RESEARCH ARTICLE-CIVIL ENGINEERING

The Use of Organic Waste in Sustainable Water Management Under the Conditions of Dry Areas: Field and Modeling Study

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Abstract

Organic waste poses a threat to the environment in the event of its repeated use; however, in this study, we converted it into a useful and environmentally safe source of fertilization. In addition to its fertilization ability, it exhibited a good ability to reduce water stress in cultivated plants in area in which irrigation is lacking and are suffering the impact of climate change. Two field experiments were conducted during the 2019/2020 and 2020/2021 seasons to study the effect of the regulated deficit irrigation strategy and organic N-fertilization ratio during wheat cultivation. The majority of the studied characteristics were slightly higher when irrigation was 75% FI as compared to 100% FI. When using organic nitrogen fertilization in addition to mineral nitrogen fertilization, at 50% organic to 50% mineral, it was possible to irrigate at 75% FI. In this scenario, productivity increased by 28.5% in 2019/2020, and 56% in 2020/2021. The model simulated the studied characteristics of the two seasons relatively well. In summary, the field and modeling results indicate that the use of organic waste in sustainable water management in dry areas has various benefits, including a higher yield and reduced use of chemical fertilizers by up to 50%. This was replaced with 50% organic nitrogen fertilizer produced from the compost from agricultural waste, which is abundant on all farms. These additional benefits increase the income for farmers, and reduce environmental pollution.

Keywords Organic agricultural waste · Regulated deficit irrigation · Sustainable water management · Integrated fertilization · Water productivity · Wheat · SALTMED model

1 Introduction

As a result of the limited water resources and the negative effects of climate change in arid regions, it is necessary for us to adopt sustainable farming techniques. The integrated management of fertilization is one of the most important of these sustainable techniques. Integrated fertilization management is defined as organic fertilization in combination with mineral fertilization. It is well-known that organic fertilization includes all forms of organic agricultural waste in its production (as these wastes are a huge loss of resources and a severe pollutant to the environment if they are not used wisely). In view of the increasing volume of agricultural waste in developing countries, in this study, we converted it into compost to act as a source of organic fertilization in combination with mineral fertilization. In addition, the resultant compost exhibited a good ability to hold irrigation water in the area of root spread and reduce water stress in the roots of cultivated plants. In short, organic waste, which poses a threat to the environment in the event of its repeated use, was converted into a useful and environmentally safe source of fertilization. Moreover, it was shown to reduce water stress in cultivated plants in scenarios in which irrigation is lacking and under the impact of climate change.

Agricultural waste is generally defined as waste generated or by-products from the cultivation and processing of raw agricultural products. Agricultural waste materials, known as agricultural waste, consist of animal waste, food processing waste, crop residues, and toxic and hazardous agricultural waste [1]. [1] Converting this agricultural waste (crop residues, animal manure) into organic fertilizer is one of the waste treatment technologies that makes it possible to use organic waste as a fertilizer.

The obtained results indicated a significant increase and improvement in the water productivity of wheat crops and the

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protein content as a result of bio- or organic fertilizer treatments under conditions of water scarcity and water stress. The inoculation of biofertilizer led to an increase in grain, straw, and yield/fed by 26%, 18%, and 20%, respectively [2, 3], demonstrating that dense crops such as wheat can be grown using drip irrigation systems with an increased rate of organic fertilizers produced from compost.

Several studies confirmed that increasing the rate at which organic matter is added to sandy soil led to an increase in the soil's water-holding capacity [4]. A soil's water-holding capacity is closely related to its structure, texture, and organic matter content [5]. In [6], the authors indicated that in certain Sudanese regions, important benefits can be obtained from the low-input conservation of terrestrial organic matter in agricultural systems, including nutrient retention and storage and increased soil water-holding capacity. Hence, soil organic matter conservation is an essential element and is vital in sustainable land management.

Increasing and improving crop productivity with sustainable farming methods and systems is one of the most important issues globally [7]. As many studies have suggested, this can be achieved by using a method to amend and increase the organic content of the soil. Increasing the soil organic content is one of the best ways to maintain crop productivity, is economically feasible, and produces the lowest level of environmental pollution.

Many scientific studies also indicate that in order to achieve and ensure high yields, it is important to maintain soil fertility by providing the appropriate nutrients, i.e., adding organic matter [8]. Promoting and augmenting microorganisms using biofertilization is a healthy and sustainable alternative to chemical fertilization. Continually adding an appropriate level of organic matter from various sources of organic matter such as compost is important [9]. Attention has been focused on the processes of decomposing plant residues in order to release large levels of nutrients and organic matter into the soil [10]. It is difficult to increase and improve the productivity of agricultural crops in light of the high costs of mineral fertilizers, which are characterized by low application and application efficiency and a limited supply [11].

Integrated plant fertilizer and nutrition management (IPNM) is one of the best alternative approaches to improve and increase the productivity of various crops and to ensure sustainable soil health. Within the IPNM framework, many different nutrient sources are added collectively in a sustainable manner. Many of the results of previous studies proved that a combination of organic fertilizers and mineral fertilizers improved the characteristics and properties of the soil and also reduced the leaching and escape of nutrients [12, 13]. It was concluded that improving soil fertility and its ability to retain added irrigation water, thus increasing the capacity of cation exchange, the germination of seeds, soil aeration, and

plant growth, is effectively achieved by increasing the addition of integrated fertilizers [14]. Green manure crops such as Sesbania aculeata and cluster bean crops demonstrated increased growth as a result of increasing the organic matter content in the soil. This increased the availability of nutrients and improved soil fertility by improving the majority of the chemical and biophysical properties of the soil, while also reducing the loss of nutrients from the soil [15, 16].

The combination and aggregation of agricultural organic fertilizers and green fertilizers in combination with mineral fertilizers when planting wheat and rice and then wheat again increased and improved the productivity of both crops [17]. Another study confirmed that there was a significant increase in the productivity of wheat crops when using organic and mineral fertilizers in combination with each other [18]. The production and cultivation of different crops with a good yield cannot be done without healthy soil and the addition of balanced and integrated fertilizers. Studies also confirm that soil nutrient dynamics vary according to the type of organic fertilizer source and the rate of application of mineral fertilizers.

In semiarid and arid areas with high population densities with limited fresh water sources, there is great pressure on the agricultural sector to reduce the consumption of freshwater for irrigation [15, 19]. Water scarcity is among the most important problems that impede crop production and cultivation in arid and semiarid areas [20, 21]. Increasing and improving water productivity for the production and cultivation of crops is an urgent goal in light of the increasing population and demand for food [22, 23]. The water productivity criteria of crops grown in semiarid and arid regions are very important due to the scarcity of water resources and the limited precipitation in these areas [24, 25]. The application of irrigation scheduling methods and associated techniques is also very important in semiarid and arid regions in order to ensure that the process of adding the available water is efficient [26].

