*Pak. J. Agri. Sci., Vol. 58(1), 341-356; 2021*
*ISSN (Print) 0552-9034, ISSN (Online) 2076-0906*
*DOI: 10.21162/PAKJAS/21.949*
http://www.pakjas.com.pk

# EFFECT OF DIFFERENT IRRIGATION AND NITROGEN MANAGEMENT OPTIONS ON GROWTH, YIELD AND WATER USE EFFICIENCY OF CHINESE CABBAGE IN GREENHOUSE CULTIVATION

**Amar Ali Adam Hamad[1], Junzeng Xu[1,2], Qi Wei[1,*], Yousef Alhaj Hamoud[1], Hiba Shaghaleh[3], Kechun Wang[1], Fazli Hameed[1,4], Lijun Xu[1]**

**[1]College of Agricultural Science and Engineering, Hohai University, Nanjing, China; [2]State Key Laboratory of Hydrology–Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China; [3]College of Chemical Engineering, Nanjing Forestry University, Nanjing, China; [4]Department of Agriculture, University of Swabi, Anbar, KPK, Pakistan**

***Correspondence author's e-mail: weiqi8855116@163.com**

Agriculture is currently facing demanding challenges such as water scarcity and environmental pollution while Chinese cabbage (*Brassica rapa* L. *chinensis*) is one of the most important vegetables in China. However, to ensure food security, it is required to assess the effect of water and nitrogen management strategies on the growth, yield, and water use efficiency (WUE) of Chinese cabbage. Therefore, a field experiment was conducted using a randomized complete block design with a factorial arrangement of treatments adopting three irrigation methods (surface irrigation, SI; surface drip irrigation, DI; and subsurface drip irrigation with drippers at 5, 10 and 15 cm, $SDI_5$, $SDI_{10}$, $SDI_{15}$) and combined with two nitrogen fertilizer (Urea, N > 46.2%) application levels 300 kg N/ha (100%N) and 240 kg N /ha, (80%N). Dry plant biomass (DPB), dry root biomass (DRB), plant height, number of leaves/plant, maximum root length and leaf area index (LAI) (growth parameters) and consequently crop yield and WUE were significantly affected by irrigation systems and fertilizer levels. The obtained results indicated that SI treatment under both N fertilizer levels (100%N and 80%N) gave better results among other irrigation methods. In contrast, SDI treatments comparing with DI as a control, $SDI_{15}$ under both N fertilizer levels significantly gave higher yield 36.0 and 28.9 t/ha under 100%N and 80%N respectively. While $SDI_5$ (25.4 and 18.3 t /ha) recorded the lowest yield. $SDI_{15}$ gave the highest WUE 60.6, 52.0 t /h /mm under100%N and 80%N respectively, also $SDI_{15}$ was the optimal irrigation regime for the following growth parameters DPB (11.6 and 10.2 g/plant), DRB (5.1 and 4.6 g/plant, number of leaves/plant (25.7 and 23.7), maximum root length (11.8, 9.3 cm) and leaf area index (LAI) (1.05, 0.91) under both nitrogen level 100%N and 80%N respectively. Our findings suggested that $SDI_{15}$ irrigation combined with 100% nitrogen application rate could be an effective irrigation and fertilization management strategy for Chinese cabbage growth with water-saving and high yield.
**Keywords:** Biomass; Chinese cabbage; Nitrogen Fertilizer; Subsurface Drip Irrigation; Water productivity.

## INTRODUCTION

The cultivation of vegetables is an essential agricultural aspect in China (Zhang *et al.*, 2018). Usually, greenhouse farming's economic benefits are greater than those for open-air vegetable production (Guo *et al.*, 2012). The key crops grown in greenhouses in China have been vegetables in recent years, have high economic value and health benefits for producers (Sun *et al.*, 2013). Chinese cabbage is an essential crop grown in South and Northeast Asia and has a 30%-40% share of China's crop production sector.

Compared with other vegetable crops, easy seed production, short crop duration offers benefits to the growers and low production costs (Rasool *et al.*, 2019). Chinese cabbage can be planted in the fall, winter, spring, and summer seasons. The vegetable's whole character varies widely with the leaf size, shape, and strength of the green leaf color.

Water is a severely limited resource due to increased use, poor management, and contamination. The expected rise in dry weather in many parts of the world would further worsen the problem (Luterbacher *et al.*, 2006). The agriculture sector leads to this adverse situation in large part. Irrigated agriculture is a big water user and accounts for approximately two-thirds of the overall freshwater used for human use (Fereres and Evans, 2005). Several differing factors, such as different climatic conditions, the development stage, and water availability, determine the irrigation interval. However, the irrigation interval varies according to the irrigation method. From this viewpoint, irrigation programming and irrigation methods are closely related (Giouvanis *et al.*, 2018). One of the most effective irrigation systems is considered to be drip irrigation, saving water, reducing surface runoff and deep percolation compared to surface irrigation (Jha *et al.*, 2019). It directly supplies the needed amount of water to the root zone of crops, hence increasing water and fertilizer efficiency (Kuscu *et al.*, 2014). Hassanli *et al.* (2010) stated that yield reaction for more than 30 crops indicates that SDI crop yield was higher than or equal to that for other irrigation techniques. In most cases, it needed less water. Drippers are placed under the soil surface in the SDI system to reduce water consumption, control weeds, and minimize runoff (Afzal *et al.*, 2020). Due to its higher WUE relative to other irrigation strategies, SDI provides a better significant advantage (Li *et al.*, 2015).

