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Efficient Use of Water Regime and Nitrogen Rates Applied to Sesame Grown on Low Fertile Sand Soil with Aid of ^{15}N Stable Isotope

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ABSTRACT

In arid and semiarid regions, the plants suffered from water and nutrient deficiency, therefor the need for proper management of both irrigation water and nutrient especially nitrogen was obligate. The current study aimed recognize the most proper rate of nitrogen fertilizer in conjunction with water regime that achieve the best production of sesame crop grown on poor fertile sand soil. In this regard, a field experiment was carried out on sesame plants during 2020 summer season following the split-plot design, where the main plots comprised irrigation water regime (W) as a percentage from ETc (70, 85 and 100%) and the sub-plots comprise nitrogen fertilization rates (N) (50.0, 60.7 and 71.4 kg N ha^{-1}). Results indicated that the highest seed yield, N uptake by seeds, ^{15}N derived from fertilizer (Ndff), ^{15}N yield derived from fertilizer (Nydff), fertilizer ^{15}N recovery (FNR), fertilizer ^{15}N remaining in the soil (N_{rem}) and N loss were given by treatments receiving the moderate levels of both water and N fertilizer. Moreover, the combined treatment of high water regime and low N rate enhanced the nitrogen use efficiency (NUE), while the highest water use efficiency (WUE) was detected under conditions of low irrigation regime and moderate N rate. Therefore, application of 357.4 m^3 ha^{-1} irrigation level and 60.7 kg N ha^{-1} rate was recognized as the most proper management practice achieved the efficient water-nitrogen combination that minimized N loss by any mechanism.

***Keywords*: Sesame, Yield, N uptake, NUE, WUE, Fertilizer N recovery, ^{15}N-Isotope dilution.**

INTRODUCTION

Sesame is considered as one of the most important oil crop in the world because its seeds have high contents of oil and protein (Wei *et al.,* 2022). In Egypt, most of the seed production is consumed as edible products such as Tehena, Halawa tahiniya and bakery products (Ali *et al.*, 2023). The total production of edible oil is about 10% of the consumption in Egypt. Therefore, many attempts are being made to raise total production of oil crops particularly sesame for narrowing oil deficiency gap. Today, India and China are the world's largest producers of sesame, followed by Myanmar, Sudan, Uganda, Nigeria, Pakistan, Tanzania, Ethiopia, Guatemala, Turkey and Egypt (Cheong *et al.,* 2013). In Egypt expanding area under sesame should be taken in newly reclaimed sandy soils, which is facing many problems like low fertility, poverty and high loss of nutrients by leaching (Wacal *et al.,* 2021).

The decline of sesame yield (*Sesamum indicum* L.) in semi-arid regions is mainly attributed to lack of production inputs, inadequate management and occurrence of abiotic stresses (Ahmed *et al.,* 2023). Optimization of irrigation water and fertilization practices were found to be affective on seed yield production and oil quality of different sesame genotypes in Iran (Gholamhoseini, 2022). Thus, to achieve maximum yield and income profit per hectare, the available water should be used efficiently (Xiao *et al.,* 2019). Traditionally, agricultural research has focused primarily on maximizing total production. In recent years, the focus has been shifted to the factors limiting production systems, including the availability of land or water (Pawlak and Kołodziejczak, 2020).

Nitrogen fertilization has been intensively applied in agriculture to alleviate nitrogen limitation and boost food production over the past decades (Hu *et al.,* 2023, Kamran *et al.,* 2023). As an important nutrient, nitrogen is assimilated by plants through complex processes such as nitrogen fixation, nitrogen deposition. Limited nitrogen fertilization impedes plant growth, while excessive nitrogen would leach into water bodies and releases into the atmosphere in the form of ammonia, causing severe environmental issues (Chen *et al.,* 2023, Liu *et al.,* 2023). In addition, nitrogen fertilization could change the local hydrologic and carbon cycles (Liang *et al.,* 2020).

