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RESEARCH ARTICLE

RESPONSE OF SUNFLOWER CROP TO DIFFERENT LEVELS OF SOIL MOISTURE DEPLETION

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Abstract

The amount of water utilized by the plant has a significant impact on its yield. In this regard, yield response factor (K_y) permits measuring yield decline as a function of evapotranspiration. As a result, the purpose of this study was to calculate K_y for the sunflower crop grown in North Nile Delta, Egypt and to calculate economic water productivity. Seasons 2021 and 2022 were studied. The experiment used a complete randomized block design with three replicates. W_1 (50-55%), W_2 (55-60%), and W_3 (60-65%) maximum allowable depletion of available soil moisture (MAD of ASW) treatments were used. In total, the average two seasons (0.52 and 0.61) found for sunflower crop under W_2&W_3, respectively, demonstrated its strong sociability to water deficit. Its yield is substantially impacted by water availability, with average 0.65 & 0.47% loss in yield for every 1% reduction in evapotranspiration with w2 and w3 treatments, respectively. The treatment without stress, w1 (50-55% MAD of ASW), yielded the highest grain yield. However, after considering water and irrigation costs, it could conclude that other stressed treatments, W_2&W_3, were more cost-effective.

Introduction:-

Sunflower is a commonly cultivated crop known for its oil-rich seeds and versatile uses. Egypt's demand for sunflower oil is expected to remain consistent, with a projected increase in the cultivated area of oil crops. This is due to the country's increasing population and individual consumption rates of food oils, as well as the lack of cultivated areas for oil food crops. The country's imports of sunflower oil are also expected to continue, with a focus on the main import sources such as Ukraine, Argentina, and the Russian Federation. However, there is a need for increased self-sufficiency in oil production to meet local consumer requirements and reduce the food gap (El-Elsharkasy, et.al. 2023 and Ahmed Rashda, 2023).

The availability of soil moisture plays a crucial role in the growth and yield of the sunflower crop. Due to its strong capacity for extracting water from the subsoil, sunflower is frequently described as a drought-tolerant crop (Garcia–Vila and Fereres 2012). Because of its well-developed root system, it has good capability to survive temporary wilting and drought.

Ren et al. (2018) stated that sunflower can reduce its water use by up to 20% without significantly affecting production. However, sunflower is susceptible to water stress during critical stages, such as early flowering and seed filling (Ebrahimian et al., 2019).

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Inzunza-Ibarra et al., (2022) found that the highest water use efficiency (WUE) in sunflower was achieved when the crop consumed 60% of available soil moisture, resulting in a grain yield of 5.5 t·ha^{-1}. Ahmed (2012) suggested that reducing irrigation to 75% of the control treatment did not significantly affect grain yield, indicating potential water savings. Merrill (2004) compared water use and soil water depletion among different crop species and found that sunflower was the highest water user. Rania& Bialy (2018).proved that, increasing level of soil moisture progressively decreased irrigation water productivity of sunflower.According to Soriano et al. (2004), increasing the percentage of available soil moisture depletion (ASMD) led to a decrease in both the seasonal evapotranspiration (ETC) of sunflower and the efficiency of water use (WUE).

Economic water productivity, which encompasses both physical and economic aspects of water use, is influenced by the amount of water applied in various agricultural contexts (Amarasinghe et al., 2020; Rodrigues et al., 2023; Hassen et al., 2017). The computation of economic water productivity involves the division of economic yield by the amount of irrigation water applied, providing a measure of the economic returns derived from the water utilized in agricultural production (Poonia et al., 2022; Al-Said et al., 2012). This highlights the significance of maximizing economic water productivity to ensure efficient conversion of water into valuable agricultural outputs.

Accordingly, the problem of this study can be summarized in the lack and inadequacy of experimental studies to evaluate the effect of different levels of soil moisture depletion on the response of sunflower crop whichclassified as drought tolerant, particularly in conditions of water scarcity and the wide food gap, including oily food products, and this is important. Especially, in context of the fact that Egypt is currently importing more oily food products to meet the needs of its growing population.

The objective of this research was to investigate whether the optimization of soil moisture depletion levels can enhance water productivity and efficiency in sunflower culivated in the North Nile Delta, Egypt. Throuh the assessing some economic indicators and devising a strategy to maximize grain yield per unit of water.