Recently, Chinese agriculture faces many difficult challenges to ensure sustainability for the environment. China has become the world's largest fertilizer user, and producers have used excessive fertilization to achieve high yield (Li *et al.*, 2015). Most farming communities always use traditional methods with high fertilizer and water inputs to produce a higher yield (Delang, 2017). N Is the main nutrient in increasing crop yield (Hameed *et al.*, 2019b). N is an essential nutrient for vegetative crop growth, directly influencing the crop yield by the leaf area and plant height increase (Ata-Ul-Karim *et al.*, 2016). The average nitrogen fertilizer provided in different regions in China, about 300 kg /ha (Hameed *et al.*, 2019a). Hetao Irrigation District is about 350 kg /ha (Du *et al.*, 2011), in Jiangsu province 300 kg /ha (Peng *et al.*, 2010). There have been several studies on the impact of irrigation practices and nitrogen levels on vegetable crops. The increased amount of irrigation water causes leaching and fertilizer inefficiency (Li *et al.*, 2018). The Chinese Ministry of Agriculture examines that the quantity of fertilizer used is high and beyond the acceptable limit (Shuqin *et al.*, 2018). A better highlight for increasing crop yield and fertilizer use efficiency is proper management (Luo and Li, 2018). However, limited studies are available about the WUE, growth, and yield of leafy vegetables with SDI. Thus, we hypothesized that proper irrigation management and better fertilizer application are the most important factors on plant growth. Due to excessive fertilizer application and high water applied, proper technique and management are required. SDI at 15 cm dripper placement might be the best method to save water, enhance yield and WUE. Our study objectives were: 1) to investigate the performance of growth and yield of Chinese cabbage as affected by different irrigation systems and fertilizer rates, and 2) to explore the proper water and fertilizer management strategy for Chinese cabbage with water-saving and high yield characteristics.

## MATERIALS AND METHODS

***Description of Study Area:*** The experiment was performed in October 2019 on Chinese cabbage in the Water-Saving Park of Hohai University (31 ° 95 'N, 118 ° 83 'E), in a greenhouse without temperature monitoring under normal light conditions, in a suburban of Nanjing, in the downstream area of the Yangtze River basin with an average height of 15 m above sea level. Under the influence of the East Asia Monsoon, the study region's climate is classified as humid. The mean annual temperature is 15.7 ° C, the mean evaporation of the pan is 900 mm, and the mean annual rainfall is 1,073 mm. The field was prepared to a depth of 30 cm by well conventional tillage (manual) and then partitioned into a particular experimental unit. The soil of the experimental field is clay loam. Its detailed chemical and physical properties are shown in Table 1.

**Table 1. Soil physical and chemical properties**

| Soil property | Value |
|---|---|
| Silt | 36.68 % |
| Clay | 44.59 % |
| Sand | 19.61 % |
| pH | 7.14 |
| TN | 1.20 g/kg |
| TP | 0.33 g/kg |
| BD | 1.33 g/cm$^3$ |
| Porosity | 50.18 % |

Note: TN, TP and BD represent total nitrogen, total potassium and bulk density, respectively. Values are the replication of properties.

***Experimental Design:*** The field experiment comprised of two factors, three irrigation systems, namely surface irrigation (SI), drip irrigation (DI), and sub-surface drip irrigation (SDI) that was divided into sub-treatments with sub-surface drippers at depths of 5, 10, and 15 cm, namely $SDI_5$, $SDI_{10}$, and $SDI_{15}$ respectively, and two nitrogen fertilizer levels, Urea-N at 300 Kg N/ha (100% N) and 80% Urea-N at the rate of 240 Kg N/ha (80%N).

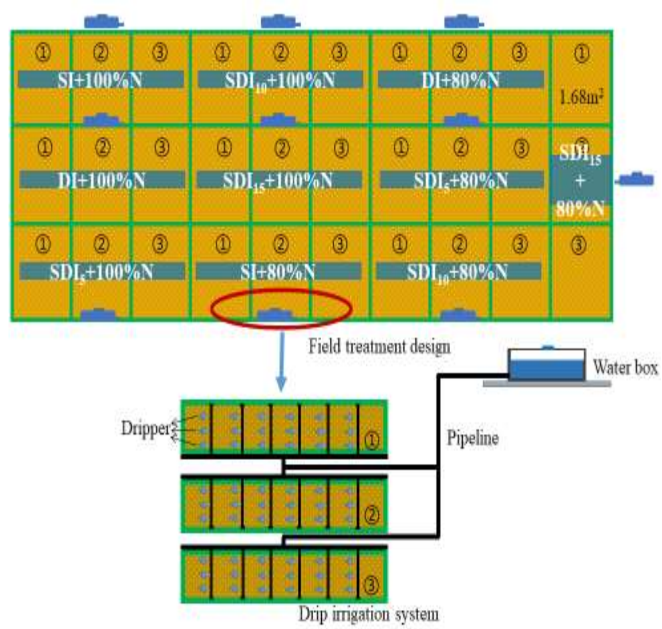


**Figure 1. Experimental design set up**

A completely randomized block design had yielded ten treatments, named SI+100%N, DI+100%N, $SDI_5$+100%N,

$SDI_{10}$+100%N, and $SDI_{15}$+100%N, and SI+80%N, DI+80%N, $SDI_5$+80%N, $SDI_{10}$+80%N and $SDI_{15}$+80%N, each treatment had to replicate three plots, totally 30 plots (Fig. 1). Each plot area was 1.68 $m^2$ (L × W = 2.1 m × 0.8 m) approximately, and the two adjacent plots separated by a ridge 25 cm thick. Every plot consisted of six lateral lines with a lateral distance of 20 cm, each lateral line had a total of three drippers with a spacing of 40 cm, all treatments received the same amount of water 0.15 $m^3$ per plot (892.8 $m^3$ /ha) except SI treatments received 0.408 $m^3$ per plot (2,428.6 $m^3$ /ha). The treatments were irrigated three times during the whole growing period with 20-d irrigation intervals. A water reservoir (0.05 $m^3$) was installed at the height of 2 m to store irrigation water. Irrigation water was delivered to the plots through a gravity drip system. Each treatment had a separate drip line, surface irrigation plot was irrigated manually, for all treatments, and nitrogen fertilizer was mixed with irrigation water.