Wheat (Triticumaestivum L.) is one of the most important crops for international and global food security, supplying approximately 20% of the total global caloric requirements and essential nutritional proteins. It has an approximate global production of 730 million tons annually, which is harvested from a total cultivated area of approximately 2.1 million square kilometers [27, 28]. The wheat crop is one of the most important grain crops in terms of production and area in all countries of the world. To address the current and future demand for food, it is necessary to increase the wheat crop cultivar production area while increasing its potential production capacity in dry areas and areas with limited water resources, as agricultural land is increasingly threatened by drought stress worldwide [29, 30].

Table 1 Chemical and physical properties of the soil

Soil properties	Soil depth (cm)		
	0–15	15–30	30–45
Physical parameters			
Texture	Sandy	Sandy	Sandy
Course sand,%	45.81	56.43	36.72
Fine sand,%	51.80	39.91	59.52
Silt + clay,%	2.39	3.66	3.76
Bulk density, t m^{-3}	1.64	1.65	1.67
Chemical parameters			
Electrical conductivity, EC, dS m^{-1}	0.85	0.81	0.75
pH, 1:2.5	8.71	8.64	8.7
Total CaCO$_3$, %	7.17	2.39	5.65
Organic matter, %	0.68	0.52	0.49

The aim of this study was to convert organic agricultural waste into organic fertilizer and introduce it into the integrated management of fertilization (wheat fertilization) in dry areas. These fertilizers could then be used as sustainable, natural, and vital sources of fertilization to relieve water stress resulting from the lack of irrigation water and the impact of climate change.

2 Material and Methods

2.1 Experimental Site

Field experiments were conducted during 2019/2020 and 2020/2021 in arid and sandy soil regions with hot summers, cold winters, and winter rains. In the central regions, the summers are hot and their winters cold and dry.

2.2 Soil Properties and the Irrigation Water

The main chemical and physical properties of sandy soils were determined in the laboratory before beginning of the field trial (Table 1). Irrigation water was obtained from a groundwater well, and its chemical properties and the results from the compost analysis are shown as in Table 2.

2.3 Compost Production from Agricultural Organic Waste

Several stages were necessary to convert agricultural waste, whether plant or animal waste, into compost (organic fertilizer): The first stage of production on the farm involved collecting and sorting. We finally produced a clear compost suitable for adding to organically poor and infertile sandy soils. This type of soil is also considered to be poor in terms of irrigation water retention. These manufactured organic fertilizers, which had undergone multiple treatments and were added in different proportions, were used to sustainably grow wheat under the conditions of dry Saudi agriculture, as shown in detail in Fig. 1.

2.4 Experimental Design

The experiment was established with a split plot design with three replicates for the cultivation wheat (Giza 168). The main plots included three regulated deficit irrigation (RDI) plots (RDI1:100% Full Irrigation (FI); RDI2:75% FI and

Table 2 Chemical analysis of compost and irrigation water

		Compost, 2019/2020	Compost, 2020/2021	Irrigation water
pH		5.97	5.85	7.76
Electrical conductivity, EC, ds/m		0.78	0.73	0.71
Anions, meq./L	HCO$_3^-$ &CO$_3^{2-}$	1.25	1.26	0.11
	Cl$^-$	3.46	3.49	2.75
	SO$_4^{2-}$	2.89	2.89	1.38
Cation, meq./L	Ca + +	2.06	1.88	1.18
	K +	2.32	2.18	0.25
	Mg +	1.04	1.15	0.50
	Na +	2.18	2.43	2.31
Organic matter, %		95.6	95.8	–
Moisture content, %		19	20	–
Nitrogen, %		0.90	0.90	0.02
C/N ratio		30:1	30:1	–

C/N ratio: the ratio between carbon and nitrogen in compost

Fig. 1 Steps for making compost from agricultural organic waste
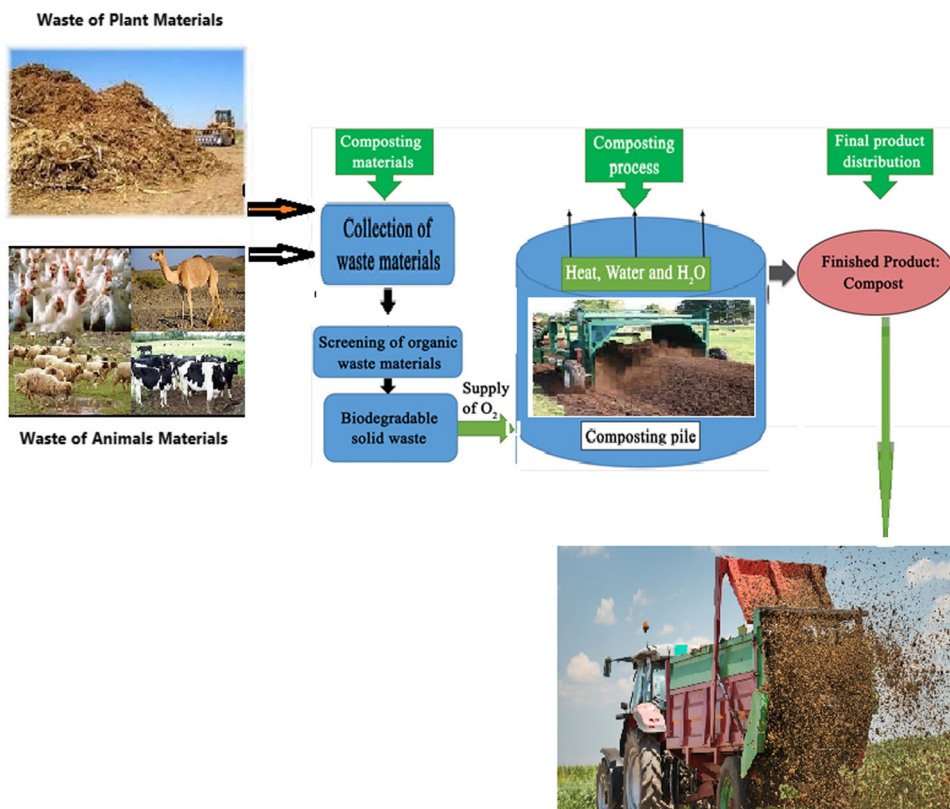
RDI3:50% FI). The main sub-plots were made up of five varying organic nitrogen ratios (ONR) from compost made from organic agricultural waste (ONR1:100% M_N + 0% O_N), (ONR2:75% M_N + 25% O_N), (ONR3:50% M_N + 50% O_N), (ONR4:25% M_N + 75% O_N), and (ONR5:0% M_N + 100%O_N), as shown in Fig. 2, where M_N denotes mineral nitrogen and O_N denotes organic nitrogen.