The ^{15}N labeling method is considered as the only direct means of measuring N uptake from the applied fertilizer and the most reliable way to follow the flow and fate of N in plant-soil systems (Sturm *et al.,* 2010). Thus, this technique has been used extensively by many researchers (Cao and Yin, 2015; Zhang *et al.,* 2012). Accordingly, the current study aims at assessing sesame response to different water regimes and N fertilization rates and its effect on the balance between irrigation regime and proper N fertilizer rate. Reflections of such management practices on yield production and its efficient uses by sesame crop were accounted.

MATERIALS AND METHODS

A field experiment was conducted on sesame (*Sesamum indicum* L.) cv. Giza-32, grown on a sand soil at the experimental farm of the Nuclear Research Center

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(NRC), Egyptian Atomic Energy Authority (EAEA), Abou-Zaabal, Egypt during 2020 summer season under drip irrigation system. Experimental treatments were distributed in a split-plot design. Main plots were assigned to irrigation (W): three levels as percent of Et_c (420.5 $m^3 ha^{-1}$) represented 70% (W_1), 85% (W_2) and 100% (W_3); sub-plots comprised of three N rates as percent of a recommended 71.4 kg N ha^{-1}, 70% (N_1), 85% (N_2) and 100% (N_3). Irrigation water required (100% of ETc) during the growth duration was presented in Table 1. Recommendation about N rates are extracted from previous work (Hekal and Mousa 2023). N was applied in urea form at 4 splits (10, 30, 30 and 30 % starting 2 weeks after seeding with intervals of 2 weeks between. The plot area was 5 m^2 (0.625 m x 8 m). Seeds were sown on April 19th 2020 and the harvest was on July 23rd 2020 (94-day). A micro-plot of 0.19 m^2 was located in the middle of each plot for application of ^{15}N labeled urea (2% ^{15}N atom excess). All plots received the recommended rate of P and K as follow: 24 kg P ha^{-1} (as ordinary Ca-superphosphate) with soil preparations and 80 kg K ha^{-1} (as K-sulphate) in two equal splits (4 and 8 weeks after sowing). A foliar spray with Fe, Mn, Zn and Cu micronutrients was processed with water solution containing 1300 mg of each (as chelated forms). Rate of spray was 1200 L ha^{-1} done twice, first 4 weeks after sowing and the second 2 weeks after the first application.

Table 1. Amounts of recommended irrigation water (100 % of ETc) added (mm) throughout ~~of~~ sesame growth season

Period		Growth stage	Crop coefficient (Kc)	Applied water (mm)	Operation agates (min)
Duration	No. of days				
19/4 – 21/4	3	Initial (20 days)	0.35	18.8	53
22/4 – 25/4	4			42.3	119
26/4 – 28/4	3			16.8	47
29/4 – 2/5	4			30.6	86
3/5 – 5/5	3			19.5	55
6/5 – 9/5	4	Development (30 days)	0.73	72.0	203
10/5 – 12/5	3			50.6	142
13/5 – 16/5	4			104.8	295
17/5 – 19/5	3			68.2	192
20/5 – 23/5	4			102.2	288
24/5 – 26/5	3			42.1	118
27/5 – 30/5	4			77.2	217
31/5 – 2/6	3	Mid-season (40 days)	1.1	84.7	238
3/6 – 6/6	4			137.4	386
7/6 – 9/6	3			80.5	226
10/6 – 13/6	4			149.9	422
14/6 – 16/6	3			84.1	236
17/6 – 20/6	4			149.5	421
21/6 – 23/6	3			88.2	248
24/6 – 27/6	4			142.9	402
28/6 – 30/6	3			78.3	220
1/7 – 4/7	4			138.8	390
5/7 – 7/7	3	Late-season (20 days)	0.25	19.6	55
8/7 – 11/7	4			29.8	84
12/7 – 14/7	3			17.0	48
15/7 – 18/7	4			29.2	82
19/7 – 21/7	3			17.4	49
	94			1892.4 mm $season^{-1}$	

Surface soil sample (0-30 cm) was taken to define chemical and physical properties (Table 2) using methods described by Carter and Gregorich (2008). Seeds were taken after harvest, air dried, crashed and then digested and prepared for chemical determinations processed according to Estefan *et al.* (2013).

