advances in Technology

Adv. Technol. **2023**, 3(1), 1-19

Review

Effect of Surface and Drip Irrigation on Growth, Yield and Water Use Efficiency of Okra (*Abelmoschus esculentus*) – A Review

I. Imrana Farhan*, and M. Sugirtharan

Department of Agricultural Engineering, Faculty of Agriculture, Eastern University, Chenkalady 30350, Sri Lanka

Email correspondence: imranaibrahim17@gmail.com (I. I. Farhan)

Received: 3 November 2022; Revised: 13 December 2022; Accepted: 25 December 2022; Published: 12 January 2023

Abstract

Water scarcity is a major constraint in vegetable crop production and exacerbates food insecurity in developing countries. In the future, promoting the cultivation and consumption of vegetables having diversified nutrients under suitable irrigation techniques would be an inevitable practice in mitigating the adverse consequences of food insecurity (i.e., malnutrition and diseases). Okra (*Abelmoschus esculentus*); a fruit vegetable, consumed in several countries to fight against poverty and malnutrition due to its rich nutrient content with impressive health benefits. However, okra cultivation during the dry season is mainly dependent upon water availability. Therefore, this review study is conducted to highlight; 1) the impact of surface and drip irrigation on the growth, yield, and water use efficiency (WUE) of okra, and 2) the effect of surface and drip irrigation in combination with fertilizer and mulch on growth and development of okra. According to the analysis of available literature, among surface irrigation methods, although furrow irrigation has been widely practiced among traditional farmers, growing okra under alternate furrow irrigation with black plastic mulch at the furrow bottom has a positive impact on increasing the WUE. On other hand, the combination of nitrogen fertigation along with mulching under a 25-micron thickness black plastic sheet is an effective means to achieve a better yield advantage under drip irrigation. Further, foliar treatment of organic fertilizers like humic acid, putrescine, and application of organic manures like chicken manure attribute to enhanced growth and quality okra pods under regulated deficit irrigation through the drip system. However, despite the surface drip irrigation, investing in sub-surface drip irrigation by placing the laterals between 0.10 to 0.15 m of depth below the soil surface with daily irrigation assures the better performance of okra in sandy loam soil conditions. This compilation will support future researchers, and farmers as an approach to sustainable okra production under water-scarce conditions according to the availability of resources.

Keywords: Black plastic mulch, drip irrigation, okra, water use efficiency, yield

Introduction

Water is crucial for agricultural production and food security [1]. As the global population is estimated to reach 10 billion people by 2050, 1.8 billion people living in the world will be facing absolute water scarcity, and two-thirds of the world's population could be living under water-stressed conditions, surging the food demand by more than 50 percent [2, 3]. In the future, it is a threat that food-insecure communities can face both acute and chronic hunger, where children are more at risk of conditions stemming from malnutrition, such as stunting and wasting, and chronic illnesses due to poor diet, especially in developing countries [4]. Therefore, precise application of water with irrigation management is needed in vegetable crop production [5]. Efforts are now needed to harness the available quantities of water and put them to efficient use to realize higher productivity per drop of available water [6], and a greater emphasis wants to be given to improving irrigation practices to enhance vegetable crop production and sustain productivity levels [7].

https://doi.org/10.31357/ait.v3i1.6080

Among the vegetable crops, there is okra, (*Abelmoschus esculentus*); a warm-season annual herbaceous vegetable crop belonging to the Family Malvaceae or Mallow [8] has a considerable area under cultivation in Africa and Asia with enormous socio-economic potential [9]. It is sensitive to frost and low temperatures and has a wide range of adaptability to waterlogging and drought conditions [10, 11]. It is a multi-purpose crop due to its various uses of fresh leaves, buds, flowers, pods, stems, and seeds. Immature fruits of okra are consumed as vegetables and can be used in salads, soups, and stews, fresh or dried, fried or boiled [12]. Moreover, okra is a powerhouse of essential nutrients and active ingredients (i.e., dietary fiber, vitamins, oils, polysaccharides, polyphenols), which makes it have antioxidant, anti-inflammatory, hypoglycemic, hypolipidemic, and other functions [13]. In developing countries, among rural communities, it plays a significant role in mitigating food insecurity and alleviating malnutrition due to the presence of diversified dietary components [12, 14].

However, growing okra requires large amounts of water despite its considerable resistance to drought. In general, the lack of water during the growing season has deleterious effects on the yield and the maximum yield loss occurs when continuous water shortages are persisted until the first harvest [15, 16]. Thus, irrigation has been a major boost for obtaining high okra yield during dry season farming due to the high prevalence of sunshine hours that promotes the metabolism reaction of photosynthesis [17]. Under an adequate supply of moisture, the proper functioning of stomata might increase the photosynthetic efficiency as well as the translocation of photosynthates from sources leaves to sink [18, 19].

Therefore, water-saving irrigation methods should be followed in order to save water and maximize okra yield. Various studies have been researched on the irrigation system and yield relationship of okra in specific locations, with specific cultural and water management practices. Nevertheless, there is no proper resource as one whole document collectively containing the summarized results of the research reported mainly in developing countries, relevant to the response of okra to the surface and drip irrigation. Therefore, this review study gives a compilation on; 1) the impact of surface and drip irrigation on the growth, yield, and WUE of okra, and 2) the effect of surface and drip irrigation in combination with fertilizer and mulch on growth and development of okra.

In order to conduct this review study, an analysis of relevant literature originating from numerous sources such as research articles, technical reports, and official websites, spanning almost 25 years was taken for compilation. This compilation will support farmers in developing countries in the proper identification and adoption of suitable irrigation techniques to meet future demand in ensuring food security, and future research as an approach to sustainable okra production under water-scarce conditions in mitigating malnutrition.

Irrigation Under Water Scarce Condition

Importance of Irrigation Scheduling in Okra

In okra, vegetative, flowering as well as early pod-filling stages are the sensitive stages to drought stress in okra based on total photosynthetic leaf area, membrane damage, and overall growth, biomass, and yield performance [20]. Therefore, controlled irrigation is essential for a high yield of okra as the crop is sensitive to both over and under-irrigation [21]. One of the traditional irrigation techniques is irrigation scheduling which aims at achieving an optimum water supply for productivity, with soil water content maintained close to field capacity [22]. Irrigation scheduling involves the definition of the time and amount of water application to a crop, as per management objectives [23]. Scheduling irrigation is very crucial to make the most efficient water use, as over or under-irrigation reduces the yield. Irrigation frequency is one of the most important factors in irrigation scheduling. An optimum level of irrigation intervals is important for the judicious use of water. Due to the differences in soil moisture and wetting pattern, crop yields may be different when the same quantity of water is applied under different irrigation frequencies. Typically, the higher the irrigation frequency, the smaller the wetted soil volume, and the higher mean soil water content can be maintained in the wetted soil volume during a period when the total irrigation water is equal [24]. Undoubtedly, timing, duration, severity, and speed in the development of profile moisture deficit play vital roles in determining the response of the crop to soil water stress [25].

Deficit Irrigation

Several crops and genotypes have developed different degrees of drought tolerance, drought resistance, or compensatory growth to deal with stressful periods. The highest crop productivity is achieved for higher-yielding varieties with an optimal water supply and soil fertility. But, under conditions of limited water supply crops will adapt to water stress and can produce well with less water. From the viewpoint of improving water productivity, there is a growing concern, about an irrigation practice whereby water supply is reduced below maximum levels and mild effect is allowed with minimum effects on yield [26]. It is expected that any reduction in yield will be insignificant compared to the benefits gained through diverting the saved water to irrigate other crops [27].

Irrigation Systems

Surface and Drip Irrigation Systems

Many irrigation methods have been developed to increase water use efficiency (WUE) in arid or semi-arid regions including surface irrigation and drip irrigation depending on the availability of water and micro-irrigation facilities [19]. Among the surface irrigation methods, furrow irrigation is a popular technique among farming communities, where the shortage of irrigation water is severe [28]. Among furrow irrigation techniques, conventional furrow irrigation (CFI) is arguably the most traditional method (Figure 1) despite its low WUE. At the same time, alternate furrow irrigation (AFI) is a more efficient and easily implemented method (Figure 2) by alternately irrigating two adjacent furrows to promote abscisic acid (ABA) synthesis by roots on the dry side to reduce stomatal conductance and thus transpiration [29, 30, 31]. At present, AFI has been replacing CFI in most semiarid regions as the dominant irrigation method among surface irrigation methods [32].

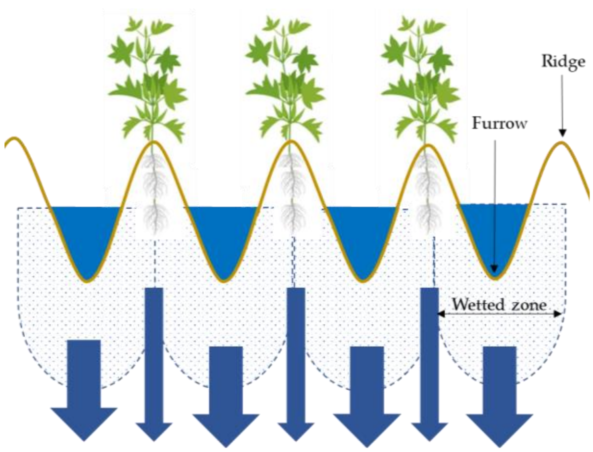

Figure 1. Conventional furrow irrigation method, where every furrow is irrigated.