2.5 Integrated Organic Fertilization Method

The nitrogen content analyses showed that the compost contained 0.90% nitrogen. Considering wheat's recommended nitrogen requirement of 192 kgN unit/ha, the total quantity and volume of compost was 192/9.0, which represents 21.3 tons, as 50% of the added manure was decomposed during the following year. This means that the total amount of compost added was 42.6 tons / hectare. It was necessary to add organic fertilizer 20 days before planting the wheat. Table 3 shows the scheduling of the organic nitrogen fertilization for all treatments under study.

2.6 Irrigation Requirements

The irrigation water requirements for the wheat crop with using sprinkler irrigation system from 20/11/2019 to 20/4/2020 and from 20/11/2020 to 20/4/2021 for second season were calculated according to Eq. 1, as shown in Table

4.

$$IRg = [(ET_o \times Kc)/I_E] - R + LR \qquad (1)$$

where IRg denotes gross irrigation requirements, mm/day; ET_O denotes the reference evapotranspiration, mm/day; Kc denotes the crop factor of common bean (FAO-56); I_E denotes irrigation efficiency, %; R denotes rainfall, mm; and LR denotes the volume of required water for leaching the salts from root zone, mm.

2.7 Evaluation Parameters

2.7.1 Water Stress Inside the Root Zone (WS $_{Inside\ root-zone}$)

The soil moisture content was measured in the roots zone of wheat plants for each plot before irrigation only. The soil moisture content at field capacity and wilting point was taken as the evaluation indicator of the exposure range of plant roots to water stress. WS $_{Inside\ root-zone}$ was measured at the mid-stage of the plant age [31].

2.7.2 Soil Moisture Content

Soil moisture content (SMC) was measured continuously during the wheat growing season, i.e., from planting time
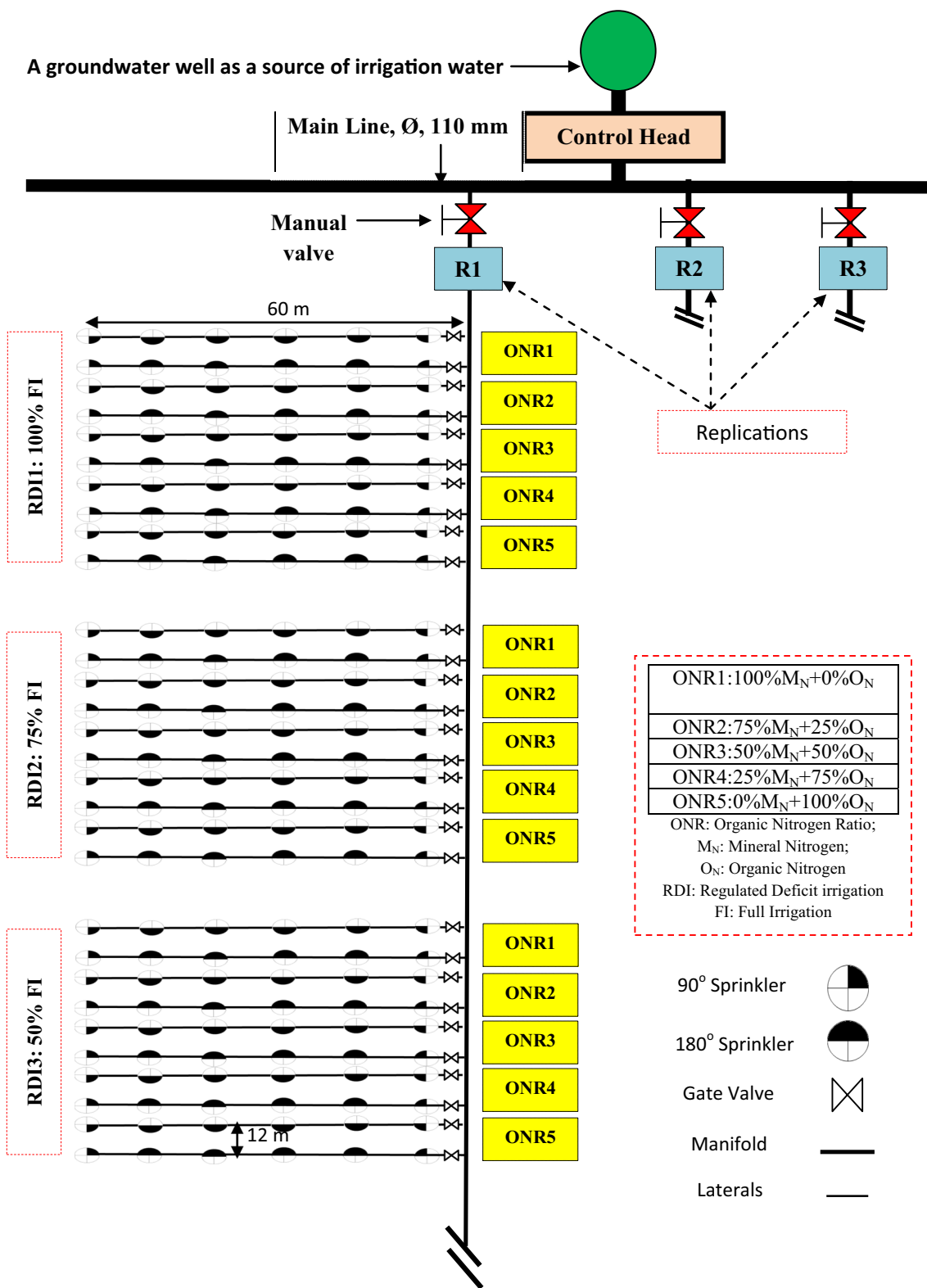
Fig. 2 Layout of experimental design

Table 3 Scheduling of the organic nitrogen ratio

Treatments	M_N, kg$_{ammonium\ nitrate(33.5\%N)}$/ha	O_N, kg$_{compost}$/ha, 2019/2020 and 2020/2021
ONR1:100%MN + 0%ON	573	0
ONR2:75%MN + 25%ON	430	10,650
ONR3:50%MN + 50%ON	287	21,300
ONR4:25%MN + 75%ON	143	31,950
ONR5: 0%MN + 100%ON	0	42,600

ONR: organic nitrogen ratio; *MN*: mineral nitrogen; *ON*: organic nitrogen; 192 kg nitrogen/ha. in the form of ammonium nitrate (33.5% N) = 573 kg/ha; 100% ON = 42.6 ton/ha. = 42,600 kg/ha. for each season equally because the proportion of nitrogen in the compost is the same in both seasons

Table 4 Net irrigation water requirements for wheat

Regulated Deficit Irrigation	2019/2020	2020/2021
RDI1 (100% FI), (m^3.ha^{-1})	2400	2350
RDI2 (75% FI), (m^3.ha^{-1})	1800	1763
RDI3 (50% FI), (m^3.ha^{-1})	1200	1175

RDI: regulated deficit irrigation; *FI*: full irrigation

to the harvest, in effective roots zone. SMC was determined using a profile probe, as shown in Fig. 3.

