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Adoption of Using Greenhouse Technology for Improving the Productivity of Cucumber Under Sudan Dry Land Conditions

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Abstract: In the hot climate of Sudan, greenhouses technology is still a challenge to be monitored and adopted to avoid overheating air temperature inside the greenhouses. Three greenhouses were built and covered by different polyethylene covers namely; single layer of polyethylene (S-PE), single layer of polyethylene with green net 50% opening (S-PE+N) and double layers of polyethylene with 9cm air gap (D-PE). The experiments were conducted at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum - Shambat, Sudan (32° 51' E, 15° 65' N and 380 m above mean sea level) during the two seasons (2018 and 2019) with the objective of improving the productivity of cucumber under greenhouses technology in Sudan dry land conditions. The parameters tested were irrigation efficiency (%), crop water requirements (mm/day), yield (kg/m^2) and crop productivity (kg/m^3). SAS Statistical Package was used to analyze the data. The results indicated that, crop water requirements, yield and crop productivity significantly difference in both seasons. Season 2019 gave the highest mean values of yield and crop productivity as compared to season 2018. Greenhouse technology covered by S-PE significantly ($P \leq 0.05$) increased the yield (15.1 kg/m^2) and crop productivity (25.3 kg/m^3) comparing to S-PE+N which ranked the least (9.20 kg/m^2 and 20.8 kg/m^3, respectively). The reductions in yield (23.4%) and crop productivity (19.1%) in season 2018 were due to the applied huge quantity of water more than crop required by drip irrigation system (irrigation efficiency 82%). It is concluded that, under the lower crop productivity of Sudan dry land conditions, greenhouse technology covered by S-PE with high efficiency of evaporative cooling system should be followed and adopted.

Keywords: Greenhouses Technology, Crop Productivity, Cucumber

1. Introduction

Greenhouses technology is required to cultivate several types of crops such as tomato and cucumber by covering greenhouses with polyethylene covers and cooling by evaporative cooling systems, which reduces the problem of excess heat in greenhouse. It provides a suitable environmental condition for improving crop growth and productivity [1]. A greenhouse traps the short wavelength solar radiation to create a favorable microclimate for higher productivity [2]. The quality of the radiation allowed by covering materials to enter the greenhouse is important for evaluating its influence on plant's growth and development [3]. Protective cultivation may reduce water and nutrient consumption by 22% and 35% respectively in crop production. Reducing water supply at seedling stage, controlling water supply at flowering stage and increasing water supply at fruiting stage can increase crop yield and water productivity [4]. Increased yield of cucumber under shading, reduced crop transpiration and thus water uptake with improved water use efficiency by 62% for cucumber crop [5]. Full irrigation at the early and late stages and then irrigation with 80% of ETc was the most appropriate treatment in terms of crop water productivity [6]. The crop yield in protected structures can be increased as compared to open field cultivation. Moreover, crop production in a greenhouse has led to the minimum use of chemical fertilizers and pesticides, which is not possible under open field conditions [7]. Cucumber (*Cucumissativus*L.) is one of the popular vegetable crops grown broadly throughout the world. It grows successfully under conditions of high light, high humidity, high soil moisture, temperature and fertilizers in green-houses [8]. Cucumber growth parameters were increased by using white net cover throughout the growing season [9]. It varies in responding to polyethylene covers which depending on materials used and environmental conditions [10]. Polyethylene covers increased the yield more than five times as compared to open field conditions. When selecting a particular Greenhouse cover, considerations should be determined; cover degradation, economic aspects, light distribution patterns in the greenhouse and the relationship between greenhouse microclimate and cover material [11]. On the other hand, the reduction in water productivity due to the huge quantities of water applied by the conventional irrigation systems is becomes a great challenge for the agricultural sector to produce more food under water scarcity conditions. In Sudan, low crop productivity is one of the major problems that are facing agricultural production. Low crop productivity in addition to high production costs, low prices and high taxes had all resulted in a general deterioration of the agricultural sector. This has contributed in converting agriculture from an attractive business to a repellent activity and caused many farmers to abandon agriculture and migrate to cities. Improving crop water productivity will require an increase in marketable crop yield per unit of water removed by plant, reduction in water losses from the plant rooting zone. Therefore, the objective of this study was to improve the crop productivity of cucumber (*Cucumissativus* L.) using greenhouse technology in Sudan dry land conditions.