Table 2. Some physico-chemical characteristics of the experimental soil

Sand(%)	Silt (%)	Clay (%)	Texture*	pH (1:2.5)	EC (dSm^{-1})	OM (g kg^{-1})	$CaCO_3$ (g kg^{-1})
96.0	4.0	0.0	Sand	7.19	2.14	0.24	0.0
Available nutrients mg kg^{-1}							
N	P	K	Fe	Mn	Zn	Cu	
0.29	0.05	0.95	3.01	0.01	0.10	0.18	

***Texture: according to the international Texture Triangle (Moeys, 2016). Extractants for available nutrients: KCl (N); NH4HCO3-DTPA (P, K, Fe, Mn, Zn and Cu); EC in paste extract.**

Nitrogen uptake was estimated by using the following equation:

Nitrogen uptake (kg ha^{-1}) = N content (%) × Dry yield (kg ha^{-1}) ………………………… (1)

^{15}N analysis was carried out using automated emission spectrometer (Fischer NOI-6 PC). The portion of nitrogen derived from fertilizer (%Ndff), Ndff (g kg^{-1}) and nitrogen yield derived from fertilizer (Nydff) present in the relevant plant part(s) were calculated in view of the ^{15}N atom excess (^{15}N a.e.) in materials according to the following equations:

Ndff (%) = (^{15}N a.e. in plant / ^{15}N a.e. in fertilizer) …………...……….. (2)

Ndff (g kg^{-1}) = Ndff (%) × N content (g kg^{-1}) …………………………. (3)

Nydff (kg ha^{-1}) = (Ndff (g kg^{-1}) × Dry Yield (kg ha^{-1})) / 1000 ………… (4)

Efficiency parameters for applied N and irrigation water:

Efficiency parameters for applied N and irrigation water concern the followings: a: FNR (Eq. 5), b: NUE (Eq. 6), and c: WUE (Eq. 7). The FNR is the amount of fertilizer N within the crop as a % of the amount of applied N (Bruulsema *et al.*, 2004). The NUE according to Hirel *et al.* (2011) is expressed as the yield obtained per unit of available N in the soil (supplied by the soil + N fertilizer). However, in the current study NUE is the crop yield, in kg, obtained per one kg of applied fertilizer N. The WUE is the grain yield obtained per one cubic meter irrigation water (Zhang *et al.*, 2005). The equations used for calculation of the 3 parameters are as follows:

FNR (%) = Ndff (kg ha^{-1}) / rate of applied N (kg ha^{-1}) x100 ……………… (5)

NUE (weight of grains per kg of applied N) = grain yield "kg ha^{-1}"/ applied N "kg ha^{-1}". .. (6)

$$\text{WUE (kg m}^{-3}) = \frac{\text{Yield (Y) (kg ha}^{-1})}{\text{Seasonal Crop Evapotranspiration (ETc) (m}^3\text{ha}^{-1})} \quad \text{….. (7)}$$

Fertilizer-N remained in soil (N_{rem}) =

$$\frac{\%\ ^{15}\text{N a.e. in soil}}{\%^{15}\text{N a.e. in fertilizer}} \times 100 \text{ ...... (8)}$$

Statistical analysis:

All experimental data were subjected to ANOVA analysis and Dunken's multiple range test (DMRT) to compare between treatments using SPSS program software version 20 (Ates *et al.*, 2019).

RESULTS AND DISCUSSION

Seed yield, N uptake and efficient use of Irrigation and N fertilizer:

Seed yield of plants irrigated with 80% and 100% of irrigation water regime combined with moderate rate of nitrogen fertilizer was increased comparable to other treatments (Table 3). Generally, seed yield was enhanced at the highest level of irrigation water. On the other hand, nitrogen fertilization with 85% gave the highest seed yield.

In case of nitrogen uptake, it turned out that the level 85% of both nitrogen fertilization and irrigation water gave the highest nitrogen uptake by seeds. This may give us the chance to conclude and recommend this strategy to save about 15% of both water and fertilizer recommended regimes and rates.