Materials and Methods:-

Experimental Site, Soil and Weather Conditions

The field experiment was conducted during two successive summer seasons of 2021 and 2022 at the Experimental Sakha Agricultural Research farm, 31° 07\\ N and 30° 57\\Kafr El-Sheikh governorate, Agricultural Research Center, Egypt, to study the effect of soil moisture depletion expressed as depletion available soil moisture on yield response factor economic water productivity of sunflower (Helianthus annuus L.) cultivar Sakha 53. The daily meteorological data for Kafr El-Sheikh area during the two growing seasons (2021/2022) were presented in Table (1).

The soil samples collected were analyzed to assess some soil chemical and physical characteristics as well as available nutrients. The hydrometer method was used to determining soil particle size distribution and soil textural class., as reported by Bouyoucos, (1962), with sodium hexametaphosphate as a dispersion agent. According to Richards (1954), soil bulk density was calculated using the undisturbed soil column. Wilting point was calculated using Stakman and Vanderhast (1962), while field capacity was calculated using Richards (1954).

EC was calculated as dSm-1 in soil paste extract using an electrical conductivity meter at 25 C˚, and organic matter content was assessed according to Jackson (1973), soil pH was evaluated in a (1:2.5) soil: water suspension using pH meter.

According to Olsen (1965), available phosphorus was extracted using sodium bicarbonate ($NaHCO_3$) 0.5 M at pH 8.5 and measured using the ascorbic acid technique published by Watanabe and Olsen andSommers, (1965). According to Cottenie et al. (1982), available potassium was extracted using ammonium acetate (CH_3COONH_4) 1N at pH 7.0 and measured using a flame-photometer. Total available nitrogen was extracted using potassium chloride 1N (KCl) and calculated using Jackson's (1973) semimacrokjeldahl technique.

The results showed that soil characteristics of the experimental field are clayey in texturewith 25.85 % sand, 24.65 % silt, and 49.5% clay. Soil pH value was 8.04 and reflects to the alkalinity of studied area. EC valuewas low, 2dSm^{-1}. The field capacity, permanent wilting point, available water, and bulk density were 37.57 %, 20.42 %, 17.15 % and 1.21 g cm^{-3}, respectively. Organic matter content was 1.82%. Available NPK were 18.72, 6.52 and 272.35 mgl^{-1}, respectively.

Table 1:- Weather parameter values of Kafr El Sheikh Area over two years during the crop period.

Month	temperature (°C))		average	Relative humidity (%)	Wind speed (m/sec)	ET_0 (mm/day)
	Maximum	Minimum				
2021						
June	36.9	19.8	28.4	50.1	3.0	8.36
July	39.7	22.8	31.2	51.0	2.9	8.61
August	40.4	23.5	31.9	52.8	2.5	8.09
September	36.3	21.9	29.1	55.4	2.9	6.89
2022						
June	39.0	22.1	30.5	51.0	2.9	8.8
July	38.99	22.06	30.5	51.05	2.88	8.53
August	38.58	23.16	30.9	54.01	2.75	7.78
September	37.05	22.15	29.60	54.57	2.71	6.99

SourceNASA POWER | Data Access Viewer

Agronomic practices and data collected

A complete randomized block design with four replicates was used in the study four irrigation treatments, which consisted of irrigation scheduling based on maximum allowable depletion (MAD) of the total available soil water (ASW), namely, W_1 (50-55%, control), W_2 (55-60%), and W_3 (60-65%) of (MAD) of (ASW) The sunflower (cultivar Sakha 53) was planted on a total surface area of 525 m^2 (14 × 15.5 m) on June 18, 2021, and June 11, 2022. With a spacing of 0.70 × 0.30 m, the plant density was 4.8 plants per m^2. Recommendations for fertilization and proper land preparation were followed. It attained physiological maturity 30 days following head formation, and harvesting took place on September 18, 2021, and September 15, 2022, respectively. The total yield from each plot was recorded, with the seed moisture content being kept at roughly 8.5%.