***Plant Sampling*****:** Three representative plants were chosen from each treatment during the growth period for the measurement of growth parameters. Among these, using 100 cm (accuracy is a 0.1 m) stainless steel ruler to determine each marked plant's height. Every plant's Leaves number was counted at 5-d intervals. Leaf area was used to measure the leaf area index (LAI), which was calculated based on the number of plants in a square meter by applying a total green leaf area. Plant samples were separated into leaves, roots, and separately weighted. On the day of harvesting, the maximum root length was measured. After oven drying, the dry plant biomass (DPB) and dry root biomass (DRB) were obtained at 70 ° C until a constant weight was achieved.

***Water Consumption, Yield and Water Use Efficiency*****:** Total crop evapotranspiration (ETc) was calculated using the soil water balance equation (Zhang *et al.*, 2017). The contributions of available precipitation, groundwater recharge, runoff, and deep percolation were negligible under the experiments' actual conditions.

$$\mathrm{ETc} = \mathrm{I} - \Delta \mathrm{W} \qquad (1)$$

where I is the irrigation amount, mm; ΔW is the change of soil water storage at the beginning, and end of the trials, mm.

Water use efficiency was measured from the yield and accumulated water determined according to the following equation:

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{IW}} \qquad (2)$$

where WUE is water use efficiency, t/ha /mm; Y is fresh yield, t/ha; $I_W$ is crop water consumption, mm/ha.

***Statistical analysis:*** The experimental data were statistically analyzed using the IBM-SPSS statistical package (IBM-SPSS 19, USA). A general linear model procedure was used to perform an analysis of variance (two-way ANOVA). Each treatment's mean values were compared by applying LSD tests at the $p<0.05$ level of significance.

## RESULTS AND DISCUSSION

### Growth Parameters

***Dry Plant Biomass*****:** The ANOVA results showed a significant difference ($P< 0.05$) of irrigation methods on DPB either in 100%N or 80%N level. Generally, dry Chinese cabbage biomass increased with the application of fertilizer rate under all irrigation treatments. Under 100%N level, the maximum DPB was observed with SI+100%N followed by $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N, and DI+100%N this decrement as flows 14.6%, 15.5%, 16.0%, and 35.1% respectively. Furthermore, the DPB in SDI ($SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N) treatments were lower than those from SI+100%N, by 33.3%, 32.0% and 31.1% higher than those from DI+100%N. The DPB in treatments under 80% N level showed the similar pattern with those under 100%N level, and its order is SI+80%N > $SDI_{15}$+80%N> $SDI_{10}$+80%N> $SDI_5$+80%N > DI+80%N. In comparison with SI+80%N, the DPB was significantly decreased by 17.9%, 18.7%, 19.5% and 39.0% for $SDI_{15}$+80%N, $SDI_{10}$+80%N, $SDI_5$+80%N and DI+80%N, respectively. While DPB among SDI treatments under 80%N, $SDI_{15}$+80%N gave the highest value, followed by $SDI_{10}$+80%N, and $SDI_5$+80%N, DPB increased by 35.3%, 34.1%, and 32.8% respectively, compared with DI+80%N (Fig. 2A). The interaction effect of the irrigation method ($p<0.05$) with the fertilizer rate was significantly affected DPB.

***Dry Root Biomass*****:** The Chinese cabbage DRB was influenced by the methods of irrigation and N fertilization is seen in (Fig. 2B). The maximum DRB was observed with SI+100%N, followed by $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N, and DI+100%N. Compared with SI+100%N, DRB was decreased as flows, 0.4%, 1.4%, 12.5% for $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N and DI+100%N respectively. On the other hand, DRB in SDI treatments was significantly increased by 14.3%, 13.2% and 8.5% for $SDI_{15}$+100%N, $SDI_{10}$+100%N and $SDI_5$+100%N, respectively, comparing with DI+100%N. Moreover, DRB under 80%N fertilizer level, $SDI_{15}$+80%N was recorded highest value followed by SI+80%N, $SDI_{10}$+80%N, $SDI_5$+80%N and DI+80%N. Comparing with SI+80%N, the $SDI_{15}$+80%N had increased DRB by 0.9% but not significant; meanwhile, other treatments decreased by 2.6%, 2.9%, and 7.0% for $SDI_{10}$+80%N, $SDI_5$+80%N and DI+80%N, respectively. While DRB under SDI treatments ($SDI_{15}$+80%N, $SDI_{10}$+80%N, and $SDI_5$+80%N) significantly increased by 8.5%, 4.7%, and 4.5%, respectively compared with DI+80%N. DRB was greatly influenced by the effects of irrigation practices and fertilizer and their interactions ($p<0.05$).

***Leaves Number*****:** The number of Chinese cabbage leaves decreased significantly under 100%N level ($p<0.05$). The maximum plant leaves were observed with SI+100%N

