Optimizing the Planting Date for Onion Production: Correlation Between Weather Conditions and Plant Growth, Yield, and Bulb Quality

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Abstract

This study was conducted during 2018 and 2019 at research farm of agriculture faculty of Kabul University, Afghanistan to evaluate the correlation between weather conditions (maximum, minimum and mean temperature, relative humidity, cumulative day light and cumulative rainfall) and onion plant growth, yield and bulb quality, as well as to find the optimal planting date for onion variety Safid e Paisaye. The research was designed in RCBD and the data was analyzed with STAR software. The results of this study reveal that increasing temperature and decreasing relative humidity and rainfall during growing season, caused faster maturity of bulbs, produced small sized bulbs, and finally reduced onion bulbs yield. It was observed that, due to relatively lower temperature and higher relative humidity during early growth stages the onion grown early in spring (seed sown in early March and transplants planted early in May) took longer period for maturation, produced larger bulbs and higher yield. This was also noted that due to longer maturation period the onion plants grown in early spring received a higher cumulative heat and sun light which contributed to improve bulb quality and yield of onion. Based on this study results we conclude that early planting date of onion variety Safid e Paisaye not only increased significantly yield but also improved bulb quality.

Keywords: correlation analysis, growth response, planting date, quality response, weather conditions, yield response

1. Introduction

Onion (*Allium cepa* L.) is one of the largest cultivated and consumed vegetables in the world. In Afghanistan onion is grown on a commercial scale and its production during year 2019 reached to 352,725 metric tons of dry bulbs for both local consumption and export (Commodities by Countries, 2017). During year 2019, Afghanistan exported approximately 79 and 49 thousand metric tons of onion bulbs to Pakistan and India, respectively, with a total export value of 38.15 million US Dollars (Onion Export from Afghanistan, 2021). Onions are thought to be originated from Afghanistan (Mehta, 2017) because large number of local varieties and their wild relatives are found in the country. The onion variety Safid e Paisaye is cultivated in central Afghanistan especially in Ghorband valley in neighboring of the capital city (Kabul) (Salari et al., 2020). The onion bulb of this variety are famous for it’s longer storability and a high market demand (Salari et al., 2020).

It is an accepted fact that weather conditions play major role in production and productivity of agricultural crops. The wide variation in planting dates of onion among regions shows effect of environment on onions’ growth and yielding capacity (M. Ali, 2016; Misra et al., 2014; Navaldey & Ram, 2014).

Temperature and day length play important roles in onion bulb formation and final size (Lancaster, 1996). To initiate bulb formation, onion plants shall attain the double threshold of minimum day length of 13.5 to 14 hours and accumulate approximately 600 Growing Degree Days (GDD) from emergence. Bulb formation is not initiated until both of these requirements are met (Lancaster, 1996). In this respect, (Khokhar, 2017) found that, high temperatures and long days promote bulb formation of onions. He also reported that, formation of bulb is highly regulated by temperature as compared to photoperiod, as determined by growing degree days (GDD). Moreover, (Mosleh UD Deen, 2008) reported that, onions requires long days for onions bulb production and maturation. He further added that, due to plant response to day length the planting time is the most important factor that influenced plant growth and yield of onion crop. (Karim & Ibrahim, 2013) reported that, sowing date is critical for onion production because the plants from too late sowing may not produce bulbs due to their response to photoperiod. They further added that, short day onion cultivars require photoperiod of 12 hours and other long-day varieties need 13.5 to 14.0 hours of photoperiod. (Ikeda et al., 2020) found that, the bulb development of onions is induced during long days, and it is inhibited by short days. They also reported that, the critical day length required for each cultivars' bulb development differs based on their genetic characteristics and the length of day is calculated from the critical day-lengths for bulb development of each cultivar. A significant interaction between day length and variety was also reported by (Habila & Namo, 2014) on mean bulb weight, bulb diameter, bulb size, bulb length and number of bulb rings. They reported that, the variety "Red Creole" is more affected by longer day length as compared to the variety "Violet de Galmi" under the Jos-Plateau environment.

The onion bulb induction is associated to temperature and photoperiod. Based on photoperiod the onion cultivars are classified as i) short-day requiring less than 12 hours light, ii) middle-day requiring 13 to 14 hours of light and iii) long-day requiring 15 to 16 hours of light. The interaction between temperature and day length may arise environmental limitations, as the warm temperature in late spring hasten bulb initiation in short-day cultivars and forces plants to develop small sized bulbs however colder winter temperatures can induce "bolting" (Sekara et al., 2017). The authors reported that, marketable yield of onion was decreased when the length of growing season reduced due to increase temperature. (Atif et al., 2020) reported that, onions bulb development and enlargement were affected by the photoperiod, and long days encouraged the bulb initiation. They further reported that, in some cultivars the bulb initiation only occurred when double thresholds of at least 600 GDD and photoperiod of 13.75 hours were achieved.

Bulb formation in the long-day onion cultivars was promoted by far-red light in 18 hours photoperiod. The higher level of far-red light reduced the duration needed for bulb initiation. Both long photoperiod without added far-red light and short photoperiod (10 hours) with added far-red light did not induce bulb formation.

(Bachie et al., 2019) reported that, onion plants cultivated under short day length and high temperature had higher photosynthetic rates and stomatal conductance as compared to onions cultivated under the long day. They found that, onion stomatal conductance and photosynthesis increased at bulb initiation stage, to provide carbohydrates desired for plant growth and bulb enlargement.

The marketable yield of onions was positively correlated with the number of rainy days and increased with increasing rainy days. The marketable yield of onion decreased with increasing temperature during the months from June to August (Tesfaendrias et al., 2011).

(Tho et al., 2019) found that, onion foliar diseases including Enterobacter cowanii, Pantoea ananatis and Pantoea agglomerans are positively correlated with relative humidity (RH), temperature and plant age. The authors reported a severe level of disease from each pathogen at 25-30°C. They found that, RH significantly influenced symptom development. The symptoms of disease were developed sooner on foliage and were more severe when RH was above 80% and were limited at RH below 60%. They also reported that, susceptibility increased with increment of plant age from 6 to 14 week.

The number of seasonal thrips increased in dry weather (30 mm rainfall) with moderately high temperatures (15.6 - 28.2 °C), while wet season (391 mm rainfall) with moderately high relative humidity (60 %) recorded reduction number of seasonal thrips (Waiganjo et al., 2008).

Small bulb size which ultimately lead to lower productivity is the main problem of onion variety *Safid e Paisaye* in Afghanistan. The studies showed that, planting date influences the growth, bulb quality and yielding capacity of onion crop. Considering the long storability, attractive color and shape and high market demand, minor improvements can allow this variety to occupy larger share of onion market in Afghanistan.

The objective of this study was to investigate the correlation between weather conditions and onion growth and bulb development to find the optimal planting date for improving bulb yield and quality of the onion variety Safid e Paisaye.

2. Material and Methods

This research was conducted for two subsequent years during 2018 and 2019 at research farm of agriculture faculty of Kabul University to study the optimal planting date for improving yield and quality of *Safid e Paisaye* onions. The experimental field (Kabul city, Afghanistan) has a dry temperate climate with cold winter and hot summer. The common growing season for onion production in Kabul starts from April and continues to November. The mean monthly weather data of 2018 and 2019 for maximum and minimum temperature (°C), relative humidity (%), day length (hours) and rainfall (mm) during the experimental periods (2018 and 2019) is presented in Table 1.

Table 1. The mean monthly weather data of Kabul city, Afghanistan during the experimental seasons of 2018 and 2019 (POWER Data Access Viewer, 2021), *(Sunrise and Sunset in Afghanistan, 2021).