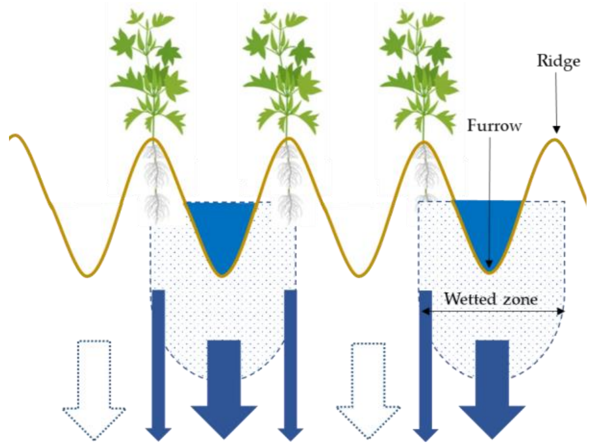

Figure 2. Alternate furrow irrigation method in which two adjacent furrows are alternately irrigated instead of all furrows.

Moreover, drip irrigation has high water application efficiency, and increased water productivity [33, 34, 35], and under conditions of scarce water supply, regulated deficit irrigation through drip technology optimizes crop water productivity (CWP) [36, 37]. In addition, it was found that the drip method of irrigation could reduce about 15% of cultivation cost, save about 47% of water resources and electrical energy, and augment about 49% of the productivity of okra over the same crop cultivated under the conventional flood method of irrigation. However, the initial high investment needed for installing drip systems remains the main impediment to the widespread adoption of it, especially in crops like okra, which is not a long-duration annual crop [38].

Impact of Surface and Drip Irrigation on Growth Components of Okra

Plant Height

In furrow-irrigated okra, full root-zone irrigation (FRI) produced higher plant height (0.603-0.710 m), than that produced under alternate partial root-zone irrigation (APRI) (0.523-0.678 m) and fixed partial root-zone irrigation (FPRI) (0.501-0.643 m) [39]. Likewise, Panigrahi et al. [40] reported that APRI and FRI produced the plant height of 0.5-0.7m and 0.4-0.7 m, respectively, which indicates the need of higher soil moisture for okra plant growth since more frequent irrigation resulted in higher vegetative growth under both APRI and FRI. Furthermore, they revealed that plant height was higher under APRI + black plastic mulch (BPM) over APRI alone and FRI, which resulted in the better metabolic activity of the plants probably caused by a consistent supply of optimum soil moisture in the root-zone coupled with effective rooting of the plants under BPM [41, 42]. Under drip irrigated conditions, a maximum average plant height of 48.73 cm was obtained at 80% of cumulative pan evaporation along with 80% of recommended doses of N fertilizer whereas a minimum plant height of 20.5 cm was observed at 60% of cumulative pan evaporation along with 60% of recommended doses of N fertilizer [43] in sandy loam soil. Further, Job et al. [44] reported that drip at 1.0 ET (Crop evapotranspiration) with 100% fertigation recorded the highest plant height of 1.78 m. While Haris et al. [45] observed the maximum plant height (105.85 cm) at 80% ET as compared to

100 and 60% ET and stated that irrigation at once in two days was found to be better than daily and once in three days irrigation. In contrast to the above findings, there are few reports suggesting that different irrigation levels had no significant influence on okra height [46, 47, 48].

Stem Diameter/ Stem Girth

The stem diameter under different levels of drip irrigation was reported to be higher than conventional furrow irrigation (CFI) [49]. This increase in stem girth can be attributed to conserve soil moisture, seedling emergence, and improved plant growth. In addition, the mean stem diameter under drip irrigation after 90 days of plant growth was 0.81cm while under surface irrigation was 0.61cm [50]. However, in furrow-irrigated okra, Panigrahi and Sahu [39] revealed that the FRI produced a higher stem diameter (20.5-22.0 mm) than that produced under APRI (15.6-17.8 mm) and FRI (14.8-15.2 mm). Meanwhile, the stem diameter under drip irrigation based on a 100% irrigation requirement with Black Liner Low-Density Polyethylene film of a 25-micron thickness (LLDPE) plastic mulch is 62.4 % higher than the stem diameter of okra under furrow irrigation without mulch [49].

Number of Nodes

In okra, yield is directly proportional to the number of nodes, as the number of nodes increases, the number of pods also increases, and vice-versa. Almost all nodes, except a few lower bears a single pod in their leaf axial [18]. Anyhow, it is noteworthy that, irrigation levels had no significant influence on a number of nodes per plant [43, 45].

Number of Branches

A maximum number of branches (3.9 plant $^{-1}$) were observed under APRI at 25% available soil moisture depletion (ASMD) + BPM, followed by APRI at 25% ASMD in furrow-irrigated okra [40]. Aliyu et al. [51] reported that 5 and 8-day irrigation intervals produced a higher number of branches than the 11-day irrigation interval, which indicates that the higher number of branches produced in the plants with short intervals is due to the provision of sufficient moisture which enables them to utilize resources efficiently.

Number of Leaves

The number of leaves produced under drip irrigation was significantly higher than watering can-irrigated plants, which could determine to a large extent the assimilates for growth and yield of okra [47]. In addition, the percentage increase of the number of leaves per plant in drip irrigation with 100% of full irrigation requirement over furrow irrigation was 112% [49]. This increase in the number of leaves may be due to the increase in the number of branches, which increased the rate of photosynthesis, produced more biomass, and induced early flowering, and increased the number of flowers in plants [52]. Further, drip irrigation with 100 % of full irrigation requirement was superior to conventional furrow irrigation, whereas drip irrigation with 80 % of full irrigation requirement and 60 % of full irrigation requirement were statistically at par with furrow irrigation treatment. However, the findings of Tiwari et al. [53] and Jayapiratha et al. [54] is contrary to the above statements, stating that irrigation methods had no significant influence in terms of the number of leaves in the okra plant.

Flowering Initiation

The increase in total biomass production interacts with ecological factors and affects the growth and flowering of plants [55]. According to Konyeha and Alatise [56], the period of flowering and fruiting was most critical in terms of water requirement in okra, and as such, adequate irrigation water application should be ensured during the period. Jayapiratha et al. [54] found that the highest percentage of flowering was around 50% from 30 minutes of drip irrigation compared to control surface irrigation and there were no significant differences in the number of flowers in the drip irrigation duration of 15 and 30 minutes. Thus, flowering could be promoted by avoiding water stress in the plant canopy. Nevertheless, the finding of Tiwari et al. [53] contrasts with the above statements. Further, Al-Ubaidi et al. [52] reported that, irrigation at 3 days interval positively affected the growth parameters and thus enhanced the flowering initiation and the flower initiation whereas irrigation at 5 days interval increased the number of flowers in okra. Aliyu et al. [51] found that 5 days and 8 days intervals recorded fewer numbers of days to attain 50% flowering which was statistically different from 11 days intervals, which reveals that shorter irrigation intervals gave plants a chance to grow and attain flowering stage within fewer days.

Root Morphology (Root Weight, Root Length and Distribution, Root Fitness)

In okra, the morphological characteristics increase with the enhancement of water availability and decrease by the increasing irrigation interval [15]. Root morphology governs the efficient utilization of water and nutrients for crop production [39]. Different studies have shown a significant relationship of different irrigation supplies with root length, which triggers the accumulation of dry matter to the roots. As roots are in direct contact with soil and the first to be affected by water logging and growth is not faster under surface irrigation [50]. However, among different furrow irrigation treatments, Panigrahi and Sahu [39] observed that the plants under APRI treatment produced higher root lengths (16.6-18.9 m) and produced thinner roots. Therefore, the higher root length with finer roots, in conjunction with better nutrient availability in soil produced the higher nutrient content in leaves and pods of alternate partially irrigated plants. Further, they stated that the root length under different furrow irrigation treatments increased with the increase in ASMD from 25% to 50%, indicating the effect of soil water deficit on increasing root length of the plants. The higher root length at 50% ASMD was probably caused by osmotic adjustment and prolonged root cell expansion under mild water stress in this treatment [57]. In addition, Panigrahi and Sahu [39] revealed that when root elongation is decreased by soil water stress at 50% ASMD under furrow irrigation, root weight increases, probably due to the suberization of roots under this treatment [58].

Consequently, Jayapiratha et al. [54] observed the maximum root growth up to 60 cm below the soil surface under drip irrigation, and it was only about 40 cm under basin irrigation. This could be due to the vertical movement of water into the soil profile in drip irrigation influenced the deep root system and slow and frequent application of water through emitters promoted root zone development (Figure 3). Whereas under basin irrigated conditions, lateral spreading of water (Figure 4) affected root growth [46, 54, 59]. Furthermore, Chandra and Singh [49] found that different levels of drip irrigation (100%, 80%, and 60% of full irrigation requirement) provided appropriate moisture at field capacity and better root development compared to furrow irrigation treatment which facilitated luxuriant growth.