Irrigation and soil moisture monitoring

The irrigation water used was measured using a flow meter put in the irrigation pump's water delivery unit. Soil water storage was monitored gravimetrically (Michael, 2009). in each plot on a regular basis at intervals of three days. The quantity of soil moisture that was accessible was utilized to calculate irrigation schedules.From the day of sowing (DAS) until the sunflower plants were fully established; all irrigation treatments received the same amount of water. After then, the aforementioned irrigation regimes were used to irrigate the plots. Three levels of MAD of ASW 50-55%, 55-60%, and 60-65% were applied in the top 0–30 cm of the soil in this irrigation schedule to initiate irrigation and replenish the soil water to the field's capacity. When the AWC in the top 30 cm of soil layer goes below 40%, for example, a MAD of 60% indicates that irrigation has been initiated to replenish the reservoir up to field capacity in this layer.

The relationship between crop yield and water use (Crop Response Factor Ky)

In the late 1970s, FAO addressed the relationship between crop yields and water usage, providing a simple equation in which relative yield decrease is tied to the equivalent relative reduction in evapotranspiration (ET). The yield response to ET is specifically stated as (Doorenbos and Kassam, 1979):

$$\left(1-\frac{Y_a}{Y_x}\right)=K_y\left(1-\frac{ET_a}{ET_x}\right)$$

Where,

Y_x and Y_a are the maximum and actual yields,

ET_x and ET_a are the maximum and actual evapotranspiration, and

K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses

Water productivities (IWP, WP, Kg/m^3) and Economic water productivity (EWP, \$/m^3)

Seed yield divided by seasonal ET and the total amount of seasonal irrigation water applied were used to determine water productivity (WP) and irrigation water productivity (IWP) (Sezen, et al., 2011). Since a farmer wants to maximize revenue and profit, it is important to consider the economic aspects of WP. The following formula defines the EWP, which is represented as \$/m^3, by replacing the numerator with the monetary value of the yield that was reached.

$$\mathrm{EWP}=\frac{\mathrm{Value}(Y_a)}{\mathrm{TWU}}$$

Statistical Analysis

ANOVA was used to statistically process the data, and the results were validated using the LSD test. The statistical software STATISTICA 8.0, Series 608c (StatSoft Inc. USA) was used for the analysis

Results:-

Irrigation and Relative Water Saved

Data on irrigation and the relative water saved in each treatment are shown in the table (2). As soil moisture depletion increased, the quantity of seasonal irrigation was reduced. In 2021, the irrigation amount among treatments ranged from 4837.29 to 6404.42 m^3ha^{-1}, and in 2022, it ranged from 5193.05 to 6728 m^3ha^{-1}. Compared to treatment W_1 (45% of MAD of ASW), treatment W_2 (55% of MAD of ASW) and W_3 (65% of MAD of ASW) saved 12 &24.5 and 10.2% & 18.9 % of irrigation, in 2021, and 2022, respectively.

Table (2):-Irrigation water applied (m^3ha^{-1}) and the relative water saved (%).

Treatments	Water Applied (m^3ha^{-1})		Relative Water Saved (%)	
	2021	2022	2021	2022
W_1(50-55%)	6404.42	6728.0	-	-
W_2 (55-60%)	5636.23	6045.08	12.0	10.2
W_3 (60- 65%)	4837.29	5193.05	24.5	18.9

Soil water content variation

Figure 1 shows the temporal change of soil moisture of the first experimental season, which was carried out in 2021. The patterns found in the results of the other season were remarkably similar.

Prior to irrigation, all treatments had similar soil water contents at the 90 cm soil layer; nevertheless, variance was noted as a result of the various irrigation treatments. Fig. 1(W_1) shows the temporal fluctuation of soil moisture in sunflower irrigated with 50-55% MAD of ASW (W_1). The largeness of the cyclic change in soil water was only large in the upper 0–30 cm layer and low in the lower levels, suggesting that underthis treatment, the majority of the water needed by the plant was taken up from the top layer.

The results also showed that the plant took up some water from the lower layers, or between 30-60 and 60-90 cm, when it reached the later phases of growth and its roots had fully developed.