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Day length (hours)*	Rainfall (mm)
March	11.2	-1.0	56.0	11.6	34.3
April	18.5	4.3	49.4	13.1	27.2
May	21.6	6.0	39.9	14.0	25.7
June	26.7	9.6	28.2	14.3	3.9
July	31.0	13.2	23.2	14.2	6.2
August	28.9	11.3	23.9	13.3	10.2
September	26.1	8.5	23.0	12.3	9.6

Based on data presented in Table 1, the average of monthly weather data for growing period of onion plants from seeding in the nursery until harvesting in different planting dates were calculated and shown in Table 2. With delay in planting date the temperature increased, and relative humidity and cumulative rainfall decreased which resulted in dry and hot climate. The mean temperature for first plating date during growing period was 16.99 °C which increased to 18.02 °C for third planting date. The higher temperature during later planting dates caused faster maturity of onion plants. Owing to relatively smaller maturity period (154 days) the onion plants in later planting dates received smaller number of growing degree days (GDD) and cumulative day light (hours) as compared to those grown in early dates. The growing degree days were calculated during the whole growing period from seeding in the nursery until harvesting based on the following formula (Lancaster, 1996). The base temperature used for calculation of growing degree days is 1.7 °C (Base Temperatures for Selected Vegetable Crops, 2021).

$$GDD = \sum_{i=1}^{n} \left[\frac{T_i^{max} + T_i^{min}}{2} - T_{base} \right] \quad (1)$$

Table 2. The average of weather data during different planting dates in growing seasons of 2018 and 2019.

Growing period	Season	Maximum temperature (°C)	Minimum temperature (°C)	Mean temperature (°C)	Growing degree days (GDD)	Relative humidity (%)	Mean day light (hours)	Cumulative day light (hours)	Cumulative rainfall (mm)
10 March to 02 Sept.	2018	26.55	8.80	17.67	2811.26	30.51	13.50	2375.13	64.48
	2019	24.78	7.81	16.29	2568.33	40.45	13.50	2375.13	129.63
	Mean	25.67	8.30	16.98	2689.80	35.48	13.50	2375.13	97.05
01 April to 10 Sept.	2018	25.83	9.04	17.44	2565.19	28.25	13.68	2229.69	57.60
	2019	24.99	8.69	16.84	2467.83	36.19	13.68	2229.69	95.22
	Mean	25.41	8.87	17.14	2516.51	32.22	13.68	2229.69	76.41
20 April to 21 Sept.	2018	26.57	9.55	18.06	2519.63	26.68	13.66	2103.46	55.11
	2019	26.15	9.32	17.74	2469.61	31.97	13.66	2103.46	68.55
	Mean	26.36	9.44	17.90	2494.62	29.32	13.66	2103.46	61.83

Onion seedlings were transplanted into the experimental field in three different planting dates (May10th, June 1st and June 20th) in a Randomized Complete Block Design (RCBD) with three replications to study the correlation of weather conditions with onion growth, yield and bulb quality.

Prior to transplanting, onion seeds were sown in nursery for 8 weeks. Seeds for first planting date were sown on March 10th under plastic tunnels, the plastic tunnel was removed on April 1st and the plants were exposed to open air conditions. The seeds for second and third planting date were sown under open air conditions on April 1st, and April 20th, respectively, in both seasons of the study. The onions were harvested when 50% of the leaves tops dried.

Recommended cultural practices such as plant spacing, fertilization, irrigation, use of pesticides and weeding were uniformly applied to all research plots.

In all treatments, the pre-harvest observations including number of leaves per plant, leaf length and leaf area per plant were recorded on fifty-four randomly labeled plants from each treatment and the mean value were worked out. The leaf area was recorded by the millimeter graph paper method (Salari et al., 2022a). Post-harvest observations such as total yield, marketable yield, polar bulb diameter, equatorial bulb diameter, bulb neck diameter, fresh bulb weight, bulb volume, bulb density, total soluble solids (TSS) and equatorial firmness were recorded on fifty-four randomly selected bulbs and the mean value were worked out. The TSS (Brix) is recorded using hand refractometer (0-32 ºB) and the firmness (kg/cm2) is recorded with penetrometer (13 kg). The diameter of penetrometer probe was one centimeter, and the data was presented in kilograms per square centimeter (Salari et al., 2022b).

The correlation analysis was done using Statistical Tool for Agricultural Research (STAR) (Products - Quantitative Genetics and Biometrics Cluster, 2021). Level of significance used is at $p=0.05$.

3. Results and Discussions

The weather conditions such as temperature, sun light, relative humidity and rainfall are major factors which changes for different growing seasons as well as impacts plant growth, bulbs yield and quality. The weather data presented in Table 1 revealed that, onion plants grown early in spring (March 10th) are exposed to lower temperature, shorter period of day light, higher humidity, and higher rainfall during early growth phases (seedlings stage). In later stages the case is opposite, and onion grown in late spring (April 20th) are exposed to higher temperature, longer period of day light, lower relative humidity, and lower rainfall (Table 2). To find the causes for diverse response of onions to different planting dates, the correlation between weather conditions and plant growth, bulb yield and quality are studied.

3.1 Temperature

Temperature plays critical role in growth, yield and quality of agricultural crops. Where it sets the amount of heat received by plant during the growing season. Calculating the cumulative growing degree days (CGDD); indicts the amount of heat received by the plant which plays a crucial role in crop maturity, yield and ultimately the product quality. The cumulative growing degree days are dependent on means of temperature and crop maturity period. According to the findings of (Atif et al., 2020; Lancaster, 1996) the bulb initiation stage started when the double threshold of minimum day length (13.5 hours) and approximately 600 growing degree days (GDD) were achieved. Owing to longer maturity period, the onion plants grown in early planting date (March 10th to September 2nd) received a higher number of cumulative growing degree days (Table 2).

3.1.1 Maximum temperature (°C)

Maximum temperature has a significant strong positive correlation with leaf length (r=0.8221**) and leaf area per plant (r=0.7936*). While its correlation with marketable yield (r=-0.7782*), total yield (r=-0.8095**) and equatorial bulb diameter (r=-0.6783*) was significant and strongly negative. This revealed that, an increase in maximum temperature caused a stronger vegetative growth expressed as leaf length and leaf area per plant (Fig. 1) resulting in lower yielding (Fig. 2) and a smaller bulb size expressed as equatorial bulb diameter (Fig. 3) of onion crop. According to the weather data presented in Table 2, the average maximum temperature increased with delaying in planting date. Therefore, the delaying in planting date of onion can cause a small bulb size which ultimately reduced the total yield of onions. Similar results were recorded by (Aboukhadrah et al., 2017; J. Ali et al., 2016; Caruso et al., 2014; Singh & Singh, 2000).