2.7.3 Water Application Efficiency

Water application efficiency (WA$_E$) is the actual storage of irrigation water in the root zone of wheat plants to the applied water depth to the field. WA$_E$ is calculated using Eq. 2 [32]:

$$WA_E = Ds/Da \tag{2}$$

where WA$_E$ denotes the application efficiency of irrigation water, %; Da denotes the depth of applied water, mm; and Ds denotes the depth of stored water in the root zone, mm, according to Eq. 3.

$$Ds = (\theta_1 - \theta_2) * d * \rho \tag{3}$$

where d denotes the soil layer depth, mm; θ_1 denotes the average soil moisture content after irrigation, g/g in the root zone; θ_2 denotes the average soil moisture content before irrigation (g/g); and ρ denotes the relative bulk density of soil (dimensionless), as shown in Fig. 3.

2.7.4 Soil Organic Matter Content

The soil organic matter content (SOMC) was measured before planting and after harvesting for the two growing seasons.

Fig. 3 Estimation of water application efficiency for all treatments
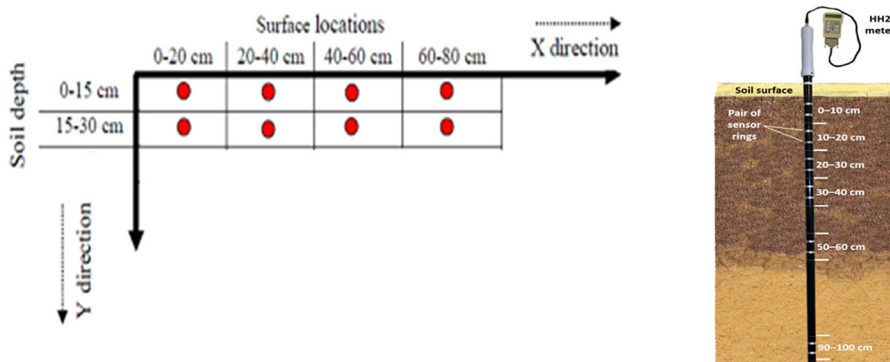
Equations 1 and 2 were used to calculate the soil moisture content before and after irrigation for a soil layer depth 0 – 30 cm.

PR2/6 Profile probe (Delta-T Devices) showing stainless steel electronic rings and data recording meter (HH2).

2.7.5 Dry Matter and Grain Yield of Wheat

At time of harvesting, the dry matter (DM_{wheat}) and grain yield (GY_{wheat}) were measured. Random samples from a 100×100 cm area were taken from each plot to determine DM_{wheat} and GY_{wheat} (kg.m^{-2}) and then converted to yield per ton.ha^{-1}.

2.7.6 Water Productivity of Wheat

The water productivity of wheat (WP_{wheat}) was calculated according to the methods in [33], using Eq. 4.

$$WP_{wheat} = Ey/Ir \qquad (4)$$

where WP_{wheat} denotes the water productivity of wheat, kg_{wheat} m$^{-3}_{water}$; Ey denotes the economical yield, kg_{wheat}/ha; and Ir denotes the volume of applied irrigation water, m$^3_{water}$. ha^{-1}.

2.7.7 Protein Content Based on Nitrogen Determination

Some of the most frequently used methods for food protein determination are based on the analysis of the total nitrogen content in the samples. Examples of such methods are found in [34] and [35]. Total nitrogen (TN) of wheat was measured using Kjeldahl's method, and total crude protein (TCP) was determined by multiplying the TN content in grains by 6.25, as follows.

$$\text{Proteins Content}, \% = N - \text{content} * 6.25 \qquad (5)$$

2.7.8 Simulation Model Used

SALTMED model (version 3.04.25) was used in this study. A detailed description of the SALTMED model is provided in many studies, e.g., [36] and [37]. This model is now freely available on the Intern. Commission on the Irrigation & Drainage (ICID) website: https://www.icid.org/wg_crop.html. The reference evapotranspiration (ETo), according to FAO56 [38], was selected using meteorological data, which was obtained from the local field weather station. Crop-specific input data were the leaf area index (LAI), plant height, minimum and maximum root depth, and the duration of each growth stage. The irrigation input values were those applied in the field for the sprinkler irrigation system using the RDI strategy during the 2019/2020 and 2020/2021 seasons. The soil profile was also determined for one layer only (0.00–0.30 m). This layer provided the initial soil moisture conditions for the model. The calibration was performed for the wheat variety (Giza 168) under study individually due to the different growth parameters, as shown in Table 5. More-

Table 5 Main calibrated values of input parameters of 100% FI and ($100\%M_N + 0\% O_N$), 2019/2020

Parameter	Growth stage	Giza 168
Sowing date		20 November
Harvest, days after sowing		150
The stages of plants	Initial	29
	Development	34
	Middle	55
	Late	32
Crop coefficient, Kc	Initial	0.75
	Middle	1.15
	End	0.45
Leaf area index, LAI	Initial	0.64
	Middle	3.51
	End	3.04
Minimum root depth, m		0.00
Maximum root depth, m		0.60
Unstressed crop yield, t.h^{-1}		7.5
Water uptake threshold	Initial	0.88
	Middle	0.52
	End	0.77
Harvest index		0.47
Saturated moisture content, m^3 m^{-3}		0.26
Field capacity, m^3 m^{-3}		0.15
Wilting point, m^3 m^{-3}		0.04
Lambda pore size		0.21
Residual water content, m^3 m^{-3}		0.00
Root width factor		0.31
Max. depth for evaporation, mm		52.0
Bubbling pressure, cm		10.2

over, the simulated water stress, soil moisture content, water application efficiency, soil organic matter content, dry matter content, and grain yield for the fully irrigated 100% FI group under the sprinkler irrigation system were compared with the measured values during the 2019/2020 season by fine-tuning the relevant SALTMED model parameters. The validation was carried out using the remaining treatments (using the calibrated parameter) by comparing the simulated values with the observed values for both the experimental years, for both regulated deficit irrigation (RDI) (RDI1(100% Full Irrigation (FI)); RDI2 (75% FI); RDI3 (50% FI)) systems, and for the five organic nitrogen ratios from compost produced from organic agricultural waste. Statistical and graphical methods were used to evaluate the model performance. For the model calibration and validation statistical measurements,

the R^2, the root-mean-square error (RMSE), and the coefficient of residual mass (CRM) are used for Eqs. 6, 7, and 8. The RMSE values indicate how much the simulation model under- or overestimated the measurements.

$$\text{RMSE} = \sqrt{\frac{\sum (y_o - y_s)^2}{N}} \qquad (6)$$

where y_o denotes observed value; y_s denotes the simulated value; and N denotes the total number of observations.