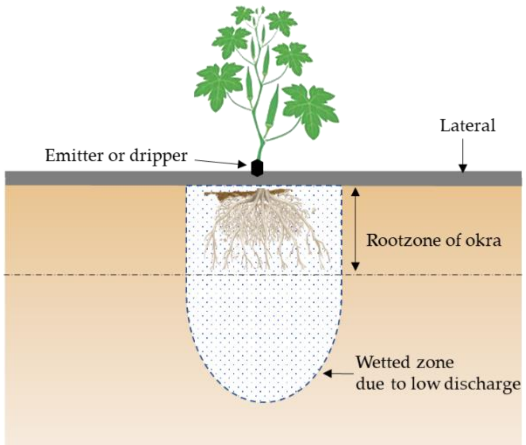

Figure 3. Low discharge under drip system

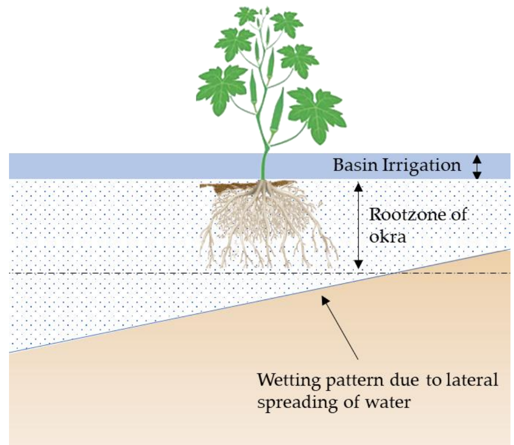

Figure 4. Lateral spreading of water under basin irrigation

Effect of Surface and Drip Irrigation on Yield of Okra Irrigation Interval and Yield Components

Irrigation intervals significantly affect the pod length, number of pods per plant, and pod weight of okra [51]. Consequently, Al-Ubaidi et al. [52] reported that irrigation every 3 days increased fruit diameter. They further stated that irrigation every 5 days significantly increased the length of fruits, while irrigation every 7 days influenced the fruit dry matter percentage and total soluble solids. According to Aliyu et al. [51], 5- and 8-days irrigation intervals resulted in significantly longer pods than the 11 days irrigation interval, which may be due to the moisture stress in plants that were irrigated at 11 days intervals which lead to a reduction in the pod length. As well as the increase in the growth rate leads to an increase in the hormones, which increases the pod length [60]. Furthermore, the maximum number of pickings and pods per plant (11 and 17 respectively) recorded with the irrigation applied at 5 days interval was significantly highest over the rest of the treatments and lowest (9.0 and 15.33 respectively) in irrigation applied at 9 days interval [18]. Similarly, Aliyu et al. [51] recorded higher pod weight from 5- and 8-day irrigation intervals, and this could be a result of the availability of moisture for photosynthesis and translocation of photosynthates for pod development which is limited at 11 days intervals. Thus, frequent irrigation increases the size and weight of fruit [61]. Further, the yield obtained from 7-day and 10-day irrigation intervals was at par with one another and a significant reduction in the growth and yield of okra was noticed when irrigation was scheduled at longer intervals of 10 or 12 days [27]. Pod length is a tone character for economic yield which depends upon various factors such as the genetic makeup of the cultivars and their response to prevailing environmental conditions. This reflects that the more the nitrogen fertilizer dose the better will be pod length [62]. The results agree with those of Arora et al. [63] who reported that pod length in okra was significantly improved by the application of nitrogen. Accordingly, Aliyu et al. [51] reported the longest pods (5.1 cm) in the plot that had a combination of 5 days irrigation interval and 100 kg N ha^{-1} while the shortest pods (2.8 cm) were in the plot that combined 11 days of irrigation interval and 0 kg N ha^{-1}.

Yield Components in Response to Surface and Drip Irrigation

Different levels of drip irrigation treatment significantly increase fruit size in comparison to control treatment of furrow irrigation [53]. Nevertheless, Tiwari et al. [53] further revealed that supply of 100% irrigation requirement through drip significantly influence fruit length of okra over supply of 60% irrigation requirement through drip. Further, it was observed that the fruit size response at the supply of

100% irrigation requirement and 80% of water requirement through drip was statistically at par with each other [44, 49]. Moreover, Chandra and Singh [49] found the highest fruit weight (22.7 g) under the treatment of drip irrigation based on 100% irrigation with LLDPE mulch, followed by drip irrigation based on 80% irrigation with LLDPE mulch (22.3 g). In addition, irrigation methods and mulch significantly affected fruit length. Tiwari et al. [53] reported the highest fruit length in drip irrigation with plastic mulch and was statistically significant at a 5% level over furrow irrigation with plastic mulch. Similarly, Chandra and Singh [49] found the highest fruit length under the treatment of drip irrigation based on 100% of full irrigation with LLDPE with a value of 20.9 cm, followed by drip irrigation based on 80% of full irrigation with LLDPE with a value of 20.1 cm and lowest for conventional furrow irrigation with a value of 16.7 cm. The result is in line with the findings of [64].

However, water deficit during vegetative growth leads to a reduction in yield [65]. The low utilization of water-deficient crops has poor carbohydrate utilization, which leads to a decrease in fruit size [66]. This was evident from the results of Sam-Amoah et al. [67], where irrigation at 100% Crop Water Requirement (CWR), 90% CWR, and 80% CWR gave 21, 16, and 9 pods, respectively. They further found that the yield parameters were greater in deficit irrigation-chicken manure combination than deficit irrigation alone and reported that when the level of chicken manure increased from 5-10 t ha^{-1}, pod weight, pod length, and stem circumference were also increased at the same level of surface irrigation applied. This may be due to the availability of chicken manure in a readily accessible form for easy absorption by the plant roots.

Total Yield in Response to Surface and Drip Irrigation

The following table shows the combined result of the maximum yield obtained from three different surface irrigation treatments in different regions of developing countries (Table 1).

Table 1. Surface irrigation treatments and the maximum yield obtained

S. No	Location	Treatments	Maximum yield (Kg ha^{-1})	References
1	Sindh, Pakistan	AFI	13118	[68]
		CFI	14158	
		Flood Irrigation	9900	
2	China	AFI	15096.96	[69]
		Every Furrow Irrigation (EFI)	19163.63	
3	Tandojam, Pakistan	EFI	8518	[70]
		AFI	7621	

Accordingly, the yield obtained under EFI was 10.5% greater than the yield obtained under AFI method and 31.40% when compared with the traditional method [70]. However, the difference in yield was not significant enough and could be compensated by saving a considerable amount of irrigation under AFI method [69]. In the AFI plots, okra plant roots were partially wetted, which may have resulted in reduced stomatal conductance, and plant transpiration. However, photosynthesis and dry matter accumulation are likely to be less affected by this stomatal closure, which is attributed to this non-significant reduction in crop yield with AFI compared with CFI. In addition, if plants are rooted partly in dry soil, a significant amount of abscisic acid is produced in the roots and transported to the shoot where the stomatal opening is regulated. Nevertheless, photosynthesis is less affected by such partial stomatal closure since photosynthesis and stomatal opening have a saturation relationship [71]. Meanwhile, APRI produced 4.1-6.0 % higher pod yield than FRI [39]. The higher yield under APRI was probably caused by: (1) better availability of nutrients with optimum soil moisture content, fewer weeds, and the higher nutrient up-take by more fine roots under this treatment and (2) a higher percentage of photosynthates used by the plants towards reproductive growth (fruiting) than the vegetative growth in APRI treatment over that of FRI.

Further, Asadipour and Madani [72] reported that the highest fresh pod yield (9993.5 kg ha-1) was obtained at 5 days irrigation interval and significant fresh pod yield reduction was found when increasing the irrigation intervals from 5 days to 10 days, in furrow-irrigated okra. Similarly, [18] found that irrigation scheduled at 5 days irrigation interval produced the highest total yield plant^{-1} (188.38g) and yield ha^{-1} (9516 kg) whereas the lowest was obtained for irrigation applied at 9 days interval. The result is because of the prevalence of soil moisture conditions congenial for the physiological and metabolic activities of okra plants which favored proper vegetative growth that ultimately reflected higher pod yield.

Furthermore, Memon et al. [73] conducted an experiment involving two treatments in okra, i.e., T_0 as furrow bottom without plastic sheet and T_1 as furrow bottom with a plastic sheet where irrigation was applied with an interval of 6-8 days and measured with cut-throat flume. They reported okra yield of 7,575 kg ha^{-1} and 8,332 kg ha^{-1} for the treatments T_0 and T_1, respectively. The increased yield is due to the installation of a plastic sheet under the furrow bottom, controlled leaching, and facilitated the uptake of a sufficient amount of soil moisture and soluble nutrients to plant roots. Correspondingly, a study was conducted by Almasraf and Hommadi [73], by installing a polyethylene membrane within the root zone of the okra crop inside the greenhouse. The experiment involved treatments *viz.* T_1 was using a membrane sheet installed under the soil surface, T_2 was without a membrane sheet (controlled irrigation) and T_3 was without using a membrane sheet and uncontrolled of irrigation process. The irrigation schedule was carried out for treatments T_1 and T_2 through the growing season when the soil water depletion reached 50 % of the available water. The total collection of the yield value for treatment T_1 was more than that in treatments T_2 and T_3 by 17.4 % and 40.3 %, respectively. This increase in the crop yield in treatment T_1 was due to the water and fertilizer materials which were detente above the membrane sheet utilized by the plant by capillary rise.

Moreover, furrow-irrigated okra showed a 54 to 57% lower yield than drip-irrigated okra crop [75]. In addition, yield per hectare land area was reported to be 15160 kg, 15140 kg corresponding to 15 minutes duration and 30-minute duration through drip irrigation on a daily basis whereas 10840 kg ha^{-1} yield was reported for basin irrigation treatment with three days irrigation interval as a control in okra plant [54]. According to the study of Saxena and Gupta [76], the yield increase for okra under drip irrigation was 20.69% with a water saving of 44.92%. Likewise, drip irrigation increased okra yield by 30.34% and brought about a water saving of 41.23% compared to the conventional method [77]. Furthermore, the maximum mean yield of 249.7 kg ha^{-1} was obtained under drip irrigation and the mean yield under surface irrigation was only 155.65 kg ha^{-1} [50]. This is because drip irrigation provides a consistent supply of water to the entire root area on a continuous basis so that “drench and dry-out” stresses are reduced [47].