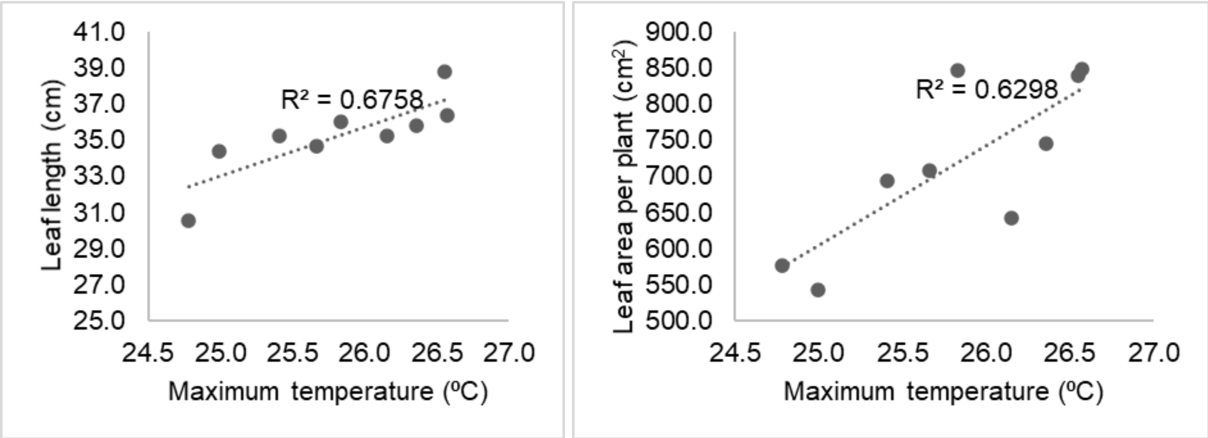


Figure 1. The correlation between maximum temperature and leaf length (left) and leaf area per plant (right) of onion plants

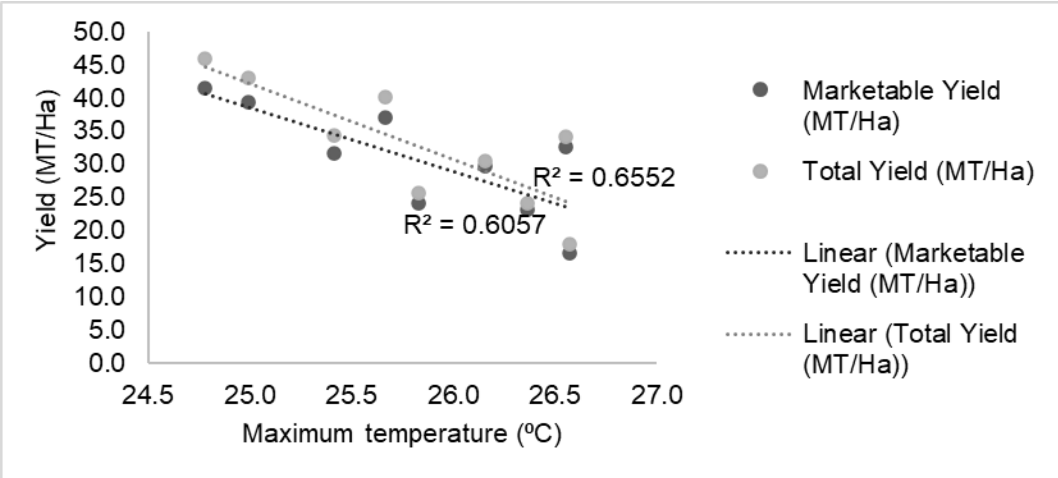


Figure 2. The correlation between maximum temperature and yield of onion plants

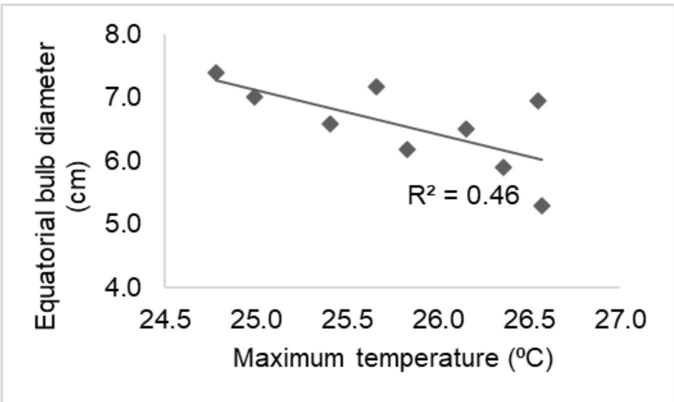


Figure 3. The correlation between maximum temperature and equatorial bulb diameter of onion plants

3.1.2 Minimum temperature (°C)

The minimum temperature has significant negative correlation with maturity period (r=-0.7808*), equatorial bulb diameter (r=-0.8899**), marketable yield (r=-0.8809**), total yield (r=-0.9016**), bulb weight (r=-0.9115**) and bulb volume (r=-0.9185**). Data presented in figure 4 showed that, a higher minimum temperature leads to early maturity of onion crop which results in a smaller bulb size (Figs. 4 & 6) and lower yielding (Fig. 5) of onion crop. The average of minimum temperature was increased with delaying in planting date (Table 2). The increment of minimum temperature for delayed planting dates of onion plants leads to early maturity and small bulb size which ultimately reduced yield of onions. Similar results were recorded by

(Abdulsalam & Hamaiel, 2004; Bosekeng & Coetzer, 2013; Caruso et al., 2014; Karim & Ibrahim, 2013).

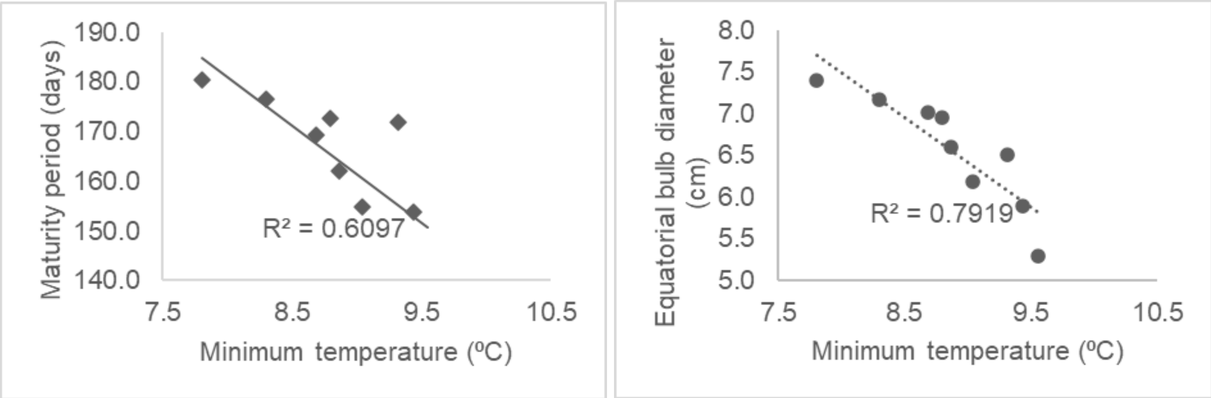


Figure 4. The correlation between minimum temperature and maturity period (left) and equatorial bulb diameter (right) of onion plants