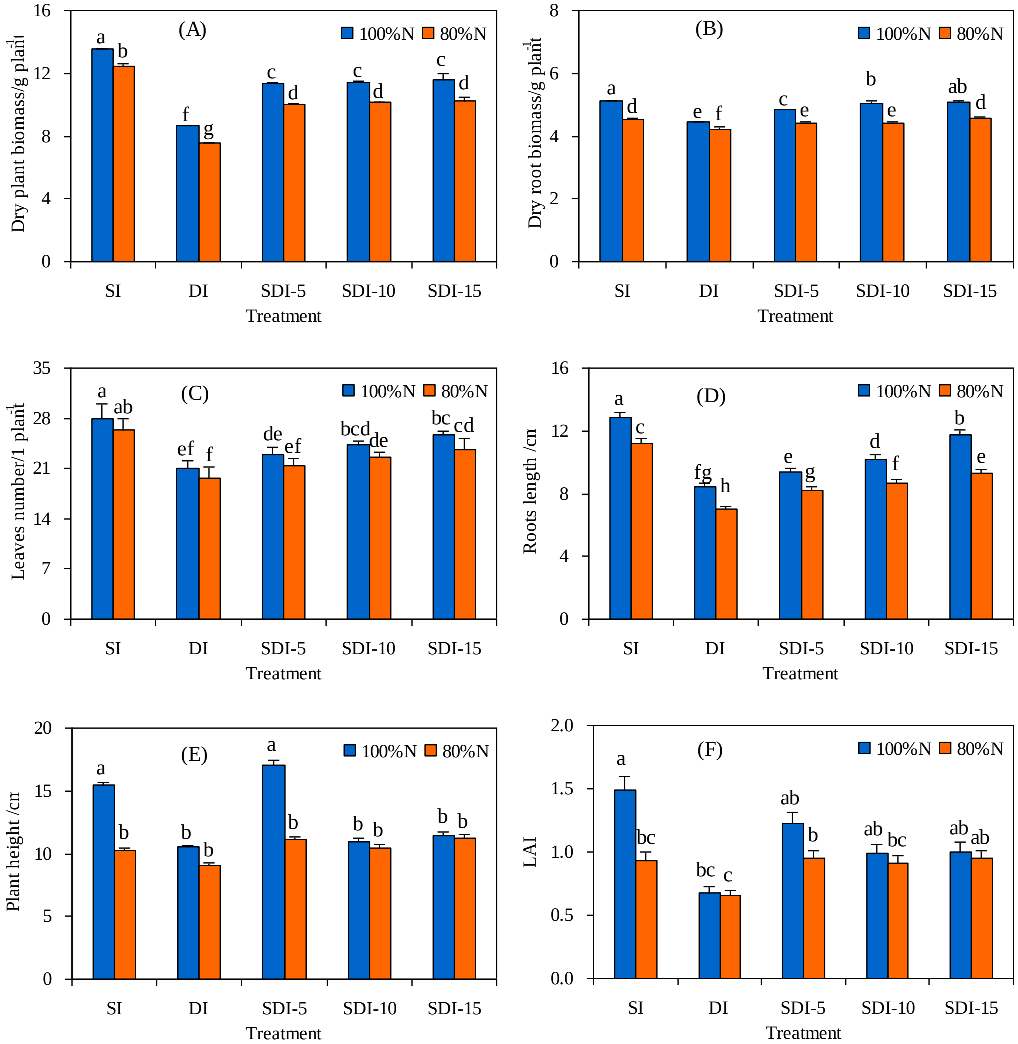


**Figure 2. DPB (A), DRB (B), leaves number (C), roots length (D), plant height (E) and LAI (F) of Cabbage under different treatments**

Note: lower case letters above the error bars are the significant differences according to the LSD tests at *p<0.05* level.

followed by $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N and DI+100%N. Compared with SI+100%N, the plant leaves number significantly decreased by about 8.3%, 13.1%, 17.9% and 25.0%, respectively. Meanwhile, leaves number in SDI treatments significantly increased by 22.2%, 15.9% and 9.5% for $SDI_{15}$+100%N, $SDI_{10}$+100%N and $SDI_5$+100%N, respectively, compared to DI+100%N. As well as the leaves number under 80%N level treatments have the same pattern with 100%N level, therefore the plant leaves significantly decreased by 11.2%, 13.9%, 19.0% and 25.3% for $SDI_{15}$+80%N, $SDI_{10}$+80%N, $SDI_5$+80%N and DI+80%N, respectively. But under SDI treatments showed that, $SDI_{15}$+80%N> $SDI_{10}$+80%N> $SDI_5$+80%N, 20.2%, 15.3% and 8.4% respectively when compared with DI+80%N (Fig. 2C).

***Maximum Root length*:** As presented in (Fig. 2D), the longest maximum root length was observed in SI+100%N, followed by $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N, and DI+100%N, however, this decrement was 8.5%, 20.7%, 27.0% and 34.2%, respectively, compared to SI+100%N. While root length was increased under SDI treatments ($SDI_{15}$+100%N, $SDI_{10}$+100%N, and $SDI_5$+100%N) by 39.0%, 20.4%, and 11.0%, respectively, compared with DI+100%N. Furthermore, a similar pattern to those under100%N level either compared to SI+80%N or DI+80%N level. Irrigation methods × nitrogen interactions were also significant in Chinese cabbage maximum root length.

***Plant Height*:** Under 100%N level treatment, the longest plant height was recorded by $SDI_5$+100%N, followed by

SI+100%N, $SDI_{15}$+100%N, $SDI_{10}$+100%N, and DI+100%N. The lowest plant height was recorded by DI+100%N. The plant height increased by about 8.9% in $SDI_5$+100%N while significantly decreased by 16.2%, 16.3%, and 22.0% for $SDI_{15}$+100%N, $SDI_{10}$+100%N, and DI+100%N, respectively compared with SI+100%N. Plant height in SDI treatments was 39.6%, 7.5%, and 7.3% higher than DI+100%N but not significant. The $SDI_{15}$+80%N showed the longest plant height followed by SI+80%N, $SDI_5$+80%N, $SDI_{10}$+80%N, and DI+80%N in comparison to SI+80%N, plant height increased by 4.86% for $SDI_{15}$+80%N, while decreased by 2.1%, 2.2%, and 5.3% for $SDI_5$+80%N, $SDI_{10}$+80%N, and DI+80%N, respectively. On the other hand, under SDI treatments, $SDI_{15}$+80%N was recorded highest value followed by $SDI_5$+80%N, and $SDI_{10}$+80%N, plant height increased by 10.8%, 3.5%, and 3.3%, respectively (Fig. 2E).

***Leaf Area Index*:** The maximum LAI was observed in SI+100%N followed by $SDI_{15}$+100%N, $SDI_5$+100%N, $SDI_{10}$+100%N, and DI+100%N (Fig. 2F). Compared with SI+100%N, the LAI was decreased by 9.5%, 13.8%, 19.8% and 29.3%, respectively. While LAI within SDI treatments, compared with DI+100%N, significantly increased by 28.0%, 22.0%, and 13.4% for $SDI_{15}$+100%N, $SDI_5$+100%N, $SD_{10}$+100%N, respectively. Furthermore, the LAI under 80%N level demonstrated that, maximum LAI was registered by $SDI_{15}$+80%N followed by $SDI_5$+80%N, SI+80%N, $SDI_{10}$+80%N,and DI+80%N, compared with SI+80%N, LAI increased by 8.3%, 2.4%, for $SDI_{15}$+80%N, $SDI_5$+80%N, respectively. In contrast, decreased by amount 1.19%, 27.38% for $SDI_{10}$+80%N, DI+80%N, respectively. Furthermore, LAI increased among SDI treatment as follows $SDI_{15}$+80%N, $SDI_5$+80%N, and $SDI_{10}$+80%N (49.2%, 41.0%, and 36.1%), respectively compared with DI+80%N.