In addition, Sedara et al. [78] conducted an experiment comprising the treatments of 100 full irrigation treatments (FIT), 80 FIT, 60 FIT, and 40 FIT, respectively. Their results revealed that there was no difference in the mean of the yield obtained in 100 FIT, 80 FIT, and 60 FIT, which implies that a 40% reduction in crop water requirement had no negative effect on the okra yield. Therefore, they concluded that okra crops irrigated under 60FIT should be adopted in the study area and this would save 40% of water to irrigate additional land.

On another hand, a significantly higher yield was obtained with drip irrigation at 80% evapotranspiration and daily irrigation gave a significantly higher yield than once in two days and three days schedules [45]. According to Farias et al. [79], irrigation with 125% crop evapotranspiration (ETc) obtained the highest yield value (0.6325 kg plant^{-1}; 21090 kg ha^{-1}) and 0% ETc obtained the lowest yield value (0.0775 kg plant^{-1}; 2580 kg ha^{-1}), under drip irrigation. Despite that, the yield response of okra crops under subsurface drip irrigation was found to be 56.4% higher than that of the furrow irrigation treatment [80]. While Vadar et al. [81] noticed that the highest yield of 18270 kg ha^{-1} was obtained for the interaction effect of 1.0 IW /CPE irrigation regime and 0.15 m depth of lateral under sub-surface drip irrigation (SDI). Further, they concluded, the higher the level of irrigation regime, the more the amount of water applied which maintains a more congenial moisture regime within the root zone, which may result in higher okra yield under higher irrigation regimes. Similarly, Singh and Rajput [82] also suggested placing the laterals between 0.10 to 0.15 m of depth below the soil surface to obtain higher okra yield under the SDI system in sandy loam soil. In another study, Mahmoudi et al. [83] reported that the combinations of treated wastewater (TWW) and SDI produced the highest yield and growth rather than using tap water under SDI. Further, they recommended the application of TWW under (5-15) cm depth of emission to obtain higher okra productivity.

Surface and Drip Irrigation in Combination with Fertilizer (Organic/ Inorganic) Application

Humic acid is used as an organic fertilizer and an important component of humic substances that can be used to improve plant growth under water deficit conditions [84]. The interactions between the irrigation at 100% ETc and foliar spray of humic acid at 300 mg l^{-1} and putrescine at 1.5 mM can improve the growth, yield, and quality of okra fruits under different levels of water deficit conditions [85]. Further, foliar application of humic acid and putrescine during drought stress period increased plant adaptation to stress conditions and improved fruit yield of okra under water deficit conditions by increasing relative water content, proline accumulation, and antioxidant enzyme activities. In addition, the study of Ati et al. [86] concluded that the role of deficit irrigation and interaction with humic acid levels lead to increased wetted soil volume inside the root zone, which means the increase in the volume of water stored in the root zone promoted higher okra yield.

Moreover, Sam-Amoah et al. [67] reported that for efficient water use without any significant yield reduction, 10% deficit irrigation (90% crop water requirement) with a two-day irrigation interval +10 t ha^{-1} chicken manure is best for okra production under water stress. Similarly, Abd El-Kader et al. [15] in Egypt studied the effect of three irrigation levels *viz.* 1198.8 (I_1), 1798.2 (I_2), and 2397.6 (I_3) m^3/acre with a drip in conjunction with two organic fertilizers comprising of composted plant residues and chicken manure at the rate of 6 m^3/ acre. They reported that the irrigation water quantity of 1798.2 (I_2) m^3/acre along with the two types of organic fertilizers gave the highest yield (3.3 M g/acre) with a 104% increase in yield as compared to I_1 and I_3, revealing that the addition of more of irrigation water caused an increase in the uptake of N P K and if compared to the lowest level of irrigation water, it increased the growth parameters in the expense of okra yield. In addition, the yield increment may be due to the improvement of soil moisture retention and available moisture by applying both composted plant residues and chicken manure [86].

Furthermore, all micronutrients have a significant influence on plant physiology either as foliar spray or by soil application based on soil test values. Balanced application of these nutrients (multi-micronutrient mix) stimulates enzymatic activities that promote a higher rate of photosynthesis, and respiration and favor superior vegetative growth and yield in okra [87, 88]. Accordingly, Arya et al. [89] stated that under drip irrigated conditions, foliar application of KAU multi-mix resulted in greater plant height, leaf area, fruit length, fruit weight, and fruit yield.

Additionally, different levels of fertilizers, irrigation, and their combination had a significant effect on okra yield [90]. 5 days irrigation interval in combination with 100kg N ha^{-1} may be suitable for increased okra production under similar soils and agroecological conditions of Sudan Savanna zone of Nigeria [51]. Meanwhile, irrigation at 20% soil water depletion with 100 kg ha^{-1} of nitrogen fertigation (N_{100} level) produced the highest yield in lateritic sandy loam soil conditions under SDI, which could maintain relatively constant soil moisture status within the root zone of the soil for meeting the daily evapotranspiration [80]. Thus, high N concentration within the root zone profile maintained under SDI treatment led to an increase in the cell size of the plants [91]. Furthermore, maximum okra yield (15 890 kg ha^{-1}) was reported in 80% fertilizer N dose and 80% drip irrigation level [43]. As well as, the maximum yield of 21160 kg ha^{-1}, with an increased yield of 27.01% was obtained from 80% recommended doses of fertilizer and 0.8 ET over the traditional method of irrigation [90] which is similar to the finding of Job et al. [44]. It's noteworthy that, the split application of nutrients by drip fertigation as compared to the traditional furrow method may have resulted in reduced nutrient wastage and hence, led to better yield in the drip fertigation method [92]. In contrast to the above findings, Tan et al. [93] found that in okra, a low level of nitrogen application (30 kg N ha^{-1}) with low but daily watering had a significantly higher yield (1,365 g plot^{-1}) than from higher level of nitrogen application (90 kg ha^{-1}). They concluded that it might be due to the efficient utilization of soil nutrients when irrigation treatments removed the condition of moisture stress in the soil. At the same time, the finding of [94] showed a significant interaction effect of N, frequency, and amount of irrigation water on okra crop yield. They revealed that it might be due to the difference in field preparation and not the treatment itself. Further, they concluded that overnight-soaked seeds were sown directly in the field without making a pit. Thus, due to the existence of a plow pan in the soil, lady's finger plants grown on the loose shallow surface soils might had likely been influenced by added water because sub-surface stored water is not readily available unless it is broken through some means of sub-soiling.

Yield Response for Surface and Drip Irrigation in Combination with Mulch

Okra preferred to hasten its pod yield instead of improving vegetative growth under water deficit conditions [95]. The deleterious effects of water deficit could be overcome by irrigation or by adopting in-situ moisture conservation techniques, such as the use of mulches [96]. Mulching is effective in reducing evaporation, and conserving soil moisture and has been known to modify the hydrothermal regime of soil [97].

Panigrahi et al. [40] reported the highest pod yield (10025 kg ha^{-1}) under APRI at 25% ASMD + BPM, which was statistically at par with the pod yield under APRI at 50% ASMD + BPM. The higher pod length and pod weight was probably due to higher nutrient assimilation supported by the availability of more nutrients in the soil solution under favorable soil moisture and temperature within the plant rhizosphere [98, 99]. In addition, 50% available soil moisture depletion could impose desirable water stress on okra plants, improving their fruit yield and quality, without producing higher vegetative growth [40]. Meanwhile, furrow-irrigated pea straw mulched okra plants exhibited 31.4% higher pod yield over non-mulched plants [27]. These results agree with the finding of Tiwari et al. [53] in okra. Enhancement in growth and yield of okra under pea straw mulch may be attributed to conserving soil moisture, moderate plant water status, soil temperature, soil mechanical resistance, and increased availability of plant nutrients [100, 101, 102]. Further, the use of a drip irrigation system either alone or in combination with mulching increase the yield of okra by up to 61 % over the surface irrigation method with the same quantity of irrigation water applied [103]. During the years 2009 and 2010, 13.6 and 14.8 percent higher okra yield was observed under drip irrigation in comparison to the flood irrigation method, respectively [104]. Thus, optimum moisture supplied by the trickle method compared to the surface irrigation method under mulched conditions enhances yield attributes and yield provides the advantage of a drip system over the furrow irrigation method [105]. Furthermore, the highest yield (14510 kg ha^{-1}) was reported under the treatment with 100% drip irrigation requirement in combination with BPM with a 72% increase in yield as compared to furrow irrigation [53].

In addition, Chandra and Singh [49] revealed that the highest yield (17440 kg ha^{-1}) of okra was recorded under drip irrigation with 100% irrigation with LLDPE mulch, followed by drip irrigation based on a supply of 80% irrigation requirement with LLDPE mulch (17230 kg ha^{-1}). They further stated that drip irrigation in combination with mulching increased the okra yield significantly over furrow irrigation to the tune of 60-167 %. The increase in soil temperature and efficient utilization of water and nutrients, resulting from the use of black polyethylene mulch might be an important reason for the higher yield [106]. According to Parte et al. [107], mulching with plastic sheet proved the best mulch practice that produced superior growth and yield attributing characters in okra, and it was followed by wheat straw and grasses mulching. Hence, plastic mulches absorb comparatively large amounts of the incoming radiation and transmit a considerable part of it to the soil.