The R^2 statistical parameter shows the ratio between the scatter of the simulated values and the average values of the measurements:

$$R^2 = \left(\frac{1}{N} \frac{\sum (y_o - y_o^-)(y_s - y_s^-)}{\sigma_{y_o} - \sigma_{y_s}} \right) \qquad (7)$$

where y_o^- denotes the averaged observed value; y_s^- denotes the averaged simulated value; σ_{y_o} denotes the observed data standard deviation; and σ_{y_s} denotes the simulated data standard deviation.

The coefficient of the residual mass (CRM) is defined as follows:

$$\text{CRM} = \frac{\left(\sum y_o - \sum y_s \right)}{\sum y_o} \qquad (8)$$

CRM is the measure of the tendency of the SALTMED model to over- or underestimate the measurements. Negative CRM values indicate that the model underestimates the measurements and positive values indicate a tendency to overestimate. For a perfect fit between the observed and simulated data, RMSE, CRM, and R^2 values should equal or be close to 0.0, 0.0, and 1.0, respectively.

2.8 Statistical Analysis

The obtained data were subjected to the analysis of variance (ANOVA), according to the method reported in [39], using the Co-Stat Software version 6.303 (2004). The L.S.D. at a 0.05 level of the significance was used for comparison between the means.

3 Results and Discussion

3.1 Water Stress Inside the Root Zone

One of the most important strategies for saving irrigation water is to expose the roots of cultivated plants to water stress; however, it is important that this stress does not lead to significant differences in crop productivity (deficit irrigation). The best way to judge the extent to which plant

roots are exposed to water stress is to measure the moisture content immediately before irrigation and determine how close it is to the field capacity level and how far it is from the wilting point. Figure 4 shows that with an increase in water deficiency, the extent of WS$_{\text{Inside root-zone}}$ to which the roots of wheat plants was exposed increased. The lowest WS$_{\text{Inside root-zone}}$ at irrigation was for the 100% FI, while the maximum WS$_{\text{Inside root-zone}}$ was for the 50% FI. The irrigation for the 75% FI represented the average WS$_{\text{Inside root-zone}}$ conditions. This may be due to the increase in the volume of the added irrigation water, which led to an increase in the volume of wet soil within the root zone, which reduces the effect of water stress on the roots, and on the contrary, with a decrease in the volume of irrigation water.

Figure 4 also shows that by increasing ONR, moisture stress decreased, e.g., the lowest WS$_{\text{Inside root-zone}}$ was observed in the roots when adding 100% ONR with no mineral fertilizers, while the largest WS $_{\text{Inside root-zone}}$ was when no organic fertilizers were added and only 100% addition mineral fertilizer was used. This may be due to the increased addition of organic fertilizers to sandy soils that are poor in organic matter to increase the soil's ability to retain irrigation water within the root spreading area, which reduces the impact of water stress on the roots of cultivated plants.

Figure 4 shows that the lowest WS$_{\text{Inside root-zone}}$ was achieved when irrigating with 100% and 75% FI with the addition of 100% ONR and the absence of mineral fertilizers; this was achieved during the two growing seasons for the wheat crop. These results are consistent with those obtained by [4, 5] and [6].

Figures 4 and 5 demonstrate the applicability of the SALTMED simulation program in its simulation of the WS $_{\text{Inside root-zone}}$ data for all the studied transactions, wherein R^2 was 0.973 for the 2019/2020 season and 0.916 for the 2020/2021 season.

3.2 Soil Moisture Content

Under conditions that lack added irrigation water, it is necessary to monitor the level of SMC in the root zone from the beginning of planting until harvesting.

By comparing Figs. 6, 7, and 8, it was found that the amount of irrigation water added had a clear effect on the SMC levels of the root zone. However, by increasing the amount of irrigation water added, the moisture level approached field capacity when irrigating with 100% FI. Contrarily, the moisture level was very close to the level of permanent wilting when irrigating with 50% FI.