The efficient use of nitrogen fertilizer means the amount of crop produced by one kilogram of fertilizer (utilization efficiency). The highest nitrogen use efficiency was achieved by the treatment supplemented with high level of water and the low nitrogen rate, and this may be attributed to effect of high irrigation water regime that assist the plants to derive more nitrogen from fertilizer, which reflected the highest fertilizer use efficiency. Interaction between N rates and water regimes confirmed the superiority of high water regime x low N rate in increasing NUE by seeds.

Irrigation water use efficiency means the productivity of one cubic meter of water from the enclosed area. The results showed that the low level of irrigation water was the significant one among other irrigation levels. Accordingly, 15% of nitrogen fertilizer was saved parallel with the highest water use efficiency.

Uçan *et al.* (2007) recorded the maximum seed yield of sesame (1.8 Mg ha^{-1}) which significantly affected by amounts of irrigation water but not the case with irrigation intervals. Low water content exerted negative effect on the growth of Chinese cabbage and the restrictions imposed by deficit irrigation were consistent with that recorded in many other crops (Badr *et al.*, 2012). It was observed that different rates of N affected the nutritional state of the sesame, with respect to N content present in the seeds. These responses are related to genotypes that require different amounts of nutrients, which is intrinsically directly linked to their nutrient utilization efficiency (Decouard *et al.*, 2022).

Table 3. Seed yield, N content, N uptake, NUE and WUE of seeds as affected by irrigation water regime and N rates

Treatment		Seed Yield(Mg ha^{-1})	N Content(g kg^{-1})	N uptake(kg ha^{-1})	NUE(kg kg^{-1})	WUE(m^3 ha^{-1})
			Irrigation water rate			
W_1		1.3±0.002^c	10.1±0.055^c	13.2±0.085^b	21.9±0.033^c	4.4±0.006^a
W_2		1.4±0.002^b	11.0±0.055^a	15.9±0.085^a	24.7±0.033^b	4.0±0.006^b
W_3		1.5±0.002^a	10.7±0.055^b	16.1±0.085^a	26.3±0.033^a	3.6±0.006^c
			Nitrogen fertilization rate			
N_1		1.5±0.002^b	10.2±0.055^c	15.3±0.085^b	29.9±0.033^a	4.2±0.006^b
N_2		1.8±0.002^a	11.0±0.055^a	19.4±0.085^a	29.0±0.033^b	5.0±0.006^a
N_3		1.0±0.002^c	10.6±0.055^b	10.6±0.085^c	14.0±0.033^c	2.9±0.006^c
			Interaction impact			
	N_1	1.2±0.003^d	10.0±0.101^e	11.5±0.104^f	23.1±0.036^f	3.9±0.011^f
W_1	N_2	1.7±0.006^b	10.7±0.101^c	17.9±0.215^d	27.5±0.098^e	5.7±0.020^a
	N_3	1.1±0.004^e	9.6±0.101^f	10.3±0.101^h	15.0±0.057^g	3.6±0.014^g
	N_1	1.5±0.003^c	10.3±0.101^d	16.0±0.137^e	30.9±0.061^b	4.3±0.009^d
W_2	N_2	1.8±0.003^a	11.7±0.101^a	20.7±0.178^a	29.1±0.055^d	4.9±0.009^b
	N_3	1.0±0.003^f	11.0±0.101^b	11.1±0.118^g	14.1±0.041^h	2.8±0.008^h
	N_1	1.8±0.001^a	10.3±0.101^d	18.4±0.184^c	35.6±0.014^a	4.2±0.002^e
W_3	N_2	1.8±0.003^a	10.7±0.101^c	19.6±0.164^b	30.2±0.051^c	4.4±0.007^c
	N_3	0.9±0.003^g	11.2±0.101^b	10.3±0.036^h	12.9±0.045^i	2.2±0.008^i

Notes: N1, N2 and N3 are 50.0, 60.7 and 71.4 kg N ha-1 respectively; W1, W2 and W3 are 294.4, 336.4 and 420.5 m3 ha-1 respectively.