Similarly, Sippo et al. [108] recorded the maximum average fruit yield per plant and per hectare as 0.68 kg $plant^{-1}$ and 17200 kg ha^{-1} in the combination treatment of 30% ASMD with black plastic mulching. Further, they found that using a drip irrigation system, BPM resulted in 14.1% water saving while wheat straw mulch showed only 5.27% over bare soil. This revealed that the BPM and proper drip irrigation scheduling may increase yield and save water and improve okra yield over control. In addition, a high yield of okra with minimum ETc was observed under SDI system with plastic mulch treatment [80] due to lower irrigation water requirement, minimum evaporation, and less weed transpiration under plastic film compared to the non-mulched conditions [53]. Moreover, maximum pod yield was reported under drip irrigation at 0.8 pan evaporation fraction in conjunction with either BPM or 100% recommended doses of nitrogen with 18% saving of water compared with surface irrigation with 100% recommended doses of nitrogen [64].

Effect of Surface and Drip Irrigation on Water Use Efficiency of Okra

Water use efficiency (WUE) is another important plant adaptation under water stress, which also has been proposed as an effective selection criterion to identify and/or develop drought-tolerant plants [109, 110].

To achieve the potential yield of any crop, it must not be allowed to suffer from water stress at any critical growth stage. At the same time, water should also be utilized efficiently for getting a higher yield per unit of water applied [111]. WUE can be divided into irrigation water use efficiency (IWUE) and crop water use efficiency (CWUE).

In furrow-irrigated okra, Memon et al. [70] reported that the crop water productivity (CWP) for AFI method (3.51 kg m^{-3}) was calculated to be greater than CWP obtained under EFI method (1.96 kg m^{-3}). Similarly, Muhammad et al. [69] reported that AFI resulted in water saving through increased IWUE, leading to a CWP of 5.21 kg m^{-3} compared to EFI (2.93 kg m^{-3}). Further, IWUE was determined as 5.29 kg m^{-3} for AFI, 2.78 kg m^{-3} for CFI, and as 1.37 kg m^{-3} for flood irrigation [68]. Furthermore, Panigrahi and Sahu [39] found that the IWUE for APRI as 8.41-9.18 kg m^{-3}, as 6.98- 7.85 kg m^{-3} for FPRI and as 6.79-7.25 kg m^{-3} for full irrigation in the field experiment conducted in Bhubaneswar, Orissa.

Meanwhile, the efficiency of drip irrigation was recorded as 126.5 % over than that of surface irrigation [50]. Further, the crop WUE was reported to range from 1.45-2.93 kgm^{-3} and 1.29-2.43 kgm^{-3} in 2005 and 2006, respectively in drip-irrigated okra plots [112]. Chandra and Singh [49] found that the increase in water productivity for drip irrigation systems alone over CFI system was 133.3 %. They further revealed, the increased WUE under drip irrigation is because the drip system provided a precise and measured quantity of water to individual plants and a lower rate of water loss through evaporation from the soil surface under drip irrigation. In addition, Jayapiratha et al. [54] found that the maximum WUE of okra for drip irrigation as 705.2 kg ha^{-1} cm^{-1} for 15 minutes duration, whereas only 99.43 kg/ha/cm was obtained through basin irrigation. In Patna, India, the maximum WUE was recorded at 60% ET under drip treatment in okra plants [45]. On the contrary, Farias et al. [79] reported that the water depth that provided the highest WUE (35.80 $kg.ha^{-1}.mm^{-1}$) was 132.2 mm (125% of ETc) under drip irrigation and the lowest (5.65 $kg.ha^{-1}.mm^{-1}$) of 0 mm, equivalent to 0% of ETc on control plot. Further, they concluded, the greater WUE is associated with greater productivity and the greater availability of water for the plants, allowing the plants to extract better from the soil solution, to take advantage of the nutrients, besides being able to carry out the photosynthesis without impediments. Furthermore, Rani and Mariappan [113] found that drip irrigation resulted in considerable savings of irrigation water besides enhancing WUE. They also revealed that the irrigation given through drip at the rate of 75% Potential evapotranspiration (PE) recorded significantly higher WUE followed by irrigation at 100% PE whereas the lower WUE under surface irrigation (18.35 kg/ha/mm and 21.62 kg/ha/mm) might be due to higher consumption of water and lower yield recorded by the treatment. Meanwhile, the results of Sedara et al. [78] showed that treatment of 60 FIT had a significant effect on IWUE and CWUE with 0.041 t ha^{-1} mm^{-1} and 0.00139 t ha^{-1} mm^{-1}, respectively, compared to the other treatments and it was the best among all the other treatments. Further, they noticed a reduction in the IWUE and CWUE for 80 and 100 FIT, which concluded that the addition of water had no significant effect on the yield of okra rather, it only led to wastage of water since the crop water requirement was fully met at 60 FIT. In addition, a study conducted by Rekha et al. [75] at Rajendranagar, Hyderabad on sandy loam on bhendi (*Abelmoschus esculentus*), revealed that the higher WUE i.e., 8.23 and 8.10 kg ha^{-1} mm^{-1} were reported when the crop was drip irrigated at 1.0 Epan and fertigated with 120 kg N $ha^{-1.}$

Moreover, Saxena et al. [114] conducted a study to analyze the performance of okra under drip irrigation with four levels of saline irrigation water with electrical conductivity; 0.2, 2.0, 4.0, 8.0 dSm^{-1} in three replications and reported that the WUE reduced with the increase in the salinity of irrigation water. Further,

they revealed that the highest WUE was reported to be with available freshwater of 0.2 dSm^{-1} at 0.49; for the treatments of 2.0, 4.0, 8.0 dSm^{-1} it was reported at 0.49, 0.46 and 0.38 t ha^{-1} cm^{-1}, respectively.
Furthermore, the use of a plastic sheet at the furrow bottom [73] or the installation of a polyethylene sheet under surface trickle irrigation [74] helps to conserve water, fertilizers, and pesticides in the root zone of the plant and prevents water losses by deep percolation and improve the WUE of okra plant. Panigrahi et al. [40] reported the maximum IWUE from irrigation at 50% ASMD under APRI with BPM followed by APRI at 25% ASMD + BPM. They resolved that this was due to more frequent irrigation under APRI, caused by a higher rate of water uptake by okra plants from lower wetted soil volume. Further, Sippo et al. [108] found that the WUE was highly significant at drip irrigation treatment and the maximum value of 292.38 kg/ha/cm was obtained in drip irrigation scheduled at 30 % ASMD with BPM. This result agrees with the findings revealed by Brown and Channell-butcher [115] that BPM significantly increased the WUE of the okra crop over the control experiment. Furthermore, irrigation frequency significantly increased the WUE and IWUE [116, 117]. Maximum WUE (96.50kg/ha/cm) was recorded with irrigation scheduling at 5 days interval whereas, the lowest WUE (50.10kg/ha/cm) was observed in irrigation scheduling at 3 days interval [18]. At longer irrigation intervals, less water and subsequent closure of stomata might reduce the loss of water than it caused a decrease in CO_2 fixation, which indicated that the photosynthesis was increased at the cost of water loss resulting in lower WUE [27].

Conclusion

Since the consumption of okra is a piece of proven evidence in reducing the prevalence of malnutrition, in the future, promoting okra consumption would be a promising option in providing a healthy diet to meet the dietary needs of rural communities, as an approach to address the issue of food security. Despite the risk of water scarcity in developing countries, okra can be grown successfully throughout the year, adopting a suitable irrigation strategy in the sandy loam soil condition. Yet, not enough studies conducted based on the okra variety that is best suited to grow under water deficit conditions. Anyhow, choosing okra varieties that is best suited to grow in the region would be a practical solution for this. Further, traditional farmers reluctant to switch from surface irrigation methods should be encouraged to practice the AFI method for okra cropping specifically under BPM at the furrow-bottom, where they contribute to minimizing the infiltration from furrow to bottom and conserving a considerable amount of water leaching. The farmers already adopting the drip irrigation technique should be progressed to SDI with the emitter depth of 0.10 m to 0.15m under the soil surface to meet the efficient use of available water by the reduction of evaporation loss and provide the most suitable moisture regime in the root zone of okra. Apart from that, combining a drip irrigation system with the application of nitrogen-based inorganic fertilizers, organic fertilizers like chicken manure, and foliar application of organic fertilizers like humic acid, and putrescine offers a sensible solution under water deficit conditions. Nevertheless, since okra is not a long-duration annual crop, farmers are disinclined to espouse drip irrigation techniques. Raising awareness among okra-cultivating farmers is the main concern for the widespread adoption of drip irrigation techniques in water-scarce areas. In addition, researchers also have the responsibility to support the relevant authorities in making favorable decisions for farmers.

Conflicts of Interest

The Authors declare no conflicts of interest.

References

[1] FAO, Water scarcity - one of the greatest challenges of our time, Rome, Food and Agriculture Organization of the United Nations, https://www.fao.org/fao-stories/article/en/c/1185405/, accessed: March, **2022**.

[2] UN-Water, https://www.un.org/waterforlifedecade/scarcity.shtml, accessed: Feb, **2022**.