Soil water was drawn from all root zone levels under the irrigation with 55-60% MAD (W_2); however, the majority of the extraction occurred from the 0–30 cm, and 30–60 cm soil layers Fig. 1(W_2), because W_2 is drier than schedule W_1, there was a greater degree of cyclic variation in soil layers between 0 -30 cm and between 30 -45 cm when compared to similar layers in W_1. Compared to W_1, this irrigation treatment had a lower irrigation frequency. Under 60-65% MAD of ASW (W_3), there was a significant amount of soil water variation Fig. 1(W_3). The cyclic variation was higher in the 0–30 cm, and 30–60 cm soil layers than in the 60-90 cm soil layer. Due to soil surface evaporation and transpiration from mature plants, water was lost through the topmost soil layer more quickly. Treatments W_1 and W_2 stayed within the available soil moisture (ASW) zone until reached 50-60% MAD of ASW. Soil moisture fluctuated within the ASW in treatment W3, until 46 DAS, then dipped extremely close to the wilting point at 70 DAS

Grain Yield – MAD of ASW Relation

For each growing season, the allowable depletion of available soil moisture at different levels has statistically no significant effect on the grain yield of sunflower during the two growing seasons as shown in Table 3. The data demonstrates that a decrease in the application of irrigation water corresponded to a decline in grain yields. Notably, the fully irrigated treatment (W_1) produced the highest yields, averaging 3833.48 and 3746.23 $kgha^{-1}$ in 2021 and 2022respectively, while the treatment (W_3) yielded the lowest, with an average of 3543.07 and 3503.95 $kgha^{-1}$ in 2021 and 2022. The yields for the other treatment (W_2) fell in between these two treatments; it reached 3631.46 and 3587.25 in the 2021 and 2022 seasons respectively. The decrease in yield for W_2 and W_3 during the 2021 and 2022 seasons respectively, amounting to 5.27 and 4.24% and 7.58 and 6.47%, respectively. A strong negative linear correlation (R^2 = 0.99 in both seasons) was observed between the yield and maximum allowable depletion, as depicted in Figure 2. The seed yield demonstrated a linear response to the MAD of ASW level, whereby increasing in MAD of ASW level resulted in a decrease in seed yield.