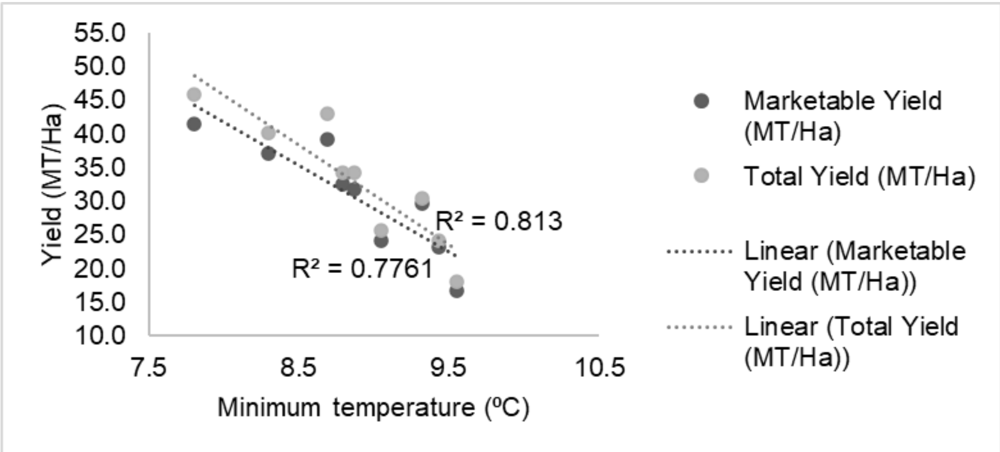


Figure 5. The correlation between minimum temperature and yield of onion plants

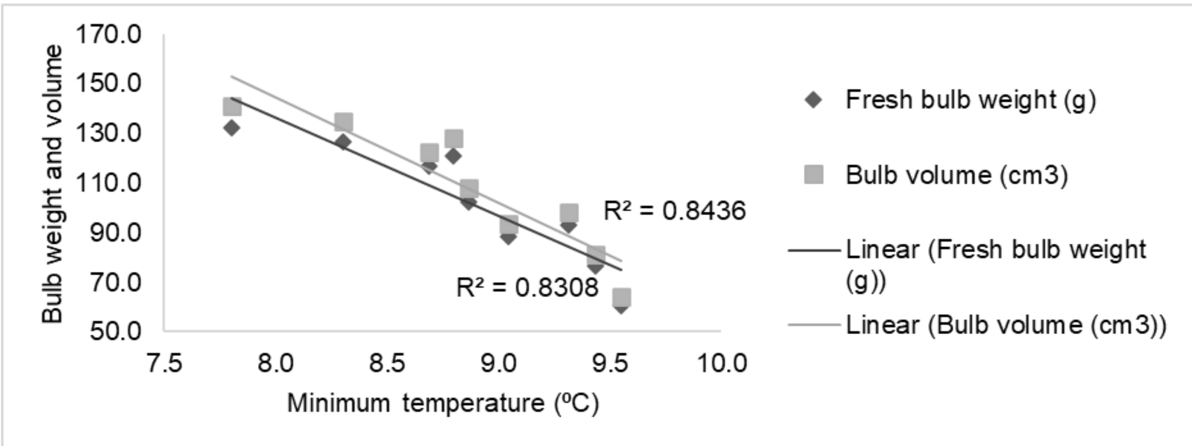


Figure 6. The correlation between minimum temperature and bulb weight and volume of onion plants

3.1.3 Mean temperature (ºC)

Mean temperature has a significant strong positive correlation with leaf length (r=0.7923*) and leaf area per plant (r=0.7137*). While its correlation with the maturity period (r=-0.6955*), equatorial bulb diameter (r=-0.8246**), marketable yield (r=-0.8776**), total yield (r=-0.9057**), bulb volume (r=-0.8155**) and bulb weight (r=-0.8127**) were significant and strongly negative. The obtained results revealed that, with an increase in mean temperature the vegetative growth was enhanced (Fig. 7) but reduced the plant maturity period (Fig. 8) which resulted in small sized bulbs (Figs. 8 & 10) and lower yielding (Fig. 9) of onion crop. According to the weather data presented in Table 2, the average mean temperature was increased with delaying in planting date. Therefore, the delaying of planting date of onion plants can cause small bulb size which ultimately reduced the total yield of onions. The authors (Aboukhadrah et al., 2017; Bosekeng & Coetzer, 2013; Salari, Antil, et al., 2021; Sekara et al., 2017; Tesfaendrias et al., 2011) reported similar results.

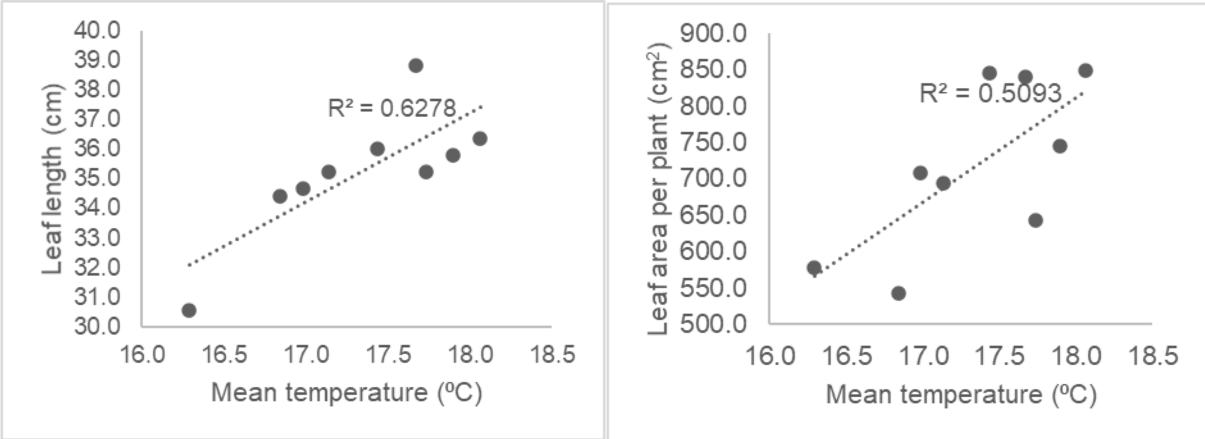


Figure 7. The correlation between mean temperature and leaf length (left) and leaf area per plant (right) of onion plants

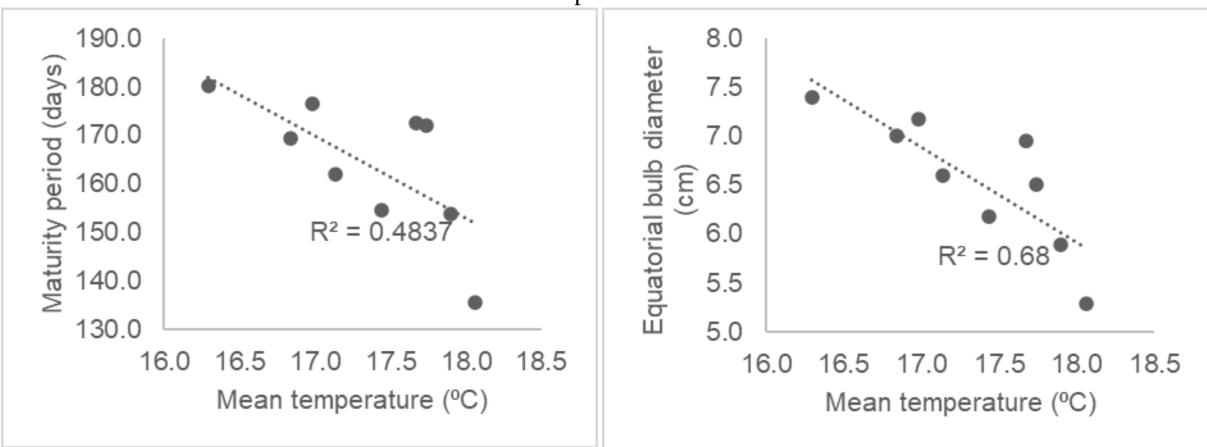


Figure 8. The correlation between mean temperature and maturity period (left) and equatorial bulb diameter (right) of onion plants

