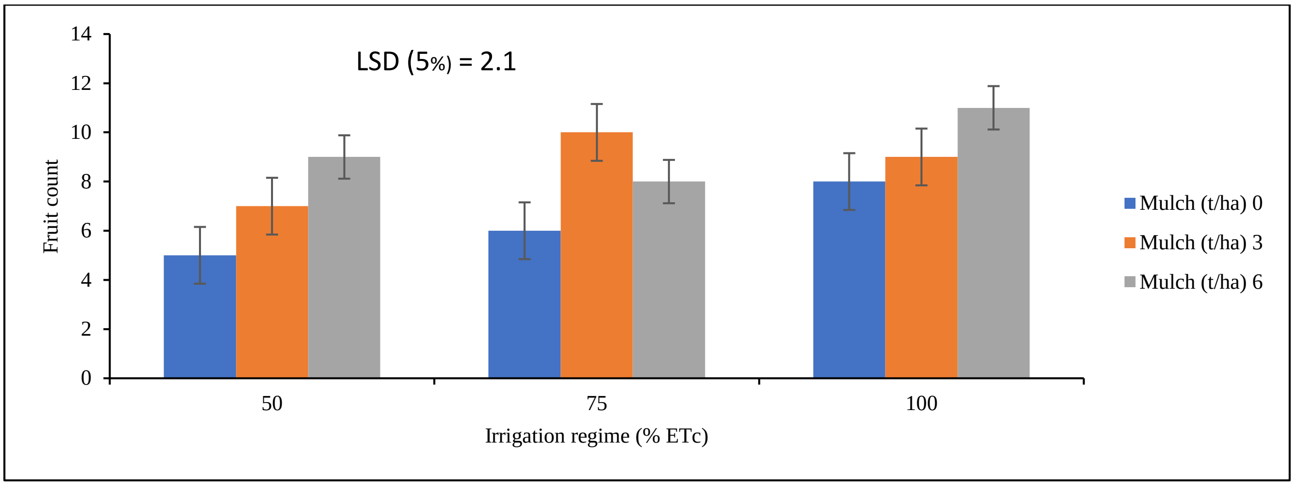

Fig. 6 Interaction effect between irrigation regimes and mulch on fruit count at 7 WATP. Bar = SEM

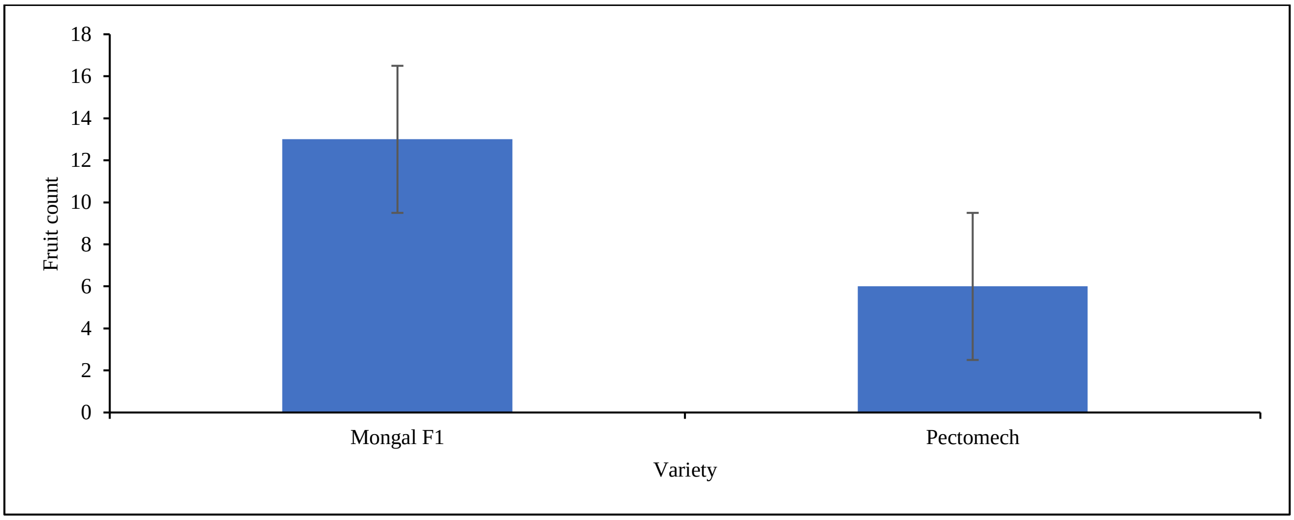

Fig. 6 Effect of Variety on Fruit Count at 8 WATP. Bar = SEM.