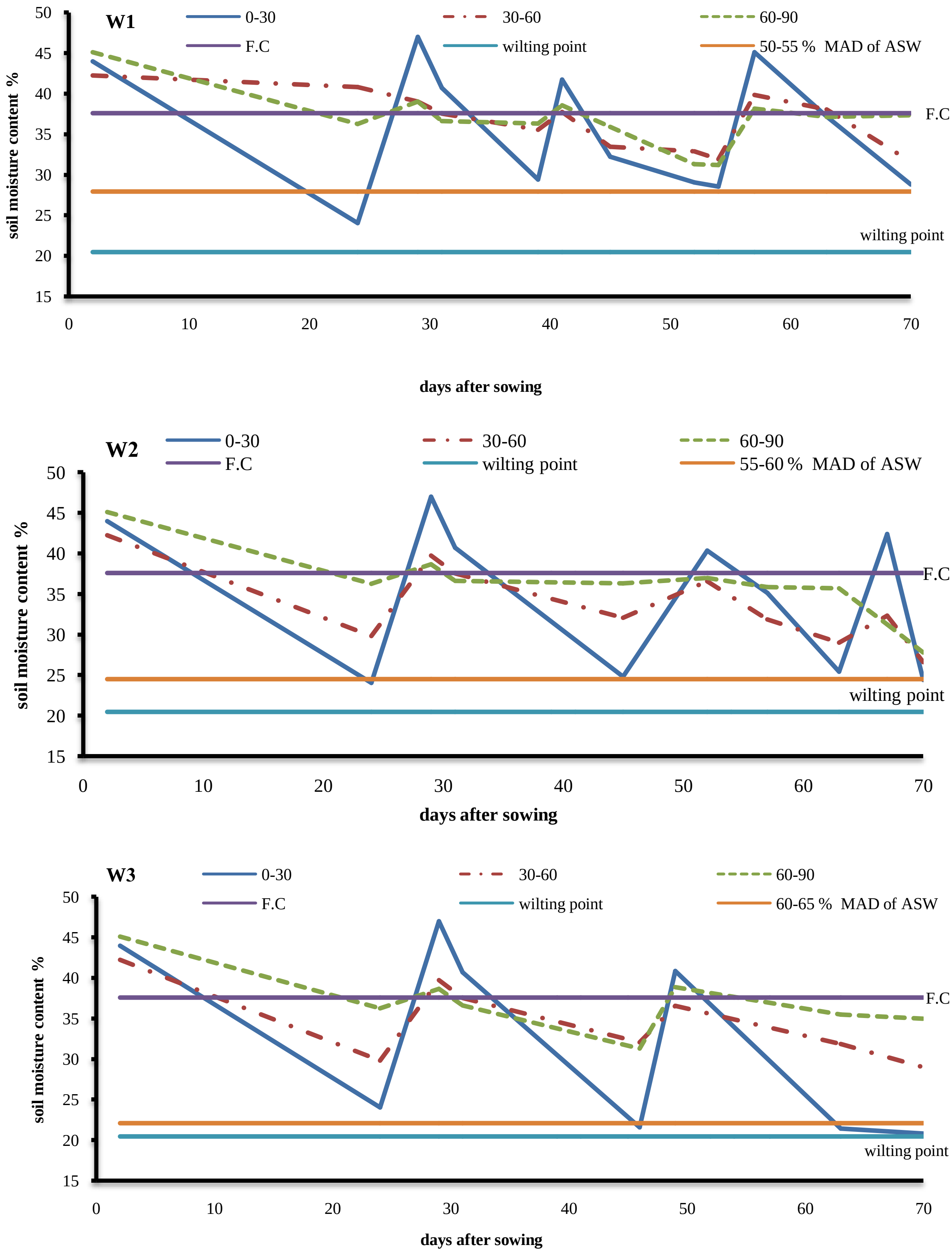

Figure1:- Changes in soil moisture in the sunflower root zone at 50–55% MAD (W1), 55–60% MAD (W2), and 60–65% MAD (W3) of ASW in the 2021 season.

Table (3):- The production of sunflower grains as affected by soil moisture depletion.

Treatment	Seed yield (kgha^{-1}.)		Yield reduction %	
	2021	2022	2021	2022
W_I	3833.48	3746.23		
W_2	3631.46	3587.25	5.27	4.24
W_3	3543.07	3503.95	7.58	6.47
F-test	N.S	N.S		

N.S not significant at 5% level of probability.

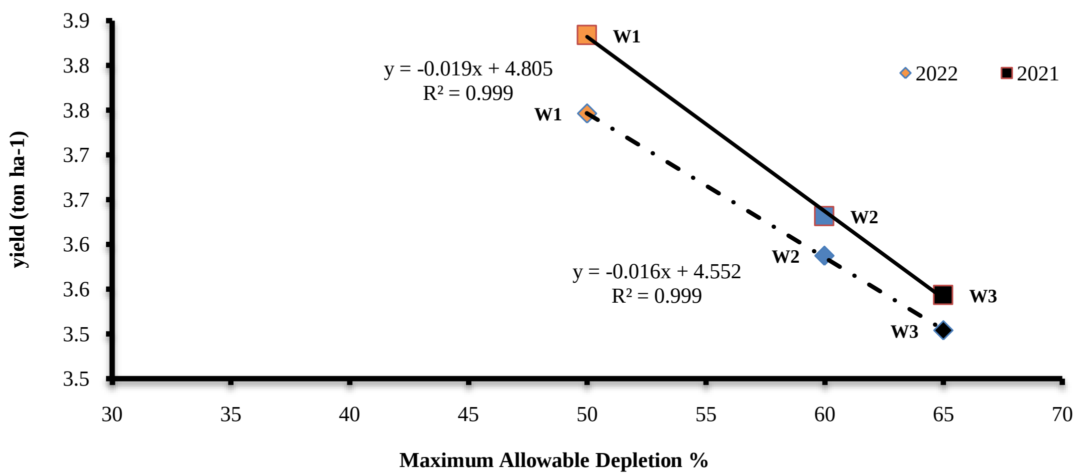

Figure2:- The relation between Sunflower Grain Yield (Y) and Maximum Allowable Depletion (MAD) of Available Soil Water (ASW).