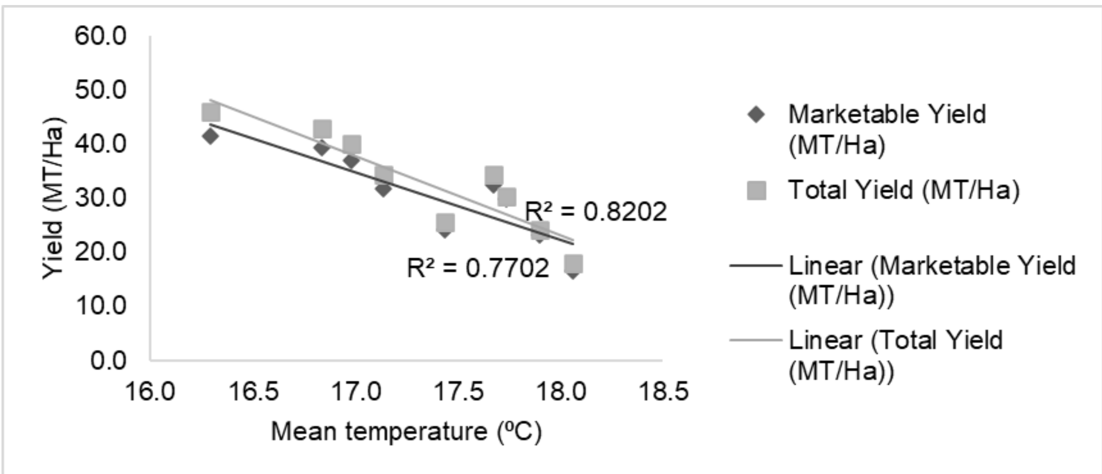


Figure 9. The correlation between mean temperature and yield of onion plants

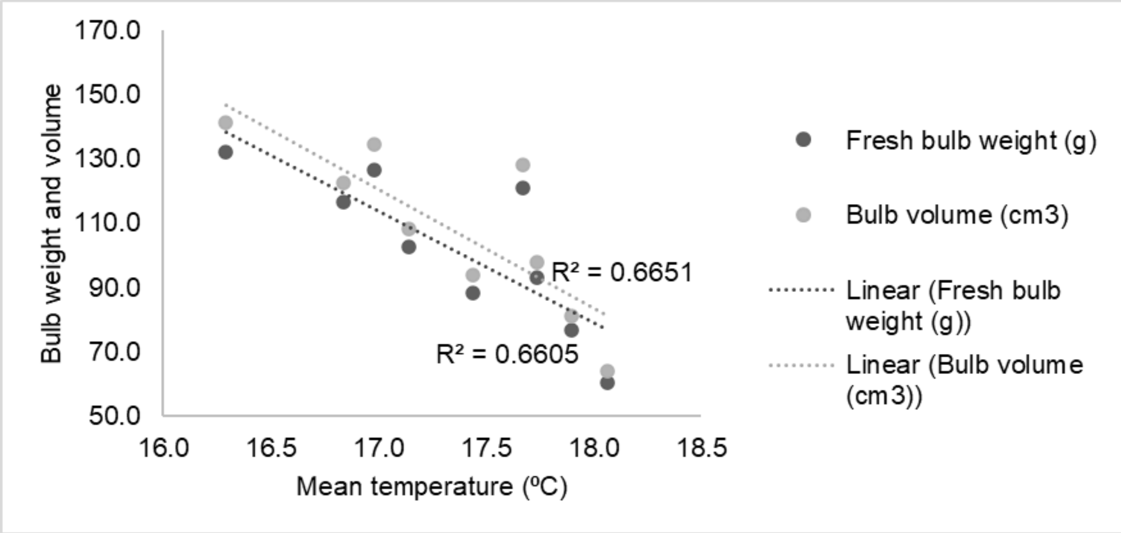
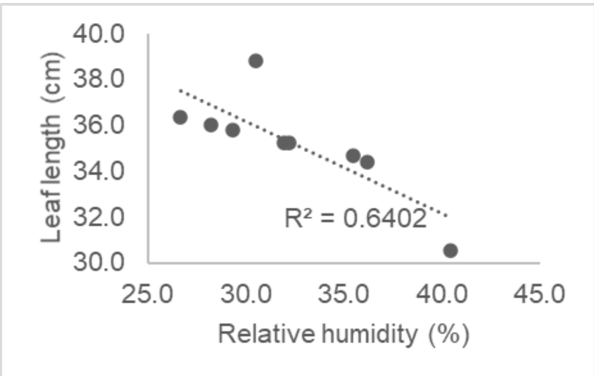


Figure 10. The correlation between mean temperature and bulb weight and volume of onion plants

3.2 Relative humidity (%)

The weather data presented in Table 1 showed that, rainfall is higher during spring months (March, April, and May) and then reduced towards summer and fall months and after that increased back in winter months. Such increment in rainfall leads to an increase in relative humidity during early planting dates and reduced for later planting dates. The higher relative humidity and lower temperature during spring months reduced the evapotranspiration rate and led to increase water use efficiency. This might be the possible reason that, relative humidity had a significant negative correlation with plant growth parameters [leaf length (r=-0.8001**) and leaf area per plant (r=-0.8448**)] and a significant positive correlation with maturity period (r=0.8215**), yield [marketable yield (r=0.9367**) and total yield (r=0.9489**)], and bulb quality [equatorial bulb diameter (r=0.8730**), neck diameter (r=-0.8101**), bulb weight (r=0.8438**) and bulb volume (r=0.8447**)]. The results showed that, increasing relative humidity led to reduce vegetative growth (Fig. 11) and increase plant maturity period (Fig. 13) which resulted in thin necked and large sized bulbs (Figs. 13, 14 & 15) and increase yield (Fig. 12) of onion crop. Based on results obtained, the early planting date (March 10th to September 2nd) can increase yield and bulb quality of onion. The authors (Aboukhadrah et al., 2017; González, 1997; Singh & Singh, 2000; Zamany et al., 2022) reported similar results.



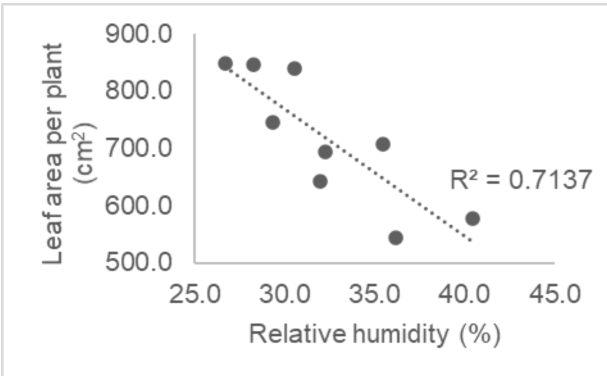


Figure 11. The correlation between relative humidity and leaf length (left) and leaf area per plant (right) of onion plants