[3] FAO, Water for Sustainable Food and Agriculture - a report produced for the G20 Presidency of Germany, Rome, Food and Agriculture Organization of the United Nations, https://www.fao.org/3/i7959e/i7959e.pdf, accessed: Feb, **2022**.

[4] FAO, Hunger and food insecurity, Rome, Food and Agriculture Organization of the United Nations, https://www.fao.org/hunger/en/, accessed: April, **2022**.

[5] M. Jabeen, S.R. Ahmed, M. Ahmed, Enhancing water use efficiency and grain yield of wheat by optimizing irrigation supply in arid and semi-arid regions of Pakistan, *Saudi Journal of Biological Sciences*. **2022**, 29(2), 878-885.

[6] A. Solaimalai, M. Baskar, A. Sadasakthi, K. Subburamu, Fertigation in high value crops - A Review, *Agricultural Review*. 2005, 26 (1), 1-13.

[7] R. Kalpana, A. Fanish, Microirrigation and fertigation to maize and millates – A Review, *Agric.Review*. **2014**, 35 (2), 103-112.

[8] A. B. Melaku, W. Mohamed, V. Kumar, Variability, heritability and genetic advance in indigenous and exotic okra [*Abelmoschus esculentus* (L.) moench] genotypes for yield and yield related traits at Dire Dawa, Eastern Ethiopia, *MOJ Ecology & Environmental Sciences*. **2020**, *5* (4), 164-169.

[9] S. Kumar, S. Dagnoko, A. Haougui, A. Ratnadass, D. Pasternak, C. Kouame, *Okra (Abelmoschus spp.) in West and Central Africa: potential and progress on its improvement, African Journal of Agricultural Research*. **2010**, 5 (25), 3590-3598.

[10] R.R. Schipper, L. Budd, African Indigenous Vegetables: An Overview of the Cultivated Species, University of Greenwich, Natural Resource Institute, Chathan, UK, **2000**, pp. 222.

[11] A. Y. Kamara, S. O. Ajala, I. Kureh, Performance of diverse maize genotypes under nitrogen deficiency in the northern Guinea Savanna of Nigeria, *Exper. Agric*. **2005**, 41 (2), 199-212.

[12] H. F. Gemede, N. Ratta, G. D. Haki, A. Z. Woldegiorgis, F. Beyene, Nutritional quality and health benefits of okra (*Abelmoschus esculentus*): a review. *J Food Process Technol*. **2015**, 6 (6), 458.

[13] Y. Liu, J. Qi, J. Luo, W. Qin, Q. Luo, Q. Zhang, D. Wu, D. Lin, S. Li, H. Dong, D. Chen, H. Chen, Okra in food field: Nutritional value, health benefits and effects of processing methods on quality, *Food Reviews International*. **2019**, 37 (1), 1-24.

[14] R. Nana, Y. Maiga, R. F. Ouedraogo, W. G. B. Kabore, B. Badiel, Z. Tamini, Effect of water quality on the germination of okra (*Abelmoschus esculentus*) seeds, *International Journal of Agronomy*. **2019**, 2019 (6), 1-7.

[15] A. A. Abd El-Kader, S. M. Shaaban, M. S. Abd El-Fattah, Effect of irrigation levels and organic compost on okra plants (*Abelmoschus esculentus*) grown in sandy calcareous soil, *Agricultural and Biological Journal of North America*. **2010**, 1 (3), 225-231.

[16] T. Barzegar, P. Moradi, J. Nikbakht, Z. Ghahremani, Physiological response of okra cv. kano to foliar application of putrescine and humic acid under water deficit stress, *International Journal of Horticultural Science and Technology*. **2016**, 3 (2), 187-197.

[17] E. O. Adeogun, Yield response of okra to irrigation frequency and amount in a sprinkler irrigation system, *Continental J. Agricultural Science.* **2016**, 10 (2)**,** 24-31.

[18] R. K. Singh, T. Pratap, J. Chaurasiya, V. P. Singh, N. P. Singh, Effect of irrigation schedules and planting methods on yield and water use efficiency of okra under rice-rai-okra cropping system, *An International Quarterly Journal of Life Sciences*. **2016**, 11 (1), 359-362.

[19] M. M. El-Sahookie, A. O. Alfalahi, A. F. Almehemidi, Crop and soil management and breeding for drought tolerance, *J. Agric. Sci.* **2009**, 40 (2), 1-28.

[20] A. K. Chaturvedi, U. Surendran, G. Gopinath, K. M. Chandran, N. K. Anjali, M. C. T. Fasil, Elucidation of stage specific physiological sensitivity of okra to drought stress through leaf gas exchange, spectral indices, growth and yield parameters, *Agricultural Water Management*. **2019**, 222, 92-104.

[21] J. Singh, V. C. Pander, V. P. Kohh, Response of vegetable pea to irrigation, *Journal of Vegetable Science.* **1990**, 19, 11-15.

[22] P. O. Boamah, J. D. Owusu-Sekyere, L. K. Sam-Amoah, B. Anderson, Effect of irrigation interval on chlorophyll fluorescence of tomatoes under sprinkler, *Asian Journal of Agricultural Research*. **2011**, 5 (1), 83-89.

[23] T. A. Howell, Irrigation scheduling research and its impact on water use, Evaporation and irrigation scheduling In *Proceedings of the international conference*, San Antonio Convention Center, San Antonio, Texas, 3-6 November **1996**.

[24] E. Segal, A. Ben-Gal, U. Shani, U, Water availability and yield response to high frequency micro-irrigation in sunflowers In *6th International Micro-irrigation Congress (Micro 2000)*, Cape Town, South Africa, 22-27, Oct **2000**.

[25] S. Sarkar, M. Biswas, S. B. Goswami, P. K. Bandyyopadhyay, Yield and water use efficiency of cauliflower under varying irrigation frequencies and water application methods in Lower Gangetic Plain of India, *Agricultural Water Management.* **2010**, 97 (10), 1655-1662.

[26] C. Kirda, P. Moutonet, M. Smith, J. Henggeler, J. P. Nautiyal, Deficit Irrigation practices, Water reports-22, http://www.fao.org/3/Y3655E/Y3655E00.htm, accessed: Jan, **2022**.

[27] A. Bahadur, K. P. Singh, A. Rai, A. Verma, M. Rai, Physiological and yield response of okra (*Abelmoschus esculentus*) to irrigation scheduling and organic mulching, *Indian Journal of Agricultural Science*. **2009**, 79 (10), 813-815.

[28] H. Wang, L. Zhang, W. R. Dawes, C. Liu, Improving water use efficiency of irrigated crops in the North China Plain - measurements and modelling, *Agricultural water management*. **2011**, 48(2): 151-167.

[29] Y. E. Graterol, D. E. Eisenhauer, R. W. Elmore, Alternate-furrow irrigation for soybean production, *Agricultural water management*. **1993**, 24 (2), 133-145.

[30] S. Kang, Z. Liang, Y. Pan, P. Shi, J. Zhang, Alternate furrow irrigation for maize production in an arid area, *Agricultural water management*. **2000**, 45 (3), 267-274.

[31] S. Z. Kang, P. Shi, Y. H. Pan, Z. S. Liang, X. T. Hu, J. Zhang, Soil water distribution, uniformity and water-use efficiency under alternate furrow irrigation in arid areas, *Irrig. Sci*. **2000**, 19 (4), 181-190.

[32] Y. Liu, E. Cui, A. L. Neal, X. Zhang, Z. Li, Y. Xiao, Z. Du, F. Gao, X. Fan, C. Hu, Reducing water use by alternate-furrow irrigation with livestock wastewater reduces antibiotic resistance gene abundance in the rhizosphere but not in the non-rhizosphere, *Science of the Total Environment*. **2019**, 648, 12-24.

[33] J. O. Payero, D. D. Tarkalson, S. Irmak, D. Davison, J. L. Petersen, Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency and dry matter production in semiarid climate, *Agricultural Water Management*. **2008**, 95 (8), 895-908.

[34] A. Varughese, P. V. Habeeburrahman, Fertigation and plastic mulching in tomato and brinjal - A Review, *Agricultural Reviews*. **2015**, 36 (3), 246-249.

[35] M. Yenesew, K. Tilahun, Yield and water use efficiency of deficit irrigated maize in semi-arid region of Ethiopia, *African Journal of Food, Agriculture, Nutrition and Development*. **2009**, 9 (8), 1635-1651.

[36] N. Schahbazian, J. Eitzinger, A. Montazar, G. Akban, I. Allahdadi, Using simulation models to improve irrigation water application, *Pakistan Journal of Water Resources*. **2007**, 11 (2), 43-57.

[37] F. R. Silungwe, H. F. Mahoo, J. J. Kashaigili, J. J, Evaluation of water productivity for maize under drip irrigation In *Second RUFORUM Biennial Meeting*, Entebbe, Uganda, September **2010**.

[38] A. Narayanamoorthy, N. Devika, Economic and resource impacts of drip method of irrigation on okra cultivation: an analysis of field survey data, *Journal of Land and Rural Studies*. **2018**, 6 (1), 15-33.

[39] P. Panigrahi, N. N. Sahu, Evapotranspiration and yield of okra as affected by partial root-zone furrow irrigation, *International Journal of Plant Production.* **2013**, 7 (1), 33-54.

[40] P. Panigrahi, N. N. Sahu, S. Pradhan, Evaluating partial root-zone irrigation and mulching in okra (*Abelmoschus esculentus* L.) under a sub-humid tropical climate, *Journal of Agriculture and Rural Development in the Tropics and Subtropics*. **2011**, 112 (2), 169-175.