2. Materials and Methods

2.1. Experimental Site

The experimental works were conducted at the Demonstration Farm of the Faculty of Agriculture, University of Khartoum - Shambat, Sudan (32° 51’ E, 15° 65’ N and 380 m above the mean sea level) under three greenhouses conditions during the two seasons (2018 and 2019). The climate is semi-arid with low relative humidity and daily mean maximum and minimum temperature are 36°C and 22°C, respectively. The annual rainfall is limited and usually occurs in the form of short intense thunder storms. This means that water is deficient and crop production must be based on irrigation.

2.2. Soil Physical Properties

Soil physical properties and textural class were determined at the Laboratory of the Department of Soil and Environment Sciences, Faculty of Agriculture, University of Khartoum.

2.3. Experimental Design and Layout

As presented in Figure 1 greenhouses were designed and installed to accommodate different treatments namely; single layer of polyethylene (S-PE), single layer of polyethylene with green net with 50% opening (S-PE+N) and double layers of polyethylene with 9cm air gap (D-PE). These treatments were arranged in randomized completely block design (RCBD) with five replicates. Analysis of variance and correlation coefficients were calculated using SAS computer program.

Figure 1. *Greenhouse covers (D-PE: double-layers with 9 cm air gap of polyethylene, S-PE+N: single-layer of polyethylene covered with green net (50% opening) and S-PE: single-layer of polyethylene).*

2.4. Measurements

Evaporative cooling system; evaporative cooling system is mainly based on the process of heat absorption during the evaporation of water. It consists of cooling pads and extracting fans. A cross fluted cellulose pad was mounted in a vertical fashion at the end of the greenhouse. A PVC pipe (1 inch diameter) suspended immediately above the cooling pads. Holes drilled each 10cm long throughout the length of PVC pipe, and the end of this pipe was capped. A water sump mounted under the pads to collect the water and return it into the water tank (1000 liters), from which it can be recycled to the cellulose pads by means of the water pump. In order to bring the cold air onto the plants throughout the growth period, the cooling pads were located 20cm above the ground surface of the greenhouse. Two extracting fans (single speed, direct drive and 90cm diameter) located on the leeward side of the greenhouse and the pads on the aid toward prevailing wind (opposite side of the extracting fans). In the hot climate of Sudan, evaporative cooling systems have been commonly employed to reduce the interior ambient air temperature of greenhouses. Evaporative cooling system efficiency (η) is normally defined as the ratio of the actual dry-bulb temperature reduction to the theoretical maximum at 100% saturation as mentioned by [12] as follows:

$$\eta\% = \frac{\text{Todb} - \text{Tidb}}{\text{Todb} - \text{Towb}} \times 100 \quad (1)$$

Where:
Todb = dry-bulb temperature of outside air °C
Tidb = dry-bulb temperature of inside air °C
Towb = wet-bulb temperature of outside air °C

Plant parameters; cucumber seeds (Leader F1 Hybrid, Syngenta Company) were sown in nurseries of the CTC company, Sudan (controlled environment) and after the appearance of the third true leaf, seedlings were transplanted into the three greenhouses, one plant was placed in a hole with spacing of 0.4m between holes, each location was irrigated by a drip irrigation system The crop commenced to flower after 21 days, and fruited after 45 days. Leaves number, plant length, stem diameter and the total fresh yield were measured.

Environmental parameters; environmental parameters are generally recognized to have a major impact on the production of protected cropping. These parameters have been included ambient air temperature and air relative humidity. Temperature and relative humidity inside, outside greenhouses were measured using ISOLAB Laborgerate GmbH, ambient (outside, inside) temperature and relative humidity were recorded. Data was collected at each 4 hour (8:00am, 12:00pm, 4:00pm, and 8:00pm).

Crop water requirement (mm/day); crop water requirement (ETc) is derived from crop evapotranspiration (100% crop water use) which is the product of the reference evapotranspiration (ETo) and the crop coefficient Kc [13].

$$\text{ETc} = \text{ETo} \times \text{Kc} \times \text{Ks} \times \text{Kr} \quad (2)$$

Where:
ETc = Crop evapotranspiration (mm/day)
ETo = Reference evapotranspiration (mm/day).
Kc = Crop Coefficient (dimensionless)
Ks = Soil water availability factor = 0.9 due to the soil type (clay loam)
Kr = A reduction factor.