Furthermore, when comparing the different treatments to increase the ONR from the compost for each of Figs. 6, 7, and 8, it was also found that the SMC level increased toward the area of least SMC, which was near the field capacity moisture level. The opposite was true when the ONR decreased, i.e.,
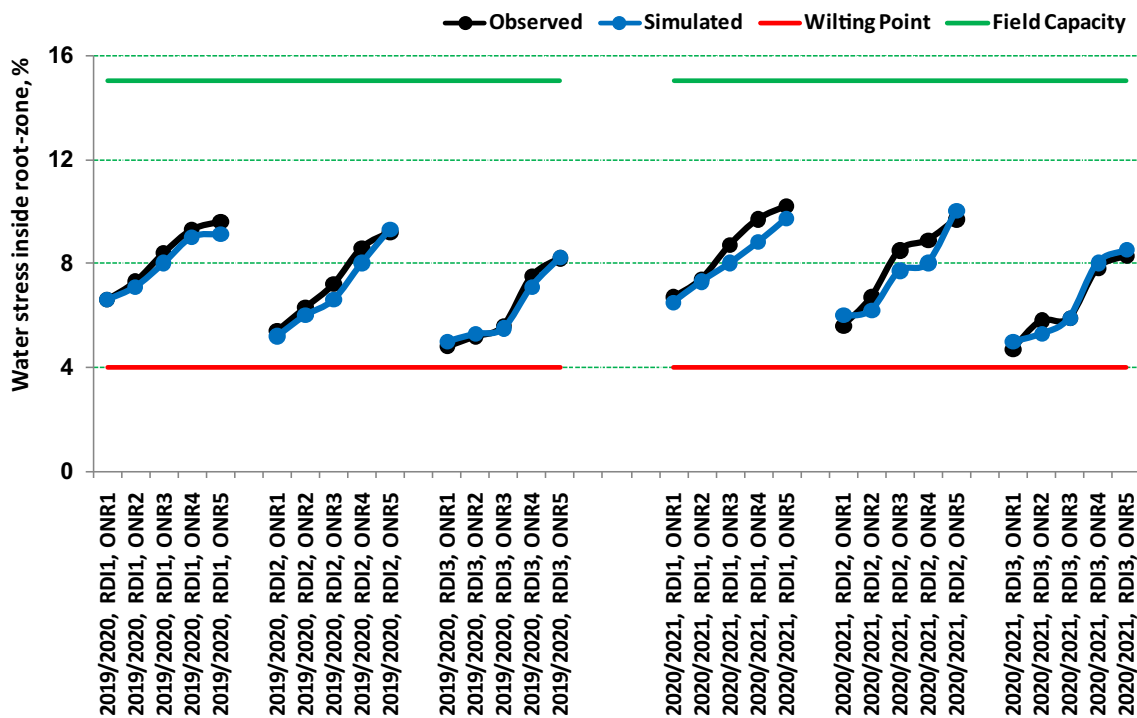
Fig. 4 Effect of regulated deficit irrigation (RDI) and organic nitrogen ratio (ONR) on the observed water stress inside the root zone of wheat plants as compared to simulated values for the average of the two seasons RDI1(100%FI); RDI2 (75%FI); RDI3(50%FI); ONR1(100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3 (50%MN + 50%ON); ONR4 (25%MN + 75%ON); ONR5(0%MN + 100%ON); MN (Mineral Nitrogen); ON (Organic Nitrogen)]
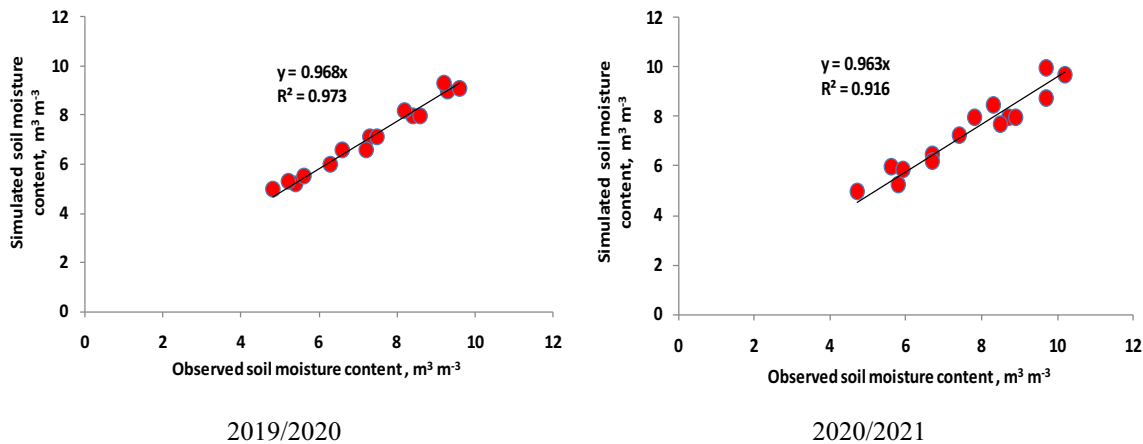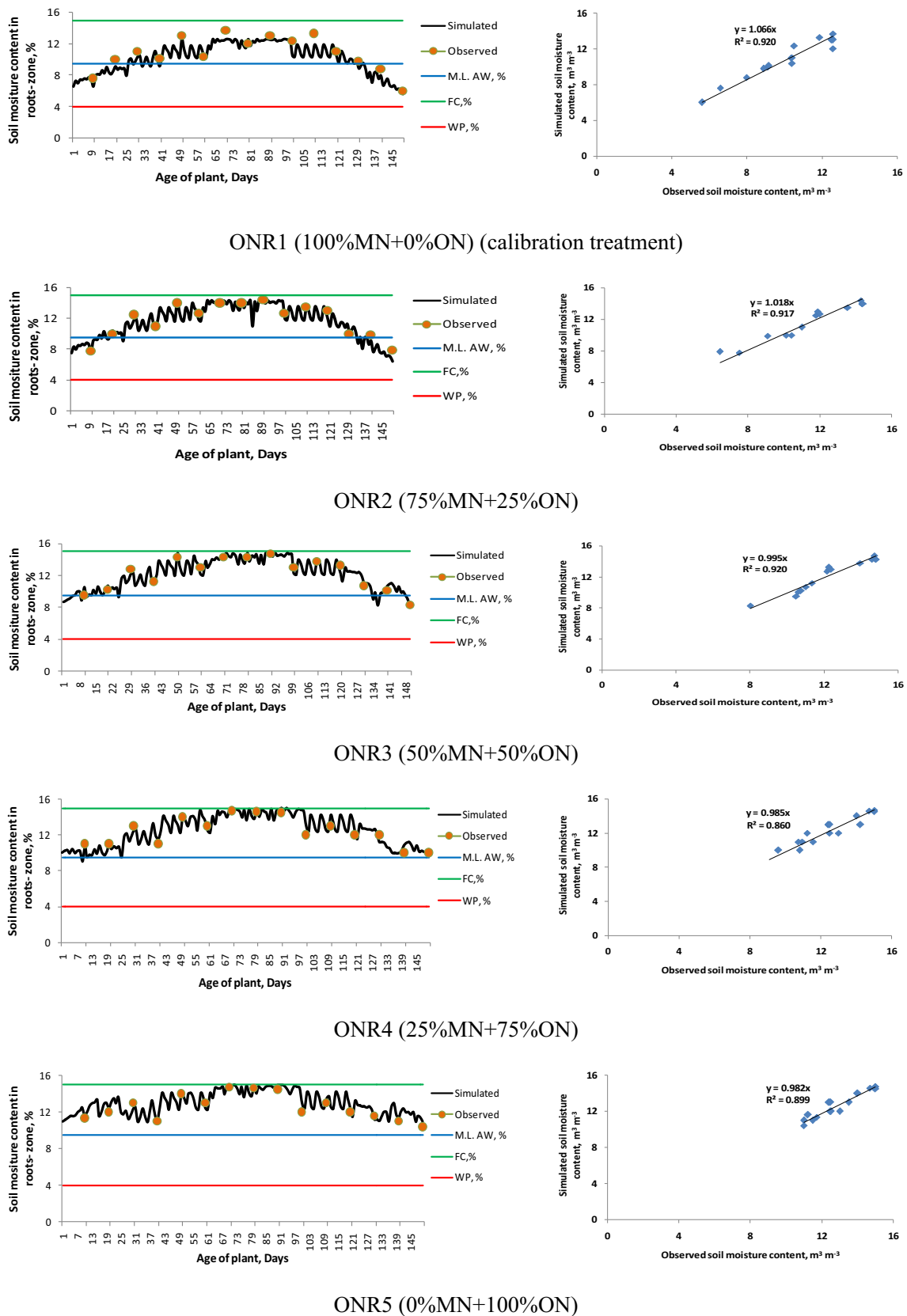

Fig. 5 Observed versus simulated water stress inside the root zone of wheat plants for all treatments

the moisture content decreased to the most stressful level, which was near the level of permanent wilting. These results are in agreement with those reported in [4] and [5].