Table 5 Interaction Effect of Variety and Irrigation Regimes on Total Fruit Yield (t/ha).

Irrigation (% ETc)	Variety	
	Mongal F1	Pectomech
100	13.46	2.7
75	9.63	3.26
50	8.87	2.04
LSD (5%)	3.818	
p-value	0.015	

Table 6 Interaction Effect of Variety and Mulch on Total Fruit Yield (t/ha).

	Mulch (t/ha)		
Variety	0	3	6
Mongal F1	8.69	11.47	11.8
Pectomech	1.98	2.96	3.06
LSD (5%)		3.886	
p-value		0.051	

are in accordance with investigations by various authors who reported increased in deficit water reduced fruit mass which was directly related to fruit yield [25, 31, 33]. The results aligned with those of Berihun (2011) [20], Kamal and Shashi (2012) [39], Biswas et al. (2015) [12] and Hott et al. (2018) [40] who reported higher yields from favourable conditions in terms of moisture availability to the plants. The investigations suggested that the difference might be due to the adaptability of the Mongal F1 variety to the local environment and tolerance to the high temperature of the study area. Pectomech variety was noted to be susceptible to blossom end rots thereby translating to lesser fruit yield as compared to the Mongal F1 variety. The results were in concurrence with findings by Ochar et al. (2019) [27] who observed Mongal F1 to be better acclimatized to cultivation than the Pectomech variety, and also Melomey et al. (2019) [29] who reported the Pectomech variety to be intolerant to heat, susceptible to blossom end rots and tomato yellow leave curl disease. The results were in line with studies by Kebede (2019) [22], which recorded the highest bulb yield of onion from treatment plots that received ET_{100} as compared to yield from ET_{60}, Kumar, 2012 that indicated the highest fruit yield (36.78 t/ha) from drip irrigation at 1.0 Epan and lowest from drip irrigation at 0.6 Epan. The results of the study were in agreement with the result from Tegen et al. (2016) [26] which recorded the highest marketable yield of 60.9 t/ha with grass mulch and the lowest (43.76 t/ha) with no mulch treatment in a polyhouse. The increase in total fruit yield gained by the application of rice straw mulch was attributed to its favourable effect on soil moisture and soil temperature which eventually generated a conducive condition for the growth and development of the tomato plant. This agrees with studies conducted by Ayankojo and Morgan (2020) [36] who reported increased temperatures resulted in lower yield. The increase in total fruit yield gained by the application of rice straw mulch could be attributed to its favorable effect on soil moisture and soil temperature which eventually generated a conducive condition for the growth and development of the tomato plant.

4. Conclusions

The results from this study demonstrated effects of variety, irrigation regimes and mulching as significant to improve yields of tomato grown under the Guinea savannah agro-ecological zone in Ghana. Drip irrigation had significant effect on flowering, fruiting and yield of tomato. Tomato yields of deficit irrigated with no mulch were significantly lower than those of full irrigation with mulch. The results of this study showed that for rain fed production Mongal F1 at 3 t/ha mulch could be adopted for optimum yield. In areas of water shortage, deficit drip irrigation combined with practices like mulching should be adopted since there is the potential to save water without compromising yield as compared to optimal irrigation with un-mulched practices. The results from this study could help in the development of water management system for tomato production in the scenario of reduced water availability and enable the tomato growers to produce tomato with optimum yield by allowing little water stress without substantial yield reduction. Future investigations should focus on implementing findings from this study in other agro-ecological zones.

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