Reference crop evapotranspiration (ETo) was determined by the following equation mentioned by [14] as follows:

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma\left(\frac{900}{\text{T}} + 273\right)\text{U}_2\,(\text{es} - \text{ea})}{\Delta + \gamma(1 + 0.34\,U_2} \quad (3)$$

Where:
ETo = Reference crop evapotranspiration (mm day^{-1})
R_n = Net radiation at crop surface (Mjm^{-2} day^{-1})
T = Average temperature at 2m height (°C)
e_s = SvpkPa
e_a = Actual vp (kPa)
(e_s –e_a) = Saturation pressure deficit for measurement at 2m height (kPa)
U_2 = Wind speed at 2m height (ms^{-1})
Δ = Slope of vapor pressure curve (k Pa °C)
γ = Psychometric constant (k Pa °C)
900 = Coefficient for reference crop (Kj Kg day^{-1})
0.34 = Wind coefficient for the reference crop (S m^{-1})
G = Soil heat flux (Mj m^{-2} day^{-1})

Depth of Applied Water; applied depth of irrigation water was calculated by using the following equation as mentioned by [15] as follows:

$$\text{Q} \times \text{T} = \text{dg} \times \text{A} \quad (4)$$

Where:
Q = applied discharge from the drip system (cm^3/min.)
T = time of irrigation (min.),
A = wetted area (cm^2)
Dg = applied depth of water (cm).

The wetted area under the emitter was assumed to be circle in a shape.

Irrigation Efficiency; the term of irrigation efficiency (IE) was used to define the effectiveness and the irrigation system in delivering all the water beneficially used to produce the crop [16] as follows:

$$\text{IE} = \frac{Totalwaterrequirements}{Totalappliedwater} \times 100 \quad (5)$$

Yield; the sum of all pickings crop's production was expressed as a total fruit yield [17]. It is important in all areas of plant production.

$$\text{Yield} = \frac{\text{The accumulation of fresh weight of the harvested fruit (kg)}}{\text{Total area of crop (m2)}} \quad (6)$$

Crop productivity; is the outcome of an entire suite of plant and environmental processes operating over the life of a crop to determine both yield and water use. Or the yield is a measure of crop's capacity to convert water into plant biomass or grain. The following equation was used for calculating the crop productivity (kg/m^3) [18].

$$\text{Crop Productivity} = \frac{\text{Yield (kg/m2)}}{\text{Total depth of applied water (m)}} \quad (7)$$

3. Results and Discussion

In the hot climate of Sudan, evaporative cooling systems have been commonly employed to reduce the interior ambient air temperature of greenhouses therefore, greenhouses were designed and installed with the high mean values of evaporative cooling efficiency (65%) and cooling effect (7°C) for the two seasons (2018 and 2019). Crop evapotranspiration (ETc%) and irrigation quantity significantly ($P \leq 0.05$) increased during the season 2018 (6.3mm/day and 0.26m^3, respectively) due to the increase in mean air temperature (28.6°C) inside the greenhouses. The reductions in ETc and irrigation quantity in season 2018 were 30% and 27.3%, respectively (Figure 2). Microclimate inside the greenhouses such as air temperature, relative humidity and wind speed were found to be the most important factors affected crop water requirements and the quantity of water applied. The results agreed with the result obtained by [19] who reported that, air temperature, relative humidity, wind, rainfall and air composition are the most important factors, which influenced the uniformity of the crop growth.

Greenhouses technology using different greenhouse covers offers a favorable environment for cucumber growth and production. Greenhouses covers significantly affected the yield and crop productivity of cucumber (Table 1). Single layer of polyethylene greenhouse cover (S-PE) gave the highest mean values of yield and crop productivity followed by double layers of polyethylene with 9cm air gap (D-PE) and single layer of polyethylene with green net and 50% opening (S-PE+N). The superiority of S-PE over other greenhouses covers in both seasons was attributed to the following and adopted irrigation schedule be side avoiding over irrigation. The results were in agreement with results obtained by. [7] who mentioned that, selecting single layer of polyethylene greenhouse cover following good management practices and irrigation schedule were significantly increased yield and crop water productivity.

Yield and crop productivity in season 2019 were increased ($13.6 kg/m^2$ and $24.3 kg/m^3$) comparing to season 2018 ($11.0 kg/m^2$ and $21.7 kg/m^3$). The reductions in yield and crop productivity in season 2018 were 19.1% and 23.4% (Figure 3). The reduction in crop productivity was due to the huge quantities of water applied by the irrigation systems during the season as mentioned by [15]. The results agreed with the result obtained by [4] who revealed that, a crop consuming less water with higher yield is more efficient than crop consuming more water with low water productivity.