Crop evapotranspiration and water productivities (WP& IWP)

The seasonal ET varied in both years for the different irrigation treatments. Crop water use for treatments W_1, W_2, and W_3 was 3805.51, 3453.66, and 3372.33 m^{3}ha^{-1}, respectively, in 2021 season, while in the 2022 season the respective values for these treatments were 3720.10, 3375.25, and 3281.11 m^{3}ha^{-1}. The marked differences observed among the treatments, can be attributed to the large difference in irrigation water applied. Table 4 shows the estimated WP and IWP for each treatment during both cropping seasons. During the 2021 season, the WP ranged from 1.01 to 1.05 kg m^{-3} and from 1.01 to 1.07 kg m^{-3} in the 2022 season. In the first season, the highest and lowest WP values were seen for treatments w2 &w3 and W_1, in the two seasons respectively. The estimated IWP ranged From 0.60 to 0.73 kg m^{-3} during the 2021 season and from 0.56 to 0.67 kg m^{-3} in the 2022 season. On average, the highest and lowest WP values were observed for treatment W_3 and W_1, in the two seasons respectively. The results show that W_3 utilized less water compared to W_1 and W_2, resulting in improved efficiency.

Table 4:- Water productivity (kg m^{-3}) and Irrigation water productivity (kg m^{-3}) of sunflower crop as affected by soil moisture depletion during two seasons.

Treatments	Yield (kg ha^{-1})	Water Consumptive Use (m^3 ha^{-1})	Irrigation Water Applied (m^3 ha^{-1})	Water Productivity (Kg m^{-3})	Irrigation Water Productivity (Kg m^{-3})
2021					
W_I	3833.48	3805.51	6404.42	1.01	0.60
W_2	3631.46	3453.66	5636.23	1.05	0.64
W_3	3543.07	3372.33	4837.29	1.05	0.73
2022					
W_I	3746.23	3720.10	6728.00	1.01	0.56
W_2	3587.25	3375.25	6045.08	1.06	0.59
W_3	3503.95	3281.11	5193.05	1.07	0.67

The Crop Yield Response Factor

The K_y values observed for the w2 and w3 treatments were 0.57 and 0.67, respectively, in the year 2021. In the subsequent year of 2022, these values were 0.46 and 0.55 for the same treatments, table (5). According toSteduto et al., (2012), in the event that the K_y value exceeds 1, the plant exhibits sensitivity to water deficiency and significant losses in production. Less yield reduction indicates that the plant can tolerate a water deficiency if the K_y value is less than 1. A linear relationship exists between yield and water deficit if the Ky value is equal to 1.

In our study, it was consistently observed that the K_y values were smaller than 1 across all irrigation treatments. Additionally, the analysis of w1 and w2 treatments revealed that the yield loss attributed to moisture depletion was insignificantly low.A water deficit of 9% and 11% under W_2 and W_3 treatments occurring during 2021season reduced the yield by 5% and 8% under aforementioned treatments respectivelySimilarly, during the 2022 season, a water deficit of 9% and 12% under the W_2 and W_3 treatments respectively resulted in a decrease in yield by 4% and 6% figure (3).

Table 5:- The relative yield reduction (1-Ya/Ym), the relative water consumptive use deficit (1-eta/etm) and the crop yield response factor (ky) during the two seasons.

treatments	Y_x (kg/ha)		$1-Y_a/Y_x$	ET mm		$1-ET_a/ET_x$	K_y
	Y_x	Y_a		ET_x	Et_a		
2021							
W_I	3833.48		0	380.6		0	0
W_2		3631.46	0.05		345.4	0.09	0.57
W_3		3543.07	0.08		337.2	0.11	0.67
2022							
W_I	3746.23		0	372.0		0	0
W_2		3587.25	0.04		337.5	0.09	0.46
W_3		3503.95	0.06		328.1	0.12	0.55