From the results shown in Figs. 6, 7, and 8, it was found that the best areas for wheat plant root growth and the least SMC stress were those irrigated with 100% or 75% FI with the addition of the highest ratio (100%) of organic nitrogen fertilizers from compost produced from agricultural residues and no mineral nitrogen fertilizer addition. The areas exhibiting the most moisture stress were those irrigated with 50% FI with the addition of 100% mineral nitrogen fertilizers only.

Moreover, Figs. 6, 7, 8, and 9 and Table 6 indicate the potential of the SALTMED model program in terms of its superior ability to simulate soil moisture data over the whole wheat growing season using all the studied factors, i.e., the R^2 was 0.901 for the overall data from the first season and 0.909 for the overall data from the second season.

ONR1 (100%MN+0%ON) (calibration treatment)

ONR2 (75%MN+25%ON)

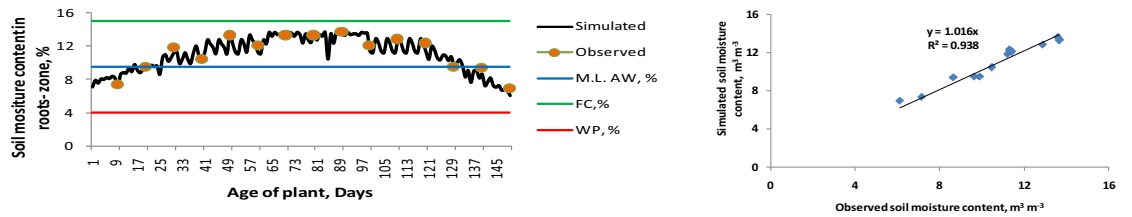ONR3 (50%MN+50%ON)

ONR4 (25%MN+75%ON)

ONR5 (0%MN+100%ON)

Fig. 6 Correlation between the observed and simulated soil moisture values with organic nitrogen ratio and 100% full irrigation (FI) during the 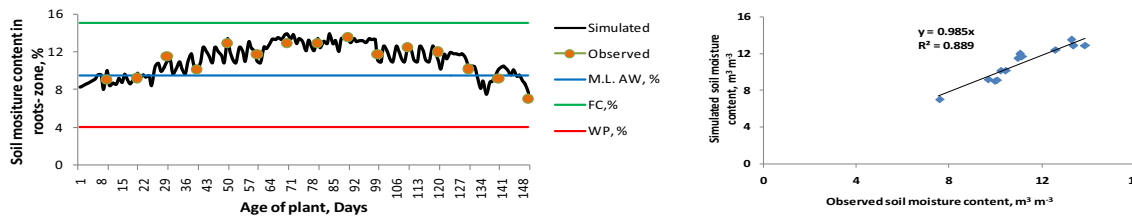2019/2020 season. [RDI1(100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3 (50%MN + 50%ON); ONR4 (25%MN + 75%ON); ONR5 (0%MN + 100%ON); MN (Mineral Nitrogen); ON (Organic Nitrogen)]
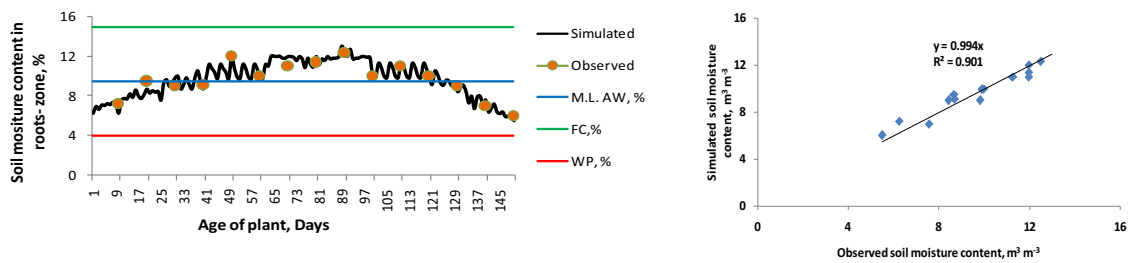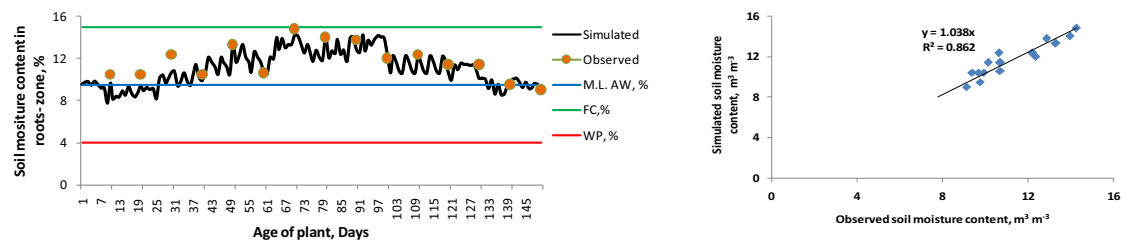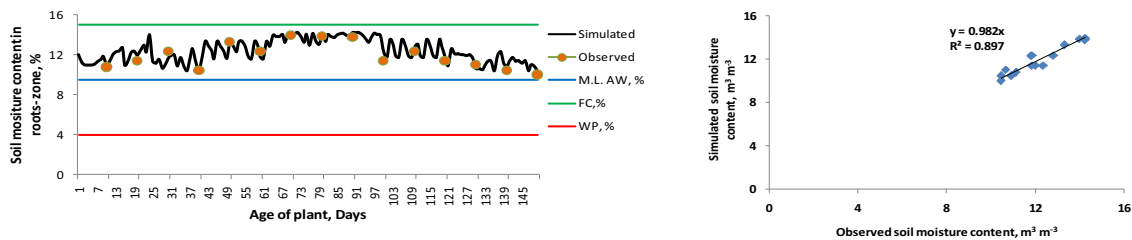
ONR1 (100%MN+0%ON)