***Yield and WUE*:** Table 2 showed that the maximum yield value was noticed by SI+100% N, followed by $SDI_{15}$ + 100% N, $SDI_{10}$ + 100% N, $SDI_5$ + 100% N, and DI+100% N.. Crop yield significantly decreased ($p<0.05$) by 10%, 33.8%, 36.5% and 42.5% respectively compared with SI+100%N. But among SDI treatments, the crop yield increased, $SDI_{15}$+100%N gave the highest value followed by $SDI_{10}$+100%N and $SDI_5$+100%N; these increments can be expressed by 56.6%, 15.2%, and 10.4% respectively compared to DI+100%N. A similar pattern was shown under an 80%N level. The crop yield was decreased significantly by 25.3%, 44.7%, 52.7% and 65.9% for $SDI_{15}$+80%N, $SDI_{10}$+80%N, $SDI_5$+80%N, and DI+80%N, respectively, by comparing to SI+80%N. On the other hand, under SDI treatments by comparison with DI+80%N, crop yield was significantly increased by 118.9%, 62.1% and 38.6% for $SDI_{15}$+80%N, $SDI_{10}$+80%N and $SDI_5$+80%N, respectively. The interaction effect of irrigation and nitrogen was significantly affected by crop yield.

**Table 2. Effect of different irrigation methods and fertilizer management and the result of ANOVA on yield and WUE.**

| Treatment | Yield (t/h) | WUE (t/h mm$^{-1}$) | Water use (mm) |
|---|---|---|---|
| SI+100%N | $40.0^{A}$ | $19.4^{G}$ | $205.8^{A}$ |
| SI+80%N | $38.7^{A}$ | $20.1^{G}$ | $192.2^{B}$ |
| DI+100%N | $23.0^{EF}$ | $41.3^{D}$ | $55.7^{F}$ |
| DI+80%N | $13.2^{H}$ | $30.0^{F}$ | $44.0^{I}$ |
| $SDI_5$+100%N | $25.4^{DE}$ | $44.5^{CD}$ | $57.1^{E}$ |
| $SDI_5$+80%N | $18.3^{G}$ | $36.3^{E}$ | $50.5^{G}$ |
| $SDI_{10}$+100%N | $26.5^{CD}$ | $45.8^{C}$ | $57.9^{D}$ |
| $SDI_{10}$+80%N | $21.4^{F}$ | $44.7^{CD}$ | $47.9^{H}$ |
| $SDI_{15}$+100%N | $36.0^{B}$ | $60.6^{A}$ | $59.4^{C}$ |
| $SDI_{15}$+80%N | $28.9^{C}$ | $51.0^{B}$ | $56.7^{E}$ |
| ANOVA | | | |
| I | * | * | * |
| N | * | * | * |
| I× N | * | * | * |

Note: SI, DI and SDI represent surface irrigation, drip irrigation and subsurface drip irrigation, respectively. I and N represent irrigation and nitrogen, respectively. WUE means water use efficiency. Values within the same columns followed with different letters are significantly different at ($p<0.05$) according to LSD test, * denotes significant at ($p<0.05$) level.

In irrigation methods under 100%N level, The findings revealed that $SDI_{15}$ + 100% N had the highest WUE values followed by $SDI_{10}$+100%N, $SDI_5$+100%N, DI+100%N and SI+100%N, in comparison with the SI+100%N, WUE was significantly increased by 211.7%, 135.5%, 129.0% and 112.4% for $SDI_{15}$+100%N, $SDI_{10}$+100%N, $SDI_5$+100%N, and DI+100%N, respectively. Further, with 80%N level, $SDI_{15}$+80%N recorded the maximum WUE value followed by $SDI_{10}$+80%N, $SDI_5$+80%N, DI+80%N, and SI+80%N, Compared with the SI+80%N, the WUE was significantly increased by 153.0%, 121.84%, 80.0% and 48.9%, respectively (Table 2

***Effect of Different Irrigation Methods and Fertilizer Management on Plant Growth Parameters:*** Irrigation and fertilization are substantial factors of plant growth, and therefore correct choosing of them can lead to enhance plant growth. The overall average of DPB, DRB, maximum root length, and leaves number per plant was significantly decreased compared with SI, plant height and LAI also decreased **(**Fig. 2A**)**. The possible reason could be the high irrigation level on SI treatment than other treatments. A high volume of irrigation water increases the height of the plant, the number of leaves and the overall fresh weight significantly (Al-Harbi *et al.*, 2008). The root length decreased as water application decreased (Maria do Rosário *et al.*, 1996). Our result also showed that the effect of fertilizer rate on all parameters, that is, 100%N level was better for all growth parameters, yield, and WUE than 80%N level. This could be due to a high application rate of N. Ouda *et al.* (2008) stated that each rise in the dose of nitrogen fertilizers increase leaves per plant. The maximum yield was achieved from supplying 300 kg N/ha (Yoldas *et al.*, 2008).