N derived from fertilizer (as ^{15}N) by sesame seeds:

Likewise, moderate irrigation water regime interacted with moderate N rate resulted in the highest Ndff (Fig. 1). On the other hand, the lowest Ndff was given by the treatments received the highest level of both of water and N fertilizer. The variation in %Ndff might have been due to the different availability of soil and fertilizer N over the growing period of white cabbage (Sturm *et al.*, 2010). In accordance, the highest Ndff was given by adding high rate on N for leaves and fruits of tomato crop (Huang *et al.*, 2020).

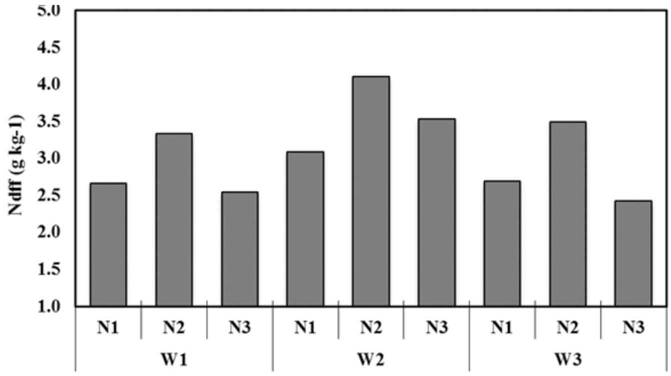

Fig. 1: Ndff (as ^{15}N) in sesame seeds under different combinations of irrigation water and N fertilization. **see foot notes of Table 3. Values are averages and no statistical analysis was done.**

Yield derived from fertilizer (as ^{15}N) by sesame seeds:

Nydff is the amount of N which uptake from N fertilizer and calculated using ^{15}N technique. Under any condition of irrigation water, the medium rate of N fertilizer gave the highest Nydff (Fig. 2). As well as, the most efficient treatment was W_2N_2. On the other hand, treatments receiving high rate of water and N fertilizer resulted in the lowest Nydff.

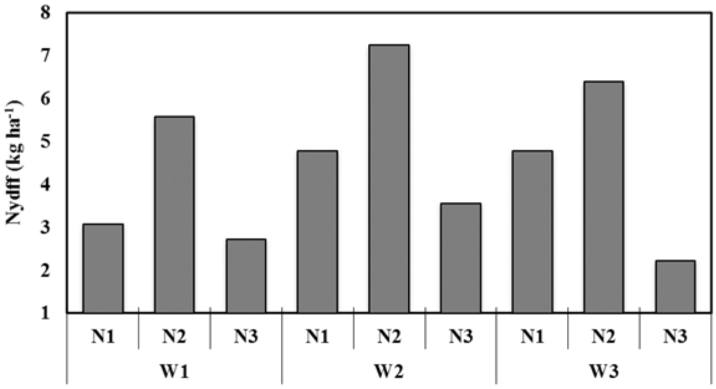

Fig. 2: Nydff (as ^{15}N) in sesame seeds under different combinations of irrigation water and N fertilization. **see foot notes of Table 3. Values are averages and no statistical analysis was done.**

Fertilizer ^{15}N recovery by sesame seeds:

^{15}N recovery toke the same trend of Nydff (Fig. 3). The treatments that received W_{80} and N_{85} gave the highest nitrogen recovery. Thus saving 20% irrigation water and 15% nitrogen fertilizer. The level of both nitrogen fertilizer and irrigation water must be controlled so that there is no loss of nitrogen fertilizer, whether by washing (in the case of an increase in the amount of irrigation water) or loss by volatilization (in the case of deficit water). The recovery rate was approximately 3.51–17.40% at the low N rate combined with irrigation level at 90% of soil field capacity (Gao *et al.*, 2017). These results are nearly closed to those obtained in the current study. Increasing N under intercropping system increased the use of N fertilizer by maize, thereby promoting greater ^{15}N recovery (Costa *et al.,* 2021).