Table 1. *Effect of greenhouse covers on the yield (kg/m^2) and crop productivity (kg/m^3) of cucumber.*

Greenhouse covers	**Season 2018**			
	Irrigation Efficiency (%)	**Applied water (m^3)**	**Yield (kg/m^2)**	**Crop productivity (kg/m^3)**
S-PE	85 ^{a}	0.250 ^{c}	13.3 ^{a}	23.4 ^{a}
D-PE+N	80 ^{b}	0.260 ^{b}	9.20 ^{b}	21.0 ^{b}
D-PE	81 ^{b}	0.273 ^{a}	10.7 ^{b}	20.8 ^{b}
Average	80.2	0.260	11.01	21.7
LSD	0.6	0.009	1.8	0.9
Season 2019				
S-PE	89 ^{a}	0.181 ^{c}	15.1 ^{a}	25.3 ^{a}
D-PE+N	86 ^{b}	0.190 ^{b}	12.7 ^{b}	23.6 ^{b}
D-PE	85 ^{b}	0.197 ^{a}	13.0 ^{b}	24.1 ^{b}
Average	87	0.189	13.60	24.3
LSD	1.7	0.005	1.3	1.1

Mean followed by the same letter (s) in the same column are not significant difference at $P \leq 0.05$.

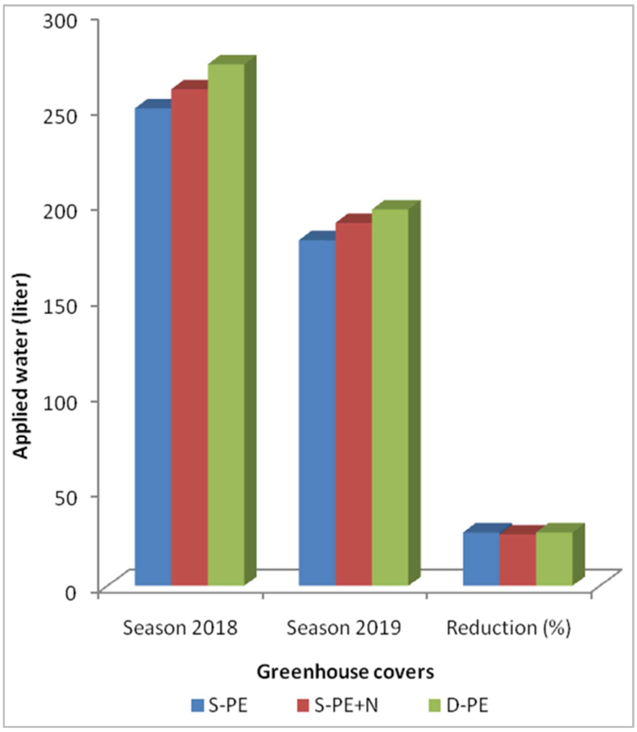

Figure 2. *Irrigation water applied in two seasons.*

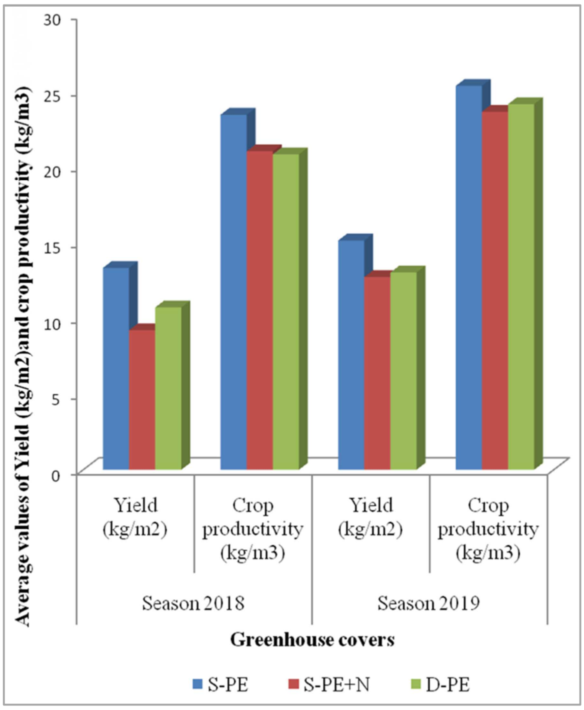

Figure 3. *Yield (kg/m^2) and Crop Productivity (kg/m^3) of Cucumber in Two Seasons.*

4. Conclusion

In the hot climate of Sudan, greenhouses technology is still a challenge to be monitored and adopted to avoid overheating air temperature inside the greenhouses and improving the crop water productivity. Greenhouse technology covered by single layer of polyethylene (S-PE) significantly ($P \leq 0.05$) increased the yield (15.1 kg/m^2) and crop productivity (25.3 kg/m^3) of cucumber as comparing to single layer of polyethylene with green net 50% opening (S-PE+N) which ranked the least (9.20 kg/m^2 and 20.8 kg/m^3, respectively). Therefore, under the lower crop water productivity of Sudan dry land conditions, greenhouse technology covered by S-PE with high efficiency of evaporative cooling system should be followed and adopted.

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