The findings from the present study showed that $SDI_{15}$ under both 100%N and 80%N rate had registered the maximum value of DPB (11.6 and 10.2 g/plant), respectively, in comparison to other SDI ($SDI_5$, $SDI_{10}$) and DI treatments (Fig. 2B). It could be due to the direct application of water and fertilizer by subsurface drip emitters in the crop's root zone, which decreases the loss of water. Therefore conveyance, evaporation, and percolation losses are minimized. A similar result has been found by Bar-Yosef *et al.* (1989), who noticed that the highest difference was obtained in overall dry matter production by subsurface fertigation. The current results showed that $SDI_{15}$ under both 100%N and 80%N level had high DRB (5.1 and 4.6 g/plant for 100%N and 80%N respectively, compared with other SDI and DI treatments (Fig. 2B), This could be due to the strong absorption of water and nutrients which help high production of biomass. Similar findings have been recorded by Al-Rawahy *et al.* (2004), they stated that significant root growth was achieved with porous pipes at a depth of 15 cm under both water applications. High root development with maximum root dry matter indicates strong uptake of water and nutrients (Alhaj Hamoud *et al.*, 2019).

Compared to the DI, SDI tends to increase root growth and distribution in the subsurface layer in the wetting zone. (Al-Omran *et al.*, 2005). Holding the drip tape inside the crop root zone and well below the soil surface successfully replenishes the root zone due to minimal soil gravity flow and decreases evaporation losses due to reduced capillary movement. (Patel and Rajput, 2007). maximum root length was recorded in mycorrhizal plants to increase water uptake in those plants (Augé, 2004). As presented in (Fig. 2D), our results showed that $SDI_{15}$ significantly increased the maximum root length as compared to DI, under both 100%N and 80%N fertilizer, SDI registered longest maximum root length 11.8, 9.3 cm respectively compared with DI. This could be due to the strong moisture balance and aeration in the root region, with increased emitter depth, which increased root system growth relative to DI, which appeared to lower the upper surface moisture level. Our findings in line with Khodke and Patil (2012), which demonstrate that the maximum root length was observed in the surface soil layer (0-15 cm) by using the SDI system followed by DI.

SDI gave a better result than SI on okra plant height (Al-Harbi *et al.*, 2008). The current study showed that, under both 100%N level, $SDI_5$ gave a higher value of plant height (15.2, 10.5 cm), while 80%N, $SDI_{15}$+80%N had the highest value (11.2 cm), compared to other SDI and DI treatments (Fig. 2E). May attributed to the proper water and nutrient uptake. Moreover, the maximum LAI under 100%N (1.05) was noticed in $SDI_{15}$+100%N. Meanwhile, LAI under 80%N (0.91) was recorded by $SDI_{15}$+80%N, compared to other SDI and DI treatment (Fig. 2F). This could be attributed to proper water and nutrient uptake. Chinese cabbage leaves number increased significantly ($p<0.05$) with $SDI_{15}$ either under 100%N or 80%N level compared to other SDI treatments and DI treatment. The maximum leaves number per plant was (25.7 and 23.7) under 100%N and 80%N, respectively, compared with DI and other SDI treatments (Fig. 2C). This is an indicator of the proper conservation of water at this depth. Our results in line with Al-Rawahy *et al.* (2004), who reported that the amount of water on the subsurface line at a depth of 15 cm gave significantly higher numbers of leaves for all three irrigation levels.

***Effect of Different Irrigation Methods and Fertilizer Management on Yield and WUE:*** Our findings showed that the yield significantly decreased in SDI and DI compared with SI under both nitrogen levels (Table 2). This decrement because SDI and DI received less amount of water than SI. Increased irrigation levels increased tomato Yield (Xiukang and Yingying, 2016; Kuscu *et al.*, 2014; Shuqin *et al.*, 2018). Wang and Xing (2016) stated that tomato yield decreased with the irrigation amount reduce. Furthermore, our findings also indicated that $SDI_{15}$ treatment either under 100%N or 80%N fertilizer level significantly ($p < 0.05$) improved crop yield compared to DI, the highest values of yield were obtained in $SDI_{15}$ under both nitrogen levels (36.0 and 28.9 t/ha) in 100%N and 80%N respectively, whereas $SDI_5$ (25.4 and 18.3 t /ha) recorded the lowest yield (Table 2). This increases due to reducing or eliminating soil water evaporation, irrigation runoff, and deep percolation. Similar results recorded by Vadar *et al.* (2019) Who observed that under SDI, the yields of vegetables and field crops were equal to or greater than those for other irrigation systems. SDI can effectively increase alfalfa production by reducing soil water evaporation (Wang *et al.*, 2018; Lamm, 2016). The results in line with Vadar *et al.* (2019) stated that burying the lateral pipe in SDI reduces the evaporation from the topsoil surface. Under the SDI method, potato yield was greater than under the DI method throughout all observation years (Patel and Rajput, 2007). Piri and Naserin (2020) observed that SDI obtained the highest yield of onions and the lowest yield obtained by SI. Our findings also indicated that the application of two nitrogen levels showed that 100%N had greater yield and WUE than 80%N, we in line with Sun *et al.* (2013) Who found that the yield of wheat grain and WUE improved with the N fertilization rates.

For SDI, the maximum WUE was significantly greater than the DI. The SDI provides more optimal plant growth and production conditions in the root zone (Al-Omran *et al.*, 2005). WUE (21.7 kg /ha /mm) with SDI 0.15 m lateral placing depth was found by (Vadar *et al.*, 2019). The highest WUE was found in the plot irrigated by the SDI method (2.1 $kg/m^3$), while the lowest WUE was in the SI (1.43 $kg/m^3$) (Hassanli *et al.*, 2010). WUE of Chinese cabbage was improved as a result of increased yield without increased water application as shown in (Table 2), our results indicated that the $SDI_{15}$ gave highest WUE under both nitrogen level 100%N and 80%N (60.6, 52.0 t /h /mm) respectively, compared with SI. The key explanation for the higher WUE in the SDI system may be lower soil-surface evaporation and better water supply and nutrients within the root zone. Furthermore, as there is limited evaporation from the SDI system, transpiration is increased and increased transpiration increases stomata opening and photosynthesis. A similar result has been reported by Bhattarai *et al.* (2008). Higher WUE at deeper emitter depth noted in the edamame was probably attributable to lower evaporative losses than shallow emitter placement (Al-Ajmi and Abdel Rahman, 2001).