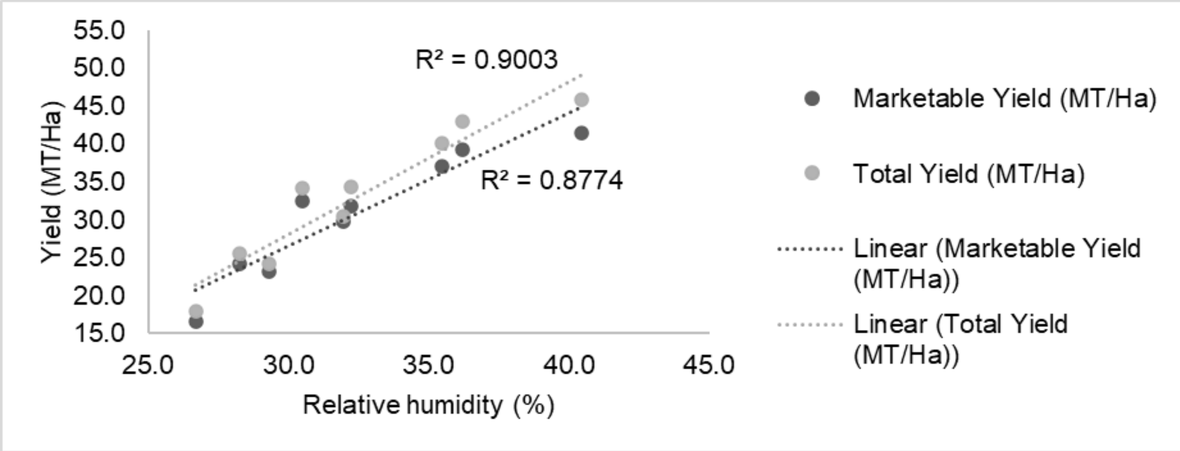


Figure 12. The correlation between relative humidity and yield of onion plants

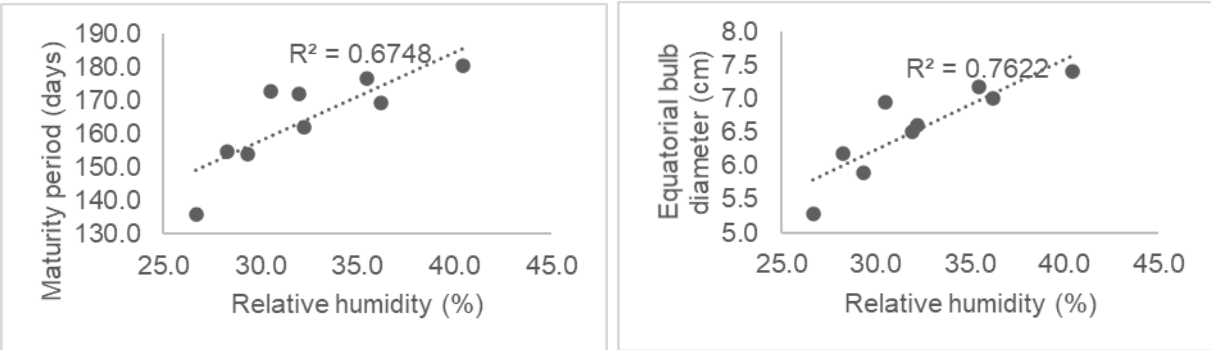


Figure 13. The correlation between relative humidity and maturity period (left) and equatorial bulb diameter (right) of onion plants

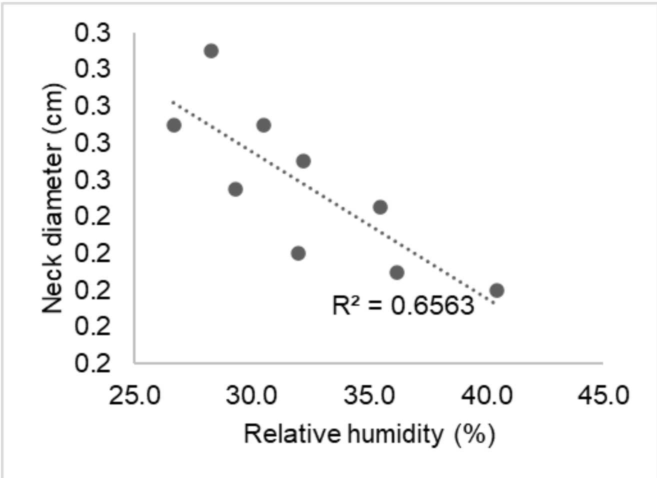


Figure 14. The correlation between relative humidity and neck diameter of onion plants

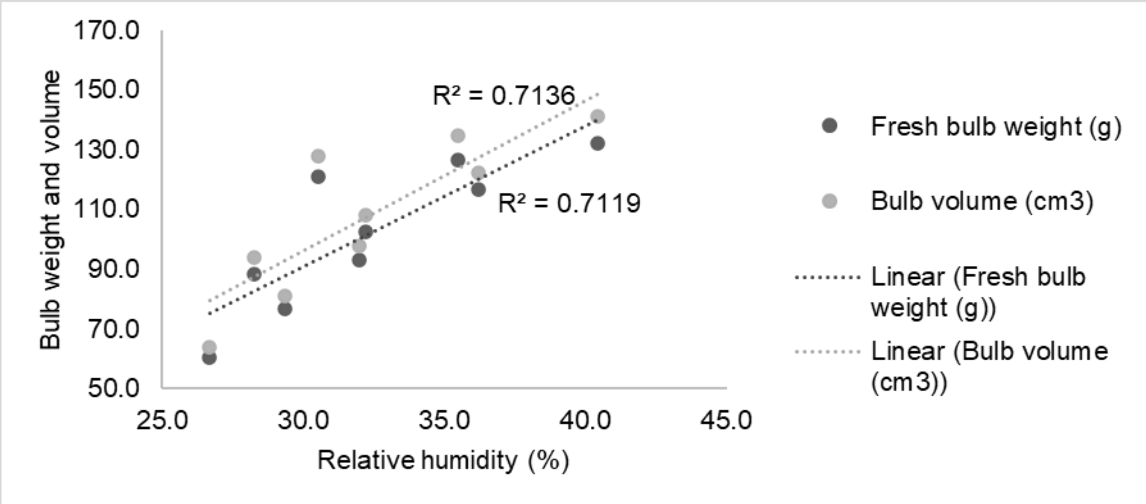


Figure 15. The correlation between relative humidity and bulb weight and volume of onion plants

3.3 Photoperiod (light)

The temperature and photoperiod are the most important factors in onion growth and bulb development (Choudhary, 2018; Karim & Ibrahim, 2013; Lancaster, 1996; Mosleh UD Deen, 2008). Based on photoperiod duration onion cultivars are classified into three types as follow, i) short-day cultivars requiring less than 12 hours of light, ii) middle-day cultivars requiring 13 to 14 hours of light and iii) long-day cultivars requiring 15 to 16 hours of light (Sekara et al., 2017). The authors (Choudhary, 2018; Ikeda et al., 2020; Khokhar, 2017; Mosleh UD Deen, 2008) reported that, long days encouragements of bulb formation in onions. The weather data presented in Table 1 showed that, late spring and summer months (May, June, July and August) are relatively hot and dry with higher number of daily sunshine hours. Such environmental conditions hasten the maturity of onion and led to produce small sized bulbs.

The cumulative day light is dependent mainly on the number of average daily sunshine hours and crop growth stage. Although the mean of day light was higher for later planting dates but due to a longer maturity period, the onions plants grown in early planting date (March 10th to September 2nd) received greater number of cumulative day light (Table 2). Cumulative day light has a significant positive correlation with maturity period (r=0.7009*), yield [marketable yield (r=0.7293*) and total yield (r=0.7381*)] and bulb quality [equatorial bulb diameter (r=0.8189**), polar bulb diameter (r=0.9112**), bulb weight (r=0.8866**) and bulb volume (r=0.8937**)]. The results showed that, late matured plants received more cumulative day light as compared to early matured once (Fig. 16). These resulted in large sized bulbs (Figs. 18 and 19) and higher yield (Fig. 17) of onion crop. Based on results obtained, the early planting date could be increased yield and bulb quality of onion. The authors (Atif et al., 2020; Khokhar, 2017; Mosleh UD Deen, 2008; Salari, Hansra, et al., 2021) reported similar results.