[41] H. C. Wien, P. C. Mirotti, V. P. Grubinger, Polyethylene mulch stimulates early root growth and nutrient uptake of transplanted tomatoes, *Journal of the American Society for Horticultural Science*. **1993**, 118 (2), 207-211.

[42] A. A. Al Masoum, I. M. El Gharib, Plastic mulches for winter okra production, *Egyptian Journal of Horticulture*. **1996**, 23 (2), 211-219.

[43] P. Sharma, A. Kaushal, A. Singh, S. Garg, Growth and yield attributes of okra under influence of drip irrigation, *Journal of Engineering Research and Applications*. **2016**, 6 (2), 85-91.

[44] M. Job, V. K. Singh, Dinmani, Study of water and nutrients requirement through drip irrigation in okra, *Journal of Pharmacognosy and Phytochemistry.* **2018**, 7, 3172-3176.

[45] A. Haris, S. Kumar, A. K. Singh, K. Rajan, Drip irrigation scheduling in okra (*Abelmoschus esculentus* (L.) Moench), *HortFlora Research Spectrum*. **2014**, 3 (3), 274-277.

[46] M. O. Amoo, T. A. Ademiju, A. J. Adesigbin, G. A. Ali, Performance evaluation of drip irrigation systems on production of okra (*Hibiscus esculentus*) in Southwestern, Nigeria, *Journal of Engineering Research and Reports*. **2019**, 5 (3), 1-10.

[47] S. O. Oshunsanya, E. A. Aiyelari, O. Aliku, R. A. Odekanyin, Comparative performance of okra (*Abelmoschus esculentus*) under subsistence farming using drip and watering can methods of irrigation, *Irrigation and Drainage*

Systems Engineering. **2016**, 5 (2), 159.
[48] S. Choudhary, A. Chandra, P. K. Yadav, Effect of crop geometry on okra (*Abelmoschus esculentus*) cultivars under different irrigation levels and mulching, *Progressive Horticulture*. **2012**, 44 (2), 276-280.
[49] R. Chandra, P.K. Singh, Response of okra to drip irrigation and mulching in tarai condition of uttarakhand, *International Journal of Agriculture Sciences*. **2019**, 11 (15), 8854-8857.
[50] B. M. A. Abubaker, M. Alhadi, Y. Shuang-En, S. Guang-Cheng, Different irrigation methods for okra crop production under semi-arid conditions, *International Journal of Engineering Research and Technology*. **2014**, 3 (4), 787-794.
[51] U. Aliyu, M. Bello, A. Muhammad, N. M. Kwaifa, Effects of irrigation intervals and nitrogen rates on growth and pod yield of okra *Abelmoschus esculentus* (L) in Sokoto North-West Nigeria, *International Journal of Research in Engineering and Science*. **2016**, 4 (9), 46-52.
[52] R. M. Al-Ubaidi, E. F. Al-Shakry, M. A. Al-Samara, S. M. Al-Mohmadawy, Effect of irrigation intervals on growth, flowering and fruits quality of okra (Abelmoschus esculentus L. Monech), *African Journal of Agricultural Research*. **2017**, 12 (23), 2036-2040.
[53] K. N. Tiwari, P. K. Mal, R. M. Singh, A. Chattopadhyay, Response of okra (*Abelmoschus esculentus* (L.) Moench.) to drip irrigation under mulch and non-mulch conditions, *Agricultural Water Management*. **1998**, 38 (2), 91-102.
[54] V. Jayapiratha, M. Thushyanthy, S. Sivakumar, Performance Evaluation of okra (*Abelmoschus esculentus*) under drip irrigation system, *Asian Journal of Agricultural Research.* **2010**, 4 (3), 139-147.
[55] G. Y. Jamala, P. G. Boni, P. Abraham, A. Musa, Soil status and yield response of different varieties of okra (*Abelmoschus esculentus* L. Moench) grown at mubifloodplain, North Eastern, Nigeria, *J. Agric. Biotechnol. Sustain. Dev*. **2011**, 3 (7), 120-125.
[56] S. Konyeha, M. O. Alatise, Evapotranspiration and Leaf Area Index (LAI) of irrigated okra (*Abelmoschus esculentus* L. Moench) in Akure, South-Western City of Nigeria, *International Journal of Engineering Research and Technology*. **2013**, 2 (9), 2880-2888.
[57] A. P. Jupp, E. I. Newman, Morphological and anatomical effects of severe drought on roots of *Lolium perenne* (L.), *New Phytol*. **1987**, 105, 393-402.
[58] P. Kramer, J. S. Boyer, Water relations of plants and soils, 1st Ed, New York, Academic Press, Inc, **1995**.
[59] M. R. Santiniketan, V. Bharati, Affordable water supply and sanitation In *Proceedings of the 20th WEDC International Conference Colombo (ICC'94)*, Sri Lanka, 22-26 Aug **1994**.
[60] H. A. Hussein, A. K. Metwally, K. A. Farghuly, M. A. Bahawirth, Effect of irrigation interval (water stress) on vegetative growth and yield in two genotypes of okra, *Australian Journal of Basic and Applied Sciences.* **2011**, 5 (12), 3024-3032.
[61] G. West, D. Inze, G. T. S. Beemster, Cell cycle modulation in the response of the primary root of arabidopsis to salt stress, *Plant Physiology*. **2004**, 135 (2), 1050-1058.
[62] M. A. Anjum, M. Amjad, The response of okra (*Abelmoschus esculentus* L. Moench) to different levels of N, P and K fertilizers, *Pak. J. of Bio. Sci*. **1999**, 2 (3), 794-796.
[63] S. K. Arora, B. R. Sharma, N. Kumar, Effect of nitrogen and phosphorus fertilization on growth and yield components in okra (*Abelmoschus esculentus* L. Moench), *Haryana J. of Horti. Sci.* **1991**, 20 (3-4), 261-266.
[64] D. V. Patel, R. H. Patel, R. B. Patel, Effect of drip irrigation, mulch and nitrogen fertigation on yield and yield attributes of okra (*Abelmoschus esculentus*), *Indian Journal of Agricultural Sciences.* **2009**, 79 (1), 12-15.
[65] J. D. Owusu-Sekyere, E. Annan, Effect of deficit irrigation on growth and yield of okro (*Abelmoschus esculentus)*, *Journal of Science and Technology (Ghana)*. **2010**, 30 (2), 128-134.
[66] F. G. Viets, The plant's need for and use of nitrogen, *Soil nitrogen*. **1965**, 10, 503-549.
[67] L. K. Sam-Amoah, W. K. T. Willie, J. D. Owusu-Sekyere, Effects of deficit irrigation and chicken manure interactions on the growth and yield of okra in a pot experiment, *Asian Journal of Agricultural Research*. **2016**, 10 (1), 47-55.
[68] A. A. Siyal, A. S. Mashori, K. L. Bristow, M. T. Van Genuchten, Alternate furrow irrigation can radically improve water productivity of okra, *Agricultural Water Management.* **2016,** 173 (C), 55-60.
[69] T. Muhammad, M. Zhu, N. A. Bazai, Water use efficiency and solute transport under different furrow irrigation treatments, *International Journal of Biosciences*. **2017**, 10 (1), 356-367.
[70] M. S. Memon, A. A. Siyal, J. Changying, A. A. Tagar, S. Ara, S. A. Soomro, Khadimullah, F. Ullah, N. Memon, Effect of irrigation methods and plastic mulch on yield and crop water productivity of okra, *Journal of Basic and applied Sciences.* **2017**, 13, 616-621.

[71] S. Z. Kang, Z. S. Liang, Y. H. Pan, P. Z. Shi, J. H. Zhang, Alternate furrow irrigation for maize production in an arid area, *Agricultural water management*. **2000**, 45 (3), 267–274.

[72] A. Asadipour, H. Madani, The effects of irrigation and sowing date on the quantitative traits of okra (*Abelmoschus esculentus* L.), *International Journal of Farming and Allied Sciences*. **2014**, 3 (5), 497-501.

[73] M. S. Memon, F. Ullah, K. Ali, N. Memon, Impacts of furrow cover plastic sheet on crop water productivity and salt distribution in the soil profile, *Science Technology and Development*. **2017**, 36 (2), 106-114.

[74] S. A. Almasraf, A. H. Hommadi, Improving water use efficiency and water productivity for okra crop by using subsurface water retention technology, *Journal of Engineering*. **2018**, 24 (7), 65-75.

[75] K. B. Rekha, M. G. Reddy, K. Mahavishnan, Nitrogen and water use efficiency of bhendi (*Abelmoschus esculentus L. Moench*) as influenced by drip fertigation, *Journal of Tropical Agriculture.* **2005**, 43 (1-2), 43-46.

[76] N. P. Saxena, S. Gupta, Performance evaluation of okra (*Abelmoshus esculentus*) under drip irrigation system, *Asian J Agric Res*. **2004**, 4, 139-147.

[77] H. Punam, B. N. Parsad, B. M. Choudhary, K. Sunita, Performance of different irrigation methods in okra, *J. Research, Birsa Agri. Uni*. **2003**, 15 (2), 205-210.

[78] O. S. Sedara, A. M. Sedara, M. O. Alatise, O. T. Faloye, Effect of varying water applications on growth, yield and water use efficiency of okra (*Abelmoschus esculentus*) under drip irrigation in Akure, *Agricultural Engineering International: CIGR Journal*. **2021**, 23 (1), 100-108.