***Conclusions:*** The results obtained in this study showed that crop growth parameters, crop yield, WUE of Chinese cabbage were all affected by different irrigation methods and fertilizer management and their interaction. DPB, DRB, root length, the number of leaves per plant and yield were significantly decreased under both 100%N and 80%N levels compared with SI, plant height and LAI were also decreased, while under SDI ($SDI_{15}$, $SDI_{10}$, and $SDI_{5}$) treatments under both nitrogen fertilizer levels, and comparing with DI. The $SDI_{15}$ gave highest values in DPB, DRB, maximum root length, number of leaves per plant, plant height, LAI, and yield while DI obtained the lowest values. Maximum WUE under both nitrogen levels was significantly recorded by $SDI_{15}$ while the minimum noticed by DI. Especially, 100%N fertilizer level gave better results than 80%N level among all growth parameters, yield and, WUE. These results suggested that $SDI_{15}$ can be considered a most effective irrigation method with moderate nitrogen application in increasing yield, growth parameters, and improving WUE of Chinese cabbage.

***Acknowledgments*:** This research was funded by the National Natural Science Foundation of China (51809077) and the Fundamental Research Funds for the Central Universities (B200201004).

## REFERENCES

Afzal, M., M. Cheema, M. Shahid, M. Arshad and T. Khaliq. 2020. Optimization of subsurface drip lateral depths and irrigation levels for best yield response of onion (Allium cepa L.). J. Anim. Plant Sci. 30:702-712.

Al-Ajmi, H. A. and H. A. Abdel Rahman. 2001. Water Mangement Intricacies in the Sultanate of Oman The Augmenation--Conservation Conundrum. Water Int. 26:68-79.

Al-Harbi, A., A. Al-Omran and F. I. El-Adgham. 2008. Effect of drip irrigation levels and emitters depth on okra (Abelmoschus esculentus) growth. J. Appl. Sci. 8:2764-2769.

Al-Omran, A.M., A.S. Sheta, A.M. Falatah and A.R. Al-Harbi. 2005. Effect of drip irrigation on squash (Cucurbita pepo) yield and water-use efficiency in sandy calcareous soils amended with clay deposits. Agr. Water Manage. 73: 43-55.

Al-Rawahy, S., H.A. Rahman and M.S. AL-Kalbani. 2004. Cabbage (Brassica oleracea L.) response to soil moisture regime under surface and subsurface point and line applications. Int. J. Agri. Biol. 6:1093-1096.

Alhaj Hamoud, Y., Z. Wang, X. Guo, H. Shaghaleh, M. Sheteiwy, S. Chen, R. Qiu and M. Elbashier. 2019. Effect of Irrigation Regimes and Soil Texture on the Potassium Utilization Efficiency of Rice. Agron. 9.

Ata-Ul-Karim, S. T., Q. Cao, Y. Zhu, L. Tang, M.I. Rehmani and W. Cao. 2016. Non-destructive Assessment of Plant Nitrogen Parameters Using Leaf Chlorophyll Measurements in Rice. Front. Plant Sci 7:1829.

Augé, R. M. 2004. Arbuscular mycorrhizae and soil/plant water relations. Can. J. Soil Sci. 84:373-381.

Bar-Yosef, B., B. Sagiv and T. Markovitch. 1989. Sweet corn response to surface and subsurface trickle phosphorus fertigation. Agron. J. 81:443-447.

Bhattarai, S.P., D.J. Midmore and L. Pendergast, 2008. Yield, water-use efficiencies and root distribution of soybean, chickpea and pumpkin under different subsurface drip irrigation depths and oxygation treatments in vertisols. Irri. Sci. 26:439-450.

Delang, C. O. 2017. Causes and distribution of soil pollution in China. Envi. Socio-econo. Stu. 5:1-17.

Du, J., P. Yang, Y. Li, S. Ren and Y. Lin. 2011. Nitrogen balance in the farmland system based on water balance in Hetao irrigation district, Inner Mongolia. Acta. Ecol. Sinica. 31:549-4559.

Funda Eryilmaz A. 2016. Seasonal variations on quality parameters of Pak Choi (Brassica rapa L. subsp. chinensis L.). Adv. Crop Sci. Technol. 4:1000233.

Fereres, E. and R.G. Evans. 2005. Irrigation of fruit trees and vines: an introduction. Irri. Sci. 24:55-57.

Giouvanis, V., K. Siafis, C. Papanikolaou, D. Dimakas and M. Sakellariou-Makrantonaki. 2018. Effects of Different Irrigation Levels in Cultivation of “Mountain Tea”. Proce. 2.

Guo, Y.J., B.W. Li, H.J. Di, L.J. Zhang and Z.L. Gao. 2012. Effects of dicyandiamide (DCD) on nitrate leaching, gaseous emissions of ammonia and nitrous oxide in a greenhouse vegetable production system in northern China. Soi. Sci. Plant Nutr. 58:647-658.

Hameed, F., J. Xu, S.F. Rahim, Q. Wei, A.R. Khalil and Q. Liao. 2019a. Optimizing nitrogen options for improving nitrogen use efficiency of rice under different water regimes. *Agronomy* 9.

Hameed, F., J. Xu, S.F. Rahim, Q. Liao, A.R. Khalil and S. Ahmed. 2019b. Rice growth and nitrogen uptake simulation by using oryza (V3) model considering variability in parameters. *Pak. J. Agric. Sci.* 56:245-259.

Hassanli, A.M., S. Ahmadirad and S. Beecham. 2010. Evaluation of the influence of irrigation methods and water quality on sugar beet yield and water use efficiency. Agr. Water Manage. 97:357-362.

Jha, S.K., T.S. Ramatshaba, G. Wang, Y. Liang, H. Liu, Y. Gao and A. W. Duan. 2019. Response of growth, yield and water use efficiency of winter wheat to different irrigation methods and scheduling in North China Plain. Agr. Water Manage. 217:292-302.