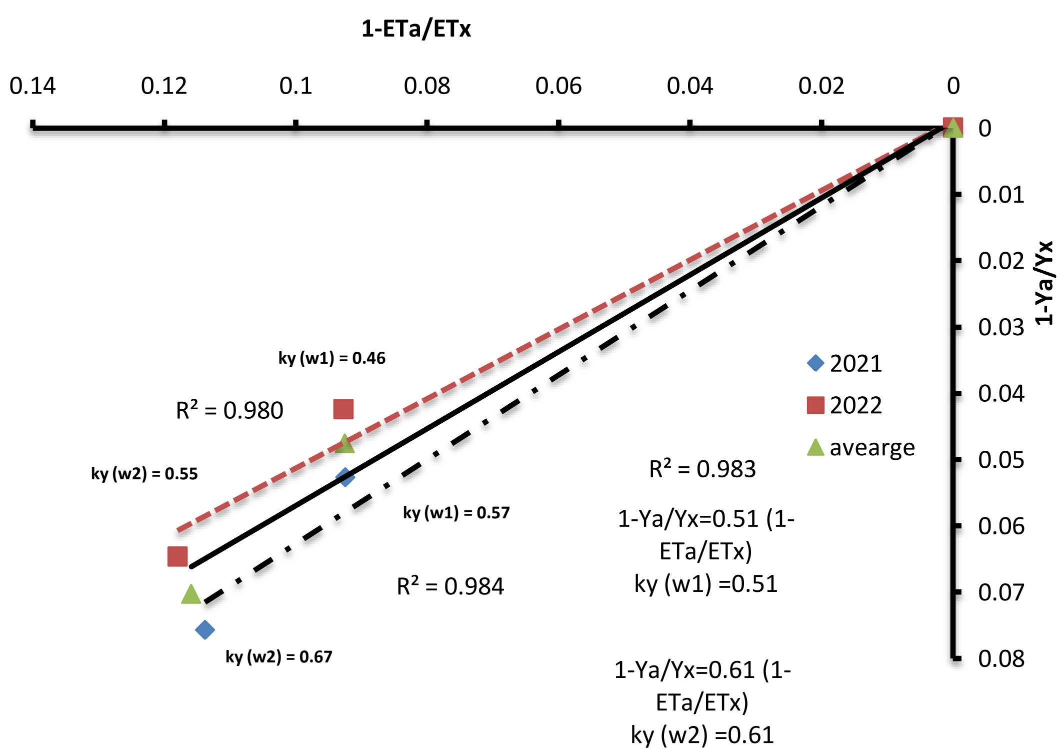

Figure 3:- Relation between relative ET deficit and relative yield reduction for sunflower.

Economic Evaluation

Economic analysis was carried out in water-limited situations. In this study, less water was used than was actually necessary, and the extra water could have been used to cultivate other areas. The highest net return (350.33&3759.30$ ha^{-1}) was obtained in treatment $W_1$by applying 50-55%MAD of ASW with 3.39% &13.58% and 5.51&8.40% increase from W_2 and W_3 treatments in 2021 and 2022 seasons, respectively. Similarly, total cost was found highest in W_1 compared to W_2 and W_3. Witch it reached (1730.43&1635.28 $$ha^{-1}$) in first and second seasons, respectively. While the lowest was found in treatment W_3which was lower than W_1 by about 6.36% and 2.02% in 2021 and 2022, respectively. This may be due to the cost of irrigation was higher in W_1than other treatments.

Economic water productivity (EWP) or water return refers to the economic benefits that farmers obtain in exchange for their irrigation investments. The values of economic water productivity (EWP) ranged from 0.05 to 0.06$$m^{-3}$ in 2021 season, and in 2022, it was ranged from 0.56 to 0.66 $$m^{-3}$ (Table 6). The highest EWP of 0.06& 0.66 $$m^{-3}$ was achieved at a 60-65% MAD of ASW level in the two growing seasons. On the other hand, the EWP for the 55-60% MAD of ASW level was estimated to be 0.06 and 0.59 $$m^{-3}$, in the first and second seasons, respectively. In contrast, the lowest EWP of 0.05& 0.56 $$m^{-3}$ was observed in farmers' practices (50-55% MAD of ASW), which can be attributed to significantly higher total costs.

The difference which is noticed between the net return through two years was due to the change of dollar ($) value in front of Egyptian pound (in 2021, $= 15.65 L.E & in 2022, $ = 19.51 L.E)

Table 6:- Effect of different levels of soil moisture depletion on economic indicators of Sunflower crop.