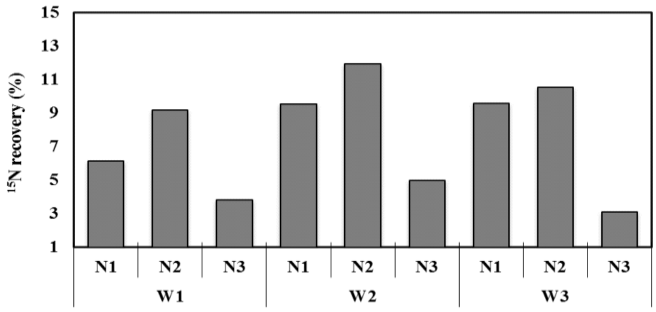

Fig. 3: ^{15}N recovery by sesame seeds under different combinations of irrigation water and N fertilization. **see foot notes of Table 3. Values are averages and no statistical analysis was done.**

Fertilizer-N balance:

The N remained in the soil after harvest and the loss of nitrogen are indications of the balance between irrigation water and nitrogen fertilization strategy followed to achieve the optimum efficiency of water and fertilizer. Table 4 and Figure 4 explained that increasing the rate of nitrogen fertilizer, caused an increases in N portion remained in soil after harvest. The loss of nitrogen fertilizer also increases (Table 4 and Fig. 5). It seems that moderate levels of water, contributed to minimize both of N fertilizer loss and N remained in the soil after harvest which confirmed that moderate amounts of water and nitrogen has an important role in achieving the most efficient water-nitrogen balance management. The soil residual of fertilizer N is an important source for increasing soil N stock and subsequent plant accumulation in the following growth seasons (Wang *et al.*, 2019; Zhang *et al.*, 2021). The previous studies had reported that 30–60% of the in-season fertilizer ^{15}N remained in 0–200 cm soil profile (Guo *et al.*, 2021). Plant use efficiency of applied N is estimated to be around 50 % for most crops. In coastal plain sandy soils particularly, leaching along with volatilization in warmer climates may be a predominant pathway for N loss to the environment (Jalpa *et al.*, 2021).

Table 4. ertilizer-N balance under sesame crop as affected by irrigation water regimes and N fertilizer rates

Water regime	N Rate	Fertilizer-N Balance (kg ha^{-1}) Nydff	N_{rem}	N Loss
	N_1	3.08	9.73	37.20
W_1	N_2	5.58	14.14	40.98
	N_3	2.73	17.78	50.89
	N_1	4.78	11.38	33.84
W_2	N_2	7.25	16.48	36.97
	N_3	3.55	16.35	51.50
	N_1	4.79	11.80	33.41
W_3	N_2	6.41	17.03	37.26
	N_3	2.23	18.92	50.25

See footnotes of Table 3

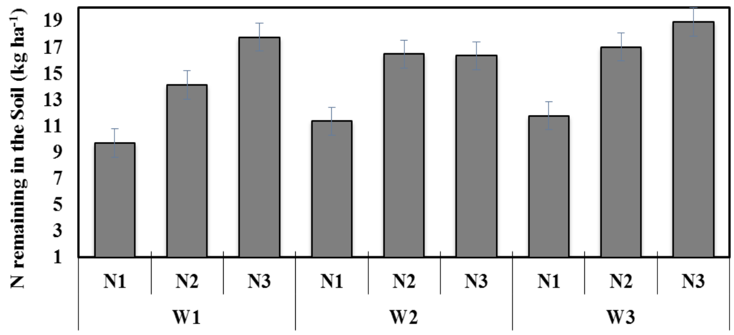

Fig. 4: N remaining in the soil (as ^{15}N) after harvesting under different combinations of irrigation water and N fertilizatio. **see foot notes of Table 3. Values are averages and no statistical analysis was done.**