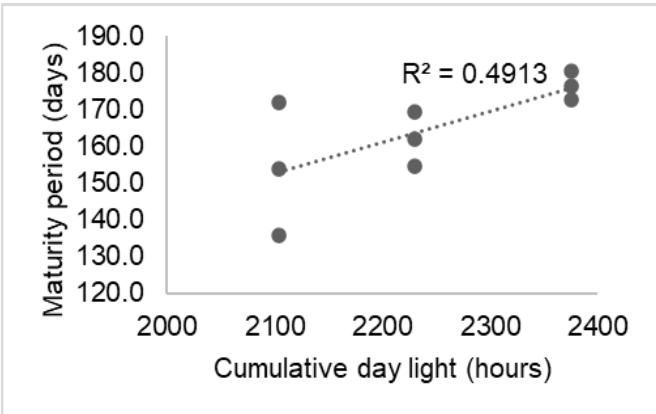


Figure 16. The correlation between cumulative day light and maturity period of onion plants

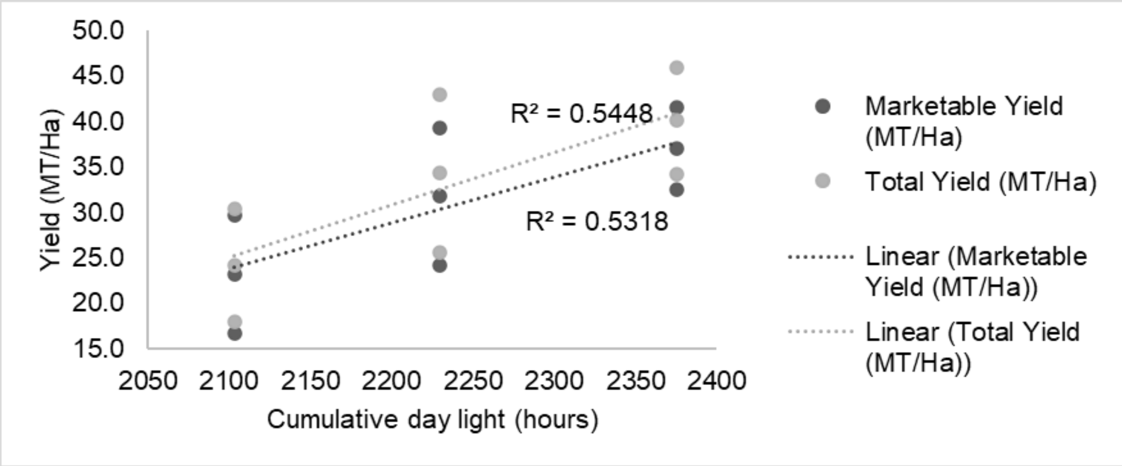


Figure 17. The correlation between cumulative day light and yield of onion plants

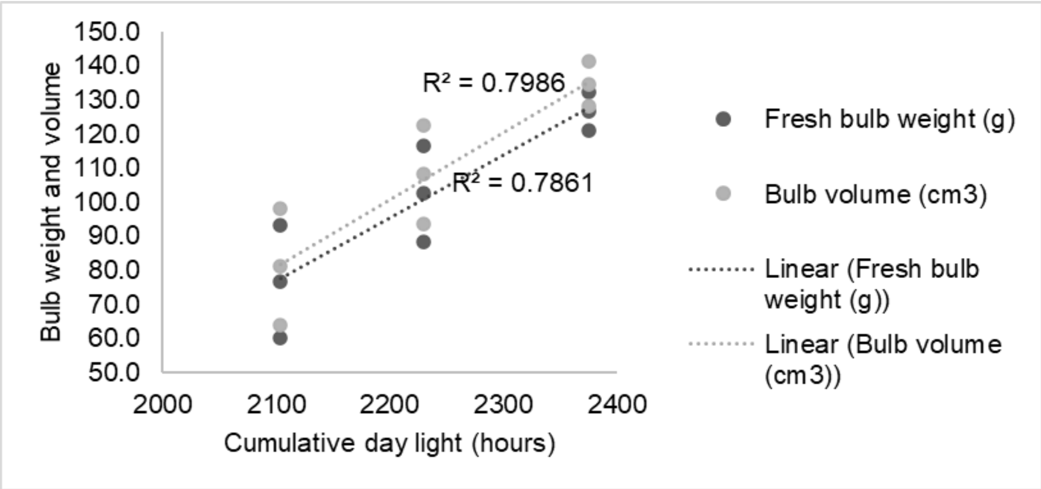


Figure 18. The correlation between cumulative day light and bulb weight and volume of onion plants

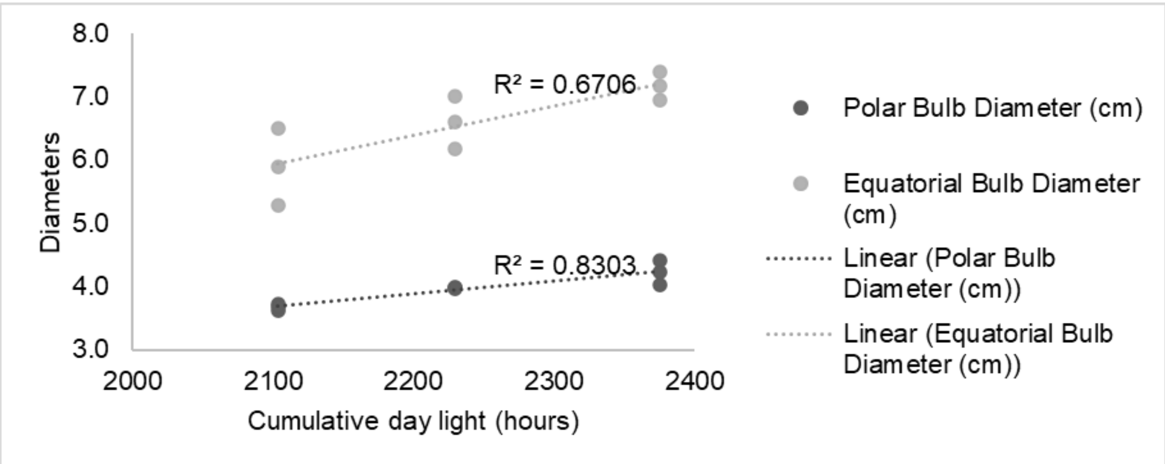


Figure 19. The correlation between cumulative day light and polar and equatorial bulb diameter of onion plants

3.4 Cumulative rainfall (mm)

Like relative humidity, the rainfall is higher during spring months (March, April, and May) then reduced towards summer and fall months and then re-increased again in winter months. Such increments in rainfall led to increase relative humidity during early growing stages and reduce towards later growth stages. The increased rainfall and relative humidity along with lower temperature during spring months reduced the evapotranspiration rate and consequently led to increase water use efficiency and better crop establishment. This might be the possible reason that, cumulative rainfall had a significant negative correlation with plant growth parameters [leaf length (r=-0.8571**) and leaf area per plant (r=-0.7729*)] and a significant positive correlation with maturity period (r=0.7209*), yield [marktable yield (r=0.8664**) and total yield (r=0.8922**)] and bulb quality [equatorial bulb diameter (r=0.7992**), neck diameter (r=-0.7524*), bulb weight (r=0.7867*) and bulb volume (r=0.7917*)]. The results showed that, with an increase in rainfall the vegetative growth of onion plants reduced (Fig. 20) and increased of plant maturity period (Fig. 21) also results in thin necked, large sized bulbs (Figs. 24, 21 & 22) and increased yielding (Fig. 23) of onion crop. These results revealed that, the early planting date could be increased yield and bulb quality of onion plants. The author (Tesfaendrias et al., 2011) reported similar results.