[79] D. B. S. Farias, A. A. T. Lucas, R. R. Araújo, M. I. de Freitas, T. S. de Jesus, Efficiency in water use and yield of okra (*Abelmoschus esculentus*) in response to different levels of irrigation, *Revista Brasileira de Agricultura Irrigada.* **2017**, 11 (5), 1732-1737.

[80] A. Patil, K. N. Tiwari, Okra crop response under subsurface drip and conventional furrow irrigation with varying n fertilization, *Communications in Soil Science and Plant Analysis.* **2018**, 49 (19), 2429-2445.

[81] H. R. Vadar, P. A. Pandya, R. J. Patel, Effect of subsurface drip irrigation depth scheduling in summer okra, *Emergent Life Sciences Research*. **2019**, 5 (2), 52-61.

[82] D. K. Singh, T. B. S. Rajput, Response of lateral placement depths of subsurface drip irrigation on okra (*Abelmoschus esculentus*), *International Journal of Plant Production*. **2007**, 1 (1), 73-84.

[83] M. Mahmoudi, M. N. Khelil, R. Ghrib, B. Douh, A. Boujelben, Assessment of growth and yield of okra (Abelmoschus esculentus) under surface and subsurface drip irrigation using treated wastewater, *International Journal of Recycling of Organic Waste in Agriculture*. **2020**, 9 (4), 349-356.

[84] N. Senesi, T. M. Miano, G. Brunetti, Humic-like substances in organic amendments and effects on native soil humic substances in *Humic Substances in Terrestrial Ecosystems*, 1st Ed, New York, Elsevier, **1996**, 531-593.

[85] A. S. Ati, D. H. Wally, A. T. Dizaye, Role of humic fertilization on reducing water deficit and its relation to fruit yield of okra and water productivity, *Kufa Journal for Agricultural Sciences*. **2018**, 10 (4), 96-108.

[86] S. M. Shaaban, Effect of Organic and inorganic nitrogen fertilizer on wheat plant under water regime, *Journal of Applied Sciences Research*. **2006**, 2 (10), 650-656.

[87] H. Mehraj, T. Taufique, M. S. H. Mandal, R. K. Sikder, A. J. Uddin, Foliar feeding of micronutrient mixtures on growth and yield of okra (*Abelmoschus esculentus*), *Am.-Eurasian J. Agric. Environ. Sci*. **2015**, 15 (11), 2124-2129.

[88] K. B. Polara, H. P. Ponkia, H. L. Sakarvadia, L. C. Vekaria, N. B. Babariya, Effect of multimicronutrients fertilizers on yield and micronutrients uptake by okra (*Abelmoschus esculentus*) grown on medium black calcareous soils of Saurashtra region of Gujarat, *Int. J. Pure Appl. Biosci*. **2017**, 5 (6), 258-264.

[89] P. Arya, S. Anita, M. V. Menon, P. S. Bhindhu, S. Antony, Foliar application of micronutrients on growth and yield of okra under different irrigated conditions, *Journal of Tropical Agriculture*. **2021**, 59 (1), 76-82.

[90] P. Krittika, A. K. Jain, N. B. Misal, Study of optimum irrigation levels and fertilizer dose in drip irrigated okra crop, *Annals of Biology*. **2018**, 34 (2), 187-190.

[91] W. G. Hopkins, N. P. A. Hüner, Introduction to plant physiology, 4th Ed, USA, Hoboken Wiley, **2008**.

[92] A. Kaushal, A. S. Lodhi, K. G. Singh, Economics of growing sweet pepper under low tunnels, *Progressive Agriculture*. **2011**, 11 (2), 426-430.

[93] Y. C. Tan, J. S. Lai, K. R. Adhikari, S. M. Shakya, A. K. Shukla, K. R. Sharma, Efficacy of mulching, irrigation and nitrogen applications on bottle gourd and okra for yield improvement and crop diversification, *Irrigation and Drainage System*. **2009**, 23 (1), 25-41.

[94] K. R. Adhikari, S. M. Shakya, Irrigation scheduling in vegetables for yield improvement and crop diversification, *Inst. of Agric. and Animal Sciences (lMS)*. **2003**, 572-585.

[95] A. Unlukara, B. Cemek, Response of okra to water stress, *Mustafa Kemal University Journal of Agricultural Sciences.*

2019, 24, 313-319.
[96] B. Walter, Influence of bark mulch on water balance, soil water quality, mineralization and nitrification in skeletal Devonian Viney and soils, *Hort. Abst*. **1988**, 59 (9), 835.
[97] R. M. Bhagat, C. L. Acharya, Soil water dynamics during wheat growth under different soil management practices, *J. Indian Soc. Soil Sci*. **1988**, 36, 389-396.
[98] G. Incalcaterra, F. Vetrano, Effects of two sowing dates and plastic mulch on okra production, *Acta Horticulture*. **2000**, 533, 329-336.
[99] A. Kumar, Effect of mulch and sowing method on pod yield at vegetable pea in Garhwal Himalaya, *Indian Journal of Soil Conservation*. **2001**, 29, 84-85.
[100] G. Kar, A. Kumar, Effects of irrigation and straw mulch on water use and tuber yield of potato in eastern India, *Agricultural Water Management*. **2007**, 94, 109-116.
[101] L. N. Mulumba, R. Lal, Mulching effects on selected soil physical properties, *Soil and Tillage Research*. **2008**, 98 (1), 106-111.
[102] Z. Huang, Z. Xu, C. Chen, Effect of mulching on labile soil organic matter pools, microbial community functional diversity and nitrogen transformations in two hardwood plantations of subtropical Australia, *Applied Soil Ecology*. **2008**, 40 (2), 229-239.
[103] J. N. Mishra, J. C. Paul, P. C. Pradhan, Response of okra to drip irrigation and mulching in coastal Orissa, *Indian Journal of Soil Conservation*. **2009**, 37 (2), 129-132.
[104] V. S. Birbal, N. S. Rathore, S. Nathawat, Bhardwaj, N. D. Yadav, Effect of irrigation methods and mulching on yield of okra in berbased vegetable production system under arid region, *Bhartiya Krishi Anusandh Patrika*. **2013**, 28 (3), 142-147.
[105] C. Sunilkumar, U. Jaikumaran, Yield and yield attributes of bhindi as influenced by mulching and methods of irrigation, *Journal of Tropical Agriculture*. **2002**, 40, 56-58.
[106] W. J. Lamont, What are the components of a plasticulture vegetable system?, *HortTechnology*. **1996**, 6 (3), 150-154.
[107] V. Parte, P. Dagore, A. Kujur, U. Markam, Effect of mulching and methods of irrigation on okra (*Hibiscus esculentus* L. Moench), *International Journal of Current Microbiology and Applied Sciences*. **2020**, 9 (2), 759-765.
[108] M. M. Sippo, B. S. Reddy, I. Kaleel, Interactive effects of irrigation and mulches on soil temperature and yield of okra (*Abelmoschus esculentus* L.), *Journal of Pharmacognosy and Phytochemistry*. **2019**, 8 (2), 1809-1814.
[109] I. M. Ray, A. Segovia-Lerma, L. W. Murray, Diallel analysis of carbon isotope discrimination and its association with forage yield among nine historically recognized alfalfa germplasms, *Crop Sci*. **2004**, 44, 1970-1975.
[110] H. X. Cao, Z. B. Zhang, P. Xu, L. Y. Chu, H. B. Shao, Z. H. Lu, J. H. Liu, Mutual physiological genetic mechanism of plant high water use efficiency and nutrition use efficiency, *Colloids Surf*. **2007**, 57: 1-7.
[111] J. Kaur, S. S. Mahal, Irrigation scheduling in direct seeded rice (*Oryza sativa* L.*)* - A Review, *Agricultural Reviews.* **2015**, 36 (3), 208-217.
[112] A. R. Al-Harbi, A. M. Al-Omran, F. I. El-Adgham, Effect of irrigation levels and emitters depth on okra (*Abelmoschus esculentus*) growth, *Journal of Applied Sciences*. **2008**, 8 (15), 2764-2769.
[113] A. S. Rani, G. Mariappan, Effect of drip irrigation regimes and fertigation levels on growth, yield, quality parameters, nutrient uptake and water use efficiency of bhendi (*Abelmoschus esculentus L. Moench*), *Journal of Pharmacognosy and Phytochemistry*. **2019**, SP2, 524-527.
[114] C. K. Saxena, S. K. Gupta, R. C. Purohit, S. R. Bhaka, B. Upadhyay, Performance of okra under drip irrigation with saline water, *Journal of Agricultural Engineering*. **2013**, 50 (4), 683-689.
[115] J. E. Brown, C. Channell-Butcher, Effect of three row covers and black plastic mulch on the growth and yield of clemson spineless okra, *Journal of Vegetable Crop Production*. **2000**, 5 (2), 67-71.
[116] S. M. Sezen, A. Yazar, M. Canbolat, S. Eker, G. Celikel, Effect of drip irrigation management on yield and quality of field grown green beans, *Agric. Water Management*. **2005**, 71 (3), 243-255.
[117] L. Hao, D. Aiwang, L. Fusheng, S. Jingsheng, W. Yancong, S. Chitao, Drip irrigation scheduling for tomato grown in solar greenhouse based on pan evaporation in North China Plain, *Journal of Integrative Agriculture*. **2013**, 12 (3), 520-531.