Treatments	Total Return ($ ha^{-1})	Costs ($ ha^{-1}))	Irrigation Water Applied (m^3 ha^{-1})	Net Return ($ ha^{-1}))	Water Return ($ m^{-3})
2021					
WI	2080.75	1730.43	6404.42	350.33	0.05
W2	1971.10	1632.65	5636.23	338.45	0.06
W3	1923.12	1620.38	4837.29	302.74	0.06
2022					
WI	5394.57	1635.28	6728	3759.30	0.56
W2	5165.64	1613.52	6045.08	3552.12	0.59
W3	5045.69	1602.31	5193.05	3443.37	0.66

Discussion:-

Soil moisture depletion has a remarkable effect on the amount of water applied and saved for sunflower. According to some sources, sunflower responds to irrigation with yield increases of 100 to 200% over dryland yields common on droughty soils and in extremely dry years. Sunflower also adapts to a wide range of soils and climatic conditions. In one study, three treatments were compared, with different levels of soil moisture depletion: 30% 50% and 70% depletion. The total volume of water applied to the crop was highest in 30% (9689 m^3 ha^{-1}) and lowest in 70% depletion (2045 m^3 ha^{-1}), Rajesh, et al., (2021).

Our findings align with the previous research conducted by Soriano et al., (2004), who reported a linear relationship between irrigation and sunflower seed yield (R^2 = 0.64), and with Marco, et al., (2022) who investigated the relationship between yield and soil moisture depletion levels on sunflower, the highest grain yield and water use efficiency (WUE) were recorded at 60% available soil moisture (ASM) depletion.

In a study found that the highest water use efficiency (WUE) of sunflower (0.922 $kg \cdot m^{-3}$) was achieved when the crop consumed 31.4 cm of water in the first stage and 28.12 cm of water in the second stage, with 58.8% and 60.5% of available soil moisture, respectively Marco, et al., (2022) .These results suggest that as soil moisture depletion increases, the amount of water applied to the crop decreases, but the water use efficiency may increase. Overall, the results indicate that sunflower plants can exhibit increased water use efficiency under severe water deficit conditions, potentially as a survival mechanism in arid regions

The values of k_y were far below the value of 0.95 as reported by Doorenbosand Kassam,(1979) but supported the results of some studies shown that the yield response factor (k_y) was obtained as 0.20 for the total growing season Marco, et al., (2022), and the results of Erdem and Delibas (2003) who stated that the sunflower is less susceptible to stress caused bya lack of moisture in the soil (k_y 0.78-0.85), this may be due to various factors such as crop variety, agro climatic conditions, and growth stages. For example, different studies may use different methodologies and approaches to determine K_y values, which can also contribute to variations in the reported values (Garg., et al., 2014). Therefore, it is important to consider these factors when interpreting and comparing K_y values for the same crop.

The results of the economic water productivity of crops, such as soybean sunflower and rice, can be positively impacted by lower amounts of irrigation water, leading to increased economic returns per unit of water applied (Rodrigues et al., 2023; Hassen et al., 2017). Conversely, it has been argued that the concept of increasing water productivity may not always align with the economic goals of individual farmers, particularly in terms of net revenue and subsistence production (Wichelns, 2015). However, research has also emphasized the importance of considering economic benefits alongside water productivity to enhance water resource efficiency and overall economic gains (Ren et al., 2022).

Conclusion:-

There were significantly fewer irrigation events in total when comparing MAD 50-55% to MAD 55-60% and MAD 60-65%, which could indicate a lower production cost. Our data suggest that a deficit irrigation rate of MAD 55-60% and MAD 60-65%, might generate acceptable yield levels while saving water and enhancing IWP for grain yields. The treatment without stress, W_1 (50-55% MAD of ASW), yielded the highest grain yield. However, after considering water and irrigation costs, it could conclude that other stressed treatments, W_2&W_3, were more cost-effective. This result confirmed that sunflower was not sensitive to soil water deficit during the total growing period

In summary, economic water productivity is indeed influenced by the amount of water applied, with lower irrigation water levels often leading to improved economic returns per unit of water utilized. However, the relationship between water application and economic water productivity is multifaceted, encompassing various factors such as irrigation scheduling, crop planting structures, and the integration of economic benefits. Therefore, a comprehensive understanding of these dynamics is essential for maximizing economic water productivity in agricultural systems.

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