Jin, S.Q. and F. Zhou. 2018. Zero growth of chemical fertilizer and pesticide use: China's objectives, progress and challenges. J. Res. Eco. 9:50-58.

Khodke, U. and D. Patil. 2012. Effect of subsurface drip irrigation on moisture distribution, root growth and production of cauliflower. In Soil and Water Engineering. Int. Conf. Agri. Engi.-CIGR-AgEng 2012: agriculture and engineering for a healthier life, Valencia, Spain, 8-12 July 2012: CIGR-Eur.AgEng.

Kuscu, H., A. Turhan, N. Ozmen, P. Aydinol and A.O. Demir. 2014. Optimizing levels of water and nitrogen applied through drip irrigation for yield, quality, and water productivity of processing tomato (Lycopersicon esculentum Mill.). Horti. Env. Bio. 55:103-114.

Lamm, F. 2016. Subsurface drip irrigation and possibilities in alfalfa. Califo. Alfa.

Li, H., R. Cong, T. Ren, X. Li, C. Ma, L. Zheng, Z. Zhang and J. Lu. 2015. Yield response to N fertilizer and optimum N rate of winter oilseed rape under different soil indigenous N supplies. Fie. Crop Res.181:52-59.

Li, Y., J. Li, L. Gao and Y. Tian. 2018. Irrigation has more influence than fertilization on leaching water quality and the potential environmental risk in excessively fertilized vegetable soils. PLoS. One. 13:e0204570.

Luo, H. and F. Li. 2018. Tomato yield, quality and water use efficiency under different drip fertigation strategies. Scie. Horti. 235:181-188.

Luterbacher, J., E. Xoplaki C. Casty, H. Wanner, A. Pauling, M. Küttel, T. Rutishauser, S. Brönnimann, E. Fischer, D. Fleitmann, F.J. Gonzalez-Rouco, R. García-Herrera, M. Barriendos, F. Rodrigo, J.C. Gonzalez-Hidalgo, M.A. Saz, L. Gimeno, P. Ribera, M. Brunet, H. Paeth, N. Rimbu, T. Felis, J. Jacobeit, A. Dünkeloh, E. Zorita, J. Guiot, M. Türkes, M.J. Alcoforado, R. Trigo, D. Wheeler, S. Tett, M.E. Mann, R. Touchan, D.T. Shindell, S. Silenzi, P. Montagna, D. Camuffo, A. Mariotti, T. Nanni, M. Brunetti, M. Maugeri, C. Zerefos, S.D. Zolt, P. Lionello, M.F. Nunes, V. Rath, H. Beltrami, E. Garnier and E.L.R. Ladurie. 2006. Chapter 1 Mediterranean climate variability over the last centuries: A review. Dev.eart.env.sci. 27-148.

Oliveira, M.R.G, A.M. Calado and C.A.M. Portas. 1996. Tomato root distribution under drip irrigation. J. Ame. Soc. Hort. Sci. 121:644-648.

Ouda, B. A. and A. Y. Mahadeen. 2008. Effect of fertilizers on growth, yield, yield components, quality and certain nutrient contents in broccoli (Brassica oleracea). Int. J. Agri. Biol.10:627-632.

Patel, N. and T. B. S. Rajput. 2007. Effect of drip tape placement depth and irrigation level on yield of potato. Agr. Water Manage. 88:209-223.

Peng, S.B., R.J. Buresh, J.L. Huang, X.H. Zhong, Y.B. Zou, J.C. Yang, G.H. Wang, Y.Y. Liu, R.F. Hu, Q.Y. Tang, K.H. Cui, F.S. Zhang and F.D. Achim.2010. Improving nitrogen fertilization in rice by sitespecific N management. A review. Agro. Sustain. Dev. 30: 649-656.

Piri, H. and A. Naserin. 2020. Effect of different levels of water, applied nitrogen and irrigation methods on yield, yield components and IWUE of onion. Scie. Horti. 268:109361.

Rasool, G., X. Guo, Z. Wang, S. Chen and I. Ullah. 2019. The interactive responses of fertigation levels under buried straw layer on growth, physiological traits and fruit yield in tomato plant. J. Plant Intera. 14:552-563.

Sun, Y., K. Hu, Z. Fan, Y. Wei, S. Lin and J. Wang. 2013. Simulating the fate of nitrogen and optimizing water and nitrogen management of greenhouse tomato in North China using the EU-Rotate_N model. Agr. Water Manage. 128:72-84.

Vadar, H.R., P.A. Pandya and R.J. Patel. 2019. Effect of subsurface drip irrigation depth scheduling in summer Okra. Emer. Life. Sci. Res. 5:52-61.

Wang, J.W, W.Q. Niu, Y. Li, and W. Lv. 2018. Subsurface drip irrigation enhances soil nitrogen and phosphorus metabolism in tomato root zones and promotes tomato growth. Appl. Soi. Eco. 124:240-251.

Wang, X.K. and Y.Y. Xing. 2016. Effects of irrigation and nitrogen fertilizer input levels on soil-N content and vertical distribution in greenhouse tomato (Lycopersicum esculentum Mill.). Scie. 5:1-13.

Wang, X. K. and Y.Y. Xing. 2016. Evaluation of the effect of irrigation and fertilization by drip fertigation on tomato yield and water use efficiency in greenhouse. Int. J. Agron. 1:1-10.

Yoldas, F., S. Ceylan, B. Yagmur and N. Mordogan. 2008. Effects of Nitrogen Fertilizer on Yield Quality and Nutrient Content in Broccoli. J. Plant Nutr. 31:1333-1343.

Zhang, H., Y. Xiong, G. Huang, X. Xu and Q. Huang. 2017. Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. Agr. Water Manage. 179:205-214.

Zhang, J., H. Li, Y. Wang, J. Deng and L.G. Wang. 2018. Multiple-year nitrous oxide emissions from a greenhouse vegetable field in China: Effects of nitrogen management. Sci. Tot. Envi. 616:1139-1148.

**[Received 09 Oct 2020; Accepted 27 Nov 2020; Published (online) 11 Jan 2021]**