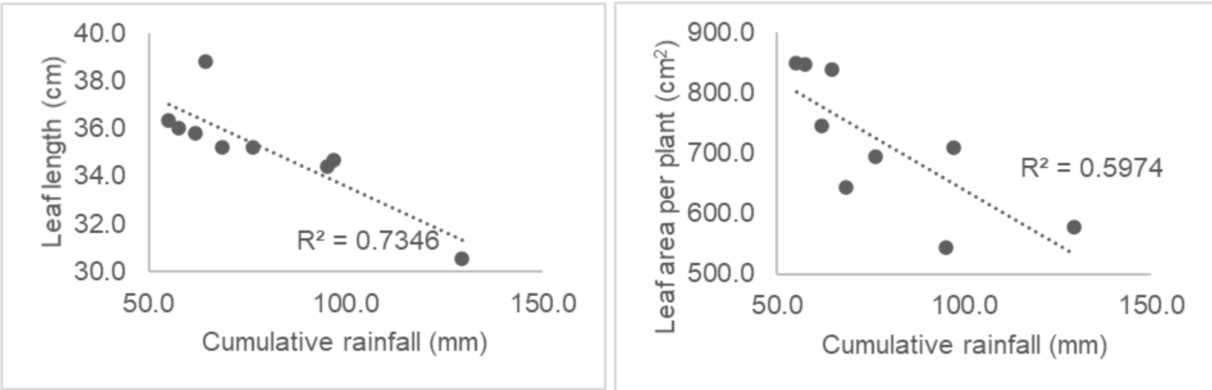


Figure 20. The correlation between cumulative rainfall and leaf length (left) and leaf area per plant (right) of onion plants

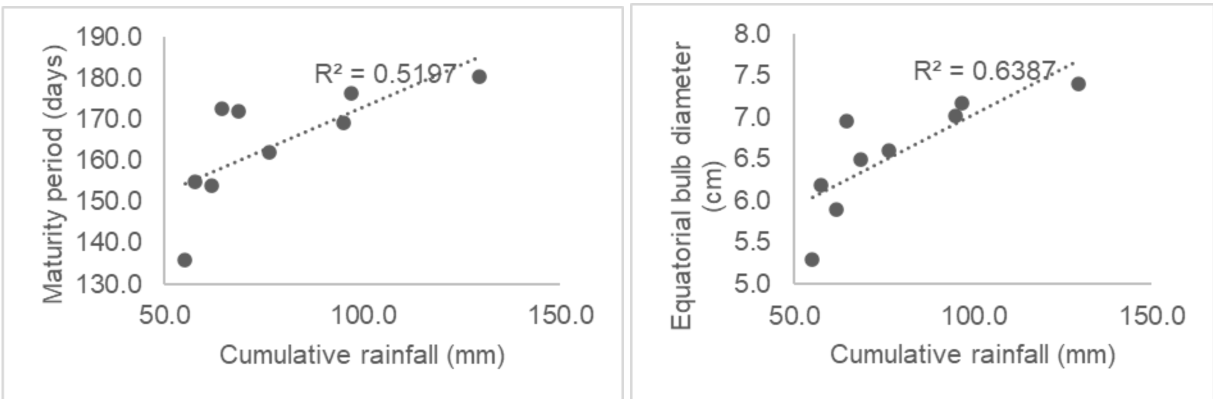


Figure 21. The correlation between cumulative rainfall and maturity period (left) and equatorial bulb diameter (right) of onion plants

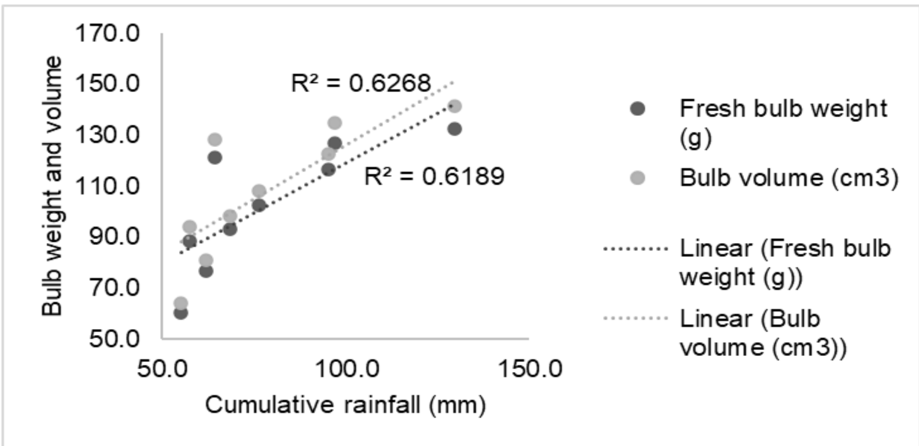


Figure 22. The correlation between cumulative rainfall and bulb weight and volume of onion plants

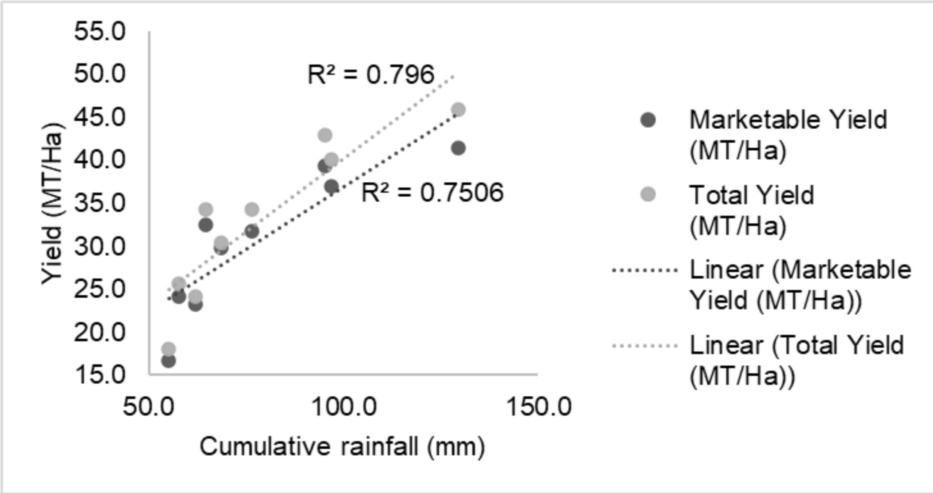


Figure 23. The correlation between cumulative rainfall and yield of onion plants

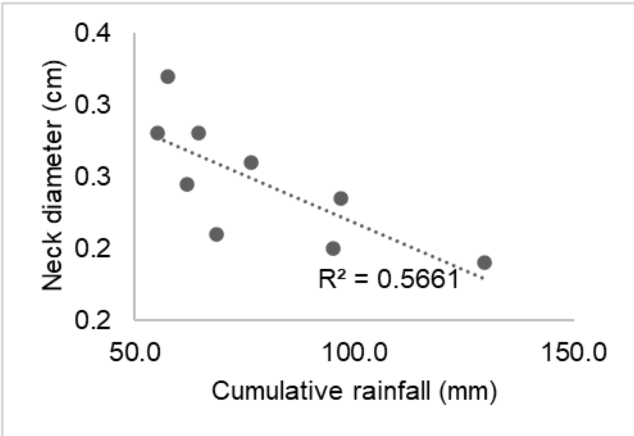


Figure 24. The correlation between cumulative rainfall and neck diameter of onion plants

4. Conclusions

The results of the study revealed that, weather conditions have strong correlation with growth, yield and bulb quality of onion variety Safid e Paisaye. The weather conditions such as temperature, sun light, relative humidity and rainfall varied for different growing seasons and its impact on plant growth, yield, and quality. The onions grown in early spring (sowing seed in nursery on March 10th and transplanting on May 10th) produced large bulbs and high yield. The bulb size and yield of onions reduced with delaying in planting date. Increment of temperature and reduction of relative humidity and rainfall in later planting dates led to faster maturity of onions and lowered the yield and quality. We could conclude that, early planting date of onion variety Safid e Paisaye can significantly increase yield and improve bulbs quality. Based on the findings of this research the farmers in hot and dry temperate regions are recommended to practice early planting of onion for higher productivity and better bulb quality.

Acknowledgments

Authors are grateful to Kabul University and Amity University Uttar Pradesh for their technical support.

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