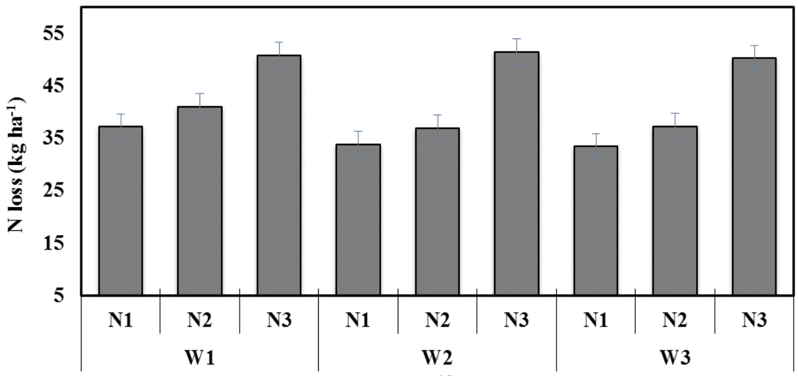

Fig. 5: : N loss from the soil (as ^{15}N) after harvest under different combinations of irrigation water regime and N fertilization rates. **see foot notes of Table 3. Values are averages and no statistical analysis was done.**

CONCLUSION

Data released from this research depicted the need for distinguish of the most proper management of irrigation water and nitrogen fertilizer strategy that achieve the optimum sesame production and in parallel reduces N loss from soil and saving money as well as minimizing environmental risks. Most efficient use of nitrogen and its impact on nutrient uptake by sesame seeds was detected under moderate supplement with both irrigation water and N fertilizer. In this regard, ^{15}N recovery and the portion of fertilizer used by plants were significantly enhanced by lowering the levels of tested factors. Also, plants grown under moderate water levels has the potential to grow well and be more productive than those irrigated with high water levels. In other turn, moderate quantities of water were much more productive as compared to other high or low levels. It could be concluded, from economic and environmental viewpoint, that one can reduce the amount of nitrogen and irrigation water by about 25% without risk on productivity but considering the environment risks and production costs. The use of nuclear technology for the ^{15}N stable isotope contributed greatly to clarifying the aforementioned results.

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الإستخدام الفعال لمياه الرى والتسميد النيتروجينى على السمسم المنزرع فى تربة رملية منخفضة الخصوبة بمساعدة النظير المستقر ن15

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الملخص

في المناطق الجافة وشبه الجافة، تأثرت النباتات من نقص المياه والمغذيات، وبالتالي كانت الحاجة إلى الإدارة السليمة لكل من مياه الري والمغذيات وخاصة النيتروجين إلزامية. تهدف هذه الدراسة إلى التعرف على أنسب معدل للتسميد النيتروجينى بالتزامن مع معدل الرى الذي يحقق أفضل إنتاج لمحصول السمسم المنزرع في تربة رملية فقيرة الخصوبة. وفي هذا الصدد، أجريت تجربة حقلية على نبات السمسم خلال صيف 2020 بتصميم القطع المنشقة، حيث تضمنت القطع الرئيسية معدل مياه الري (W) كنسبة مئوية من البخر نتح (70، 80 و 100%) وتضم القطع الفرعية معدل التسميد النيتروجينى (N) (50.0، 60.7 و 71.4 كجم نيتروجين هكتار-1). أشارت النتائج إلى أن أعلى إنتاج للبذور، وامتصاص النيتروجين بواسطة البذور، Ndff، Nydff، FNR، N_{rem} والفقد من النيتروجين تم إعطاؤهم بواسطة المعاملات التي تلقت المعدل المتوسط من مياه الرى والسماد النيتروجينى. علاوة على ذلك، فإن التداخل ما بين المستوى العالى من مياه الرى ومعدل النيتروجين المنخفض عززت كفاءة استخدام النيتروجين (NUE)، بينما كانت أفضل كفاءة لاستخدام المياه (WUE) عند معدل الري المنخفض ومعدل النيتروجين المتوسط. لذلك، تطبيق مستوى ري 357.4 م 3 هكتار-1 ومعدل 60.7 كجم نيتروجين هكتار-1 حقق ممارسة الإدارة الأكثر ملاءمة والتداخل الفعال بين مياه الرى والتسميد النتروجينى والتى قللت من فقد النيتروجين بأى آلية.

الكلمات المفتاحية: السمسم، المحصول، إمتصاص النيتروجين، كفاءة إستخدام النيتروجين، كفاءة إستخدام المياه، إسترجاع النيتروجين، التخفيف النظائرى