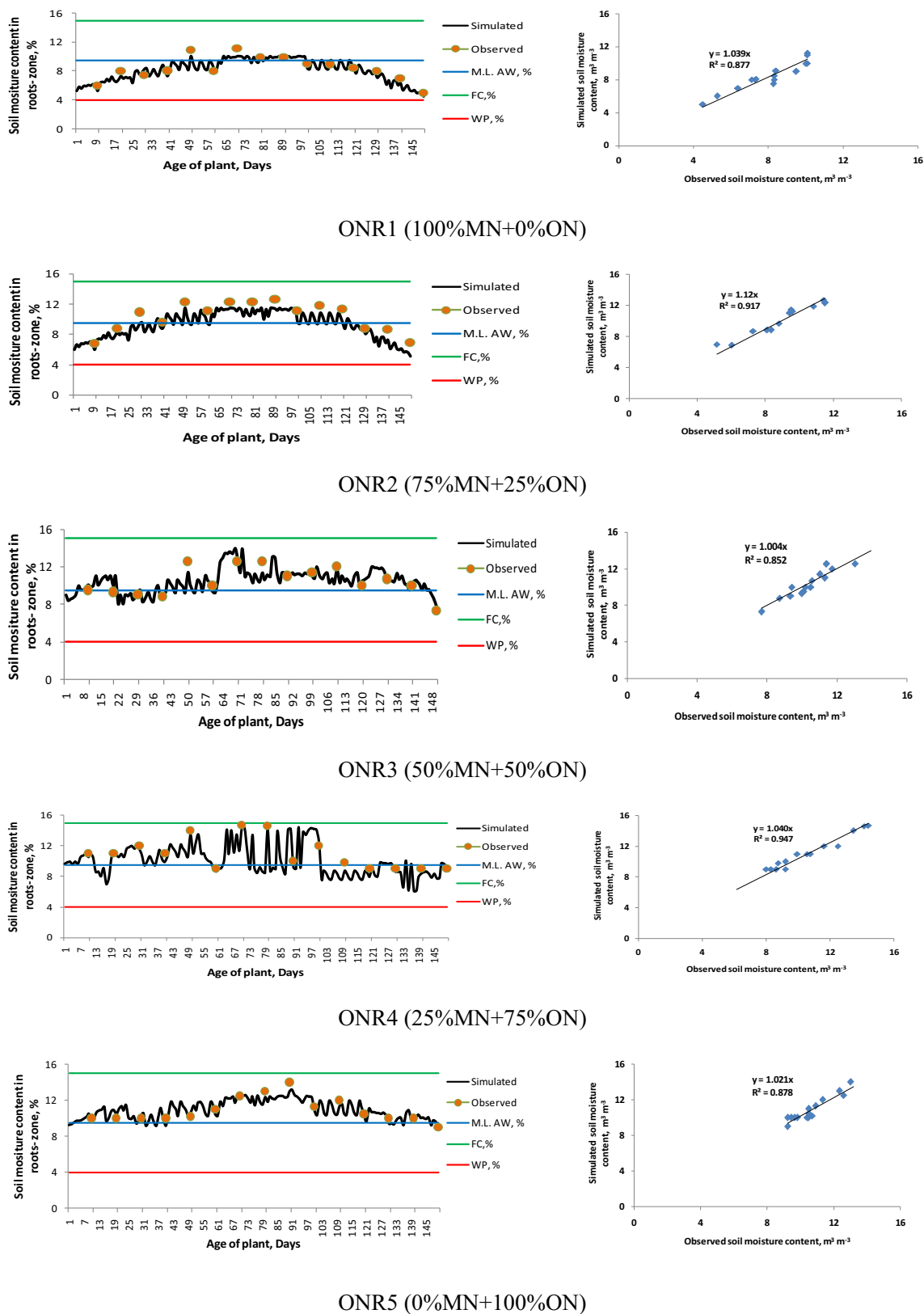
ONR2 (75%MN+25%ON)

ONR3 (50%MN+50%ON)

ONR4 (25%MN+75%ON)

ONR5 (0%MN+100%ON)

Fig. 7 Correlation between the observed and simulated soil moisture values with organic nitrogen ratio and 75% full irrigation (FI) during the 2019/2020 season. [RDI1 (100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3 (50%MN + 50%ON); ONR4 (25%MN + 75%ON); ONR5 (0%MN + 100%ON); MN (Mineral Nitrogen); ON (Organic Nitrogen)]

ONR1 (100%MN+0%ON)

ONR2 (75%MN+25%ON)

ONR3 (50%MN+50%ON)

ONR4 (25%MN+75%ON)

ONR5 (0%MN+100%ON)

Fig. 8 Correlation between the observed and simulated soil moisture values with organic nitrogen ratio and 50% full irrigation (FI) during the 2019/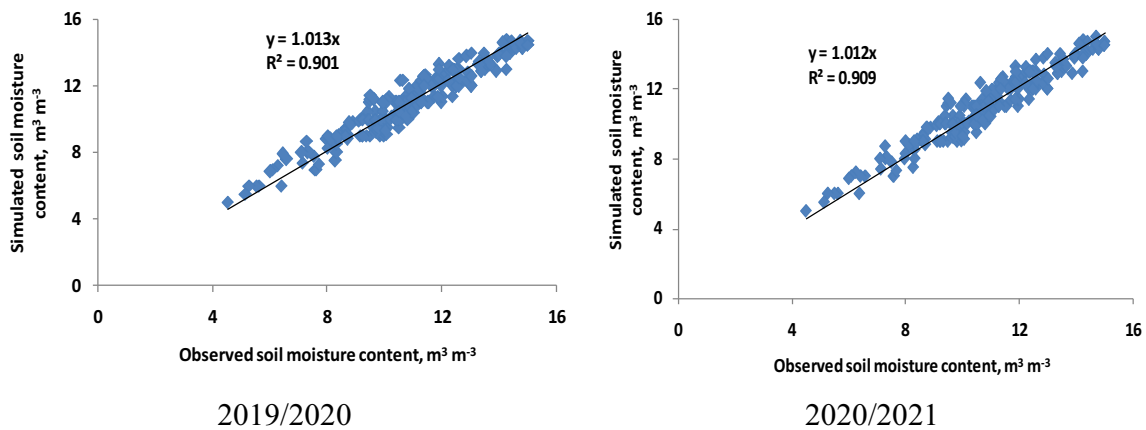2020 season. [RDI1 (100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3 (50%MN + 50%ON); ONR4 (25%MN + 75%ON); ONR5 (0%MN + 100%ON); MN (Mineral Nitrogen); ON (Organic Nitrogen)]

Fig. 9 Overall observed versus simulated soil organic matter content for all treatments

Table 6 Statistical parameters R^2, RMSE, and CRM for soil moisture in one layer (0–30 cm) for all treatments under regulated deficit irrigation and organic nitrogen ratio

Regulated Deficit Irrigation, %	The ratio of organic nitrogen to the mineral nitrogen, "ONR" %	2019/2020			2020/2021		
		R^2	RMSE	RCM	R^2	RMSE	RCM
RDI1	ONR1	0.920	0.005	0.000	0.918	0.004	0.001
	ONR2	0.917	0.004	0.004	0.929	0.004	0.003
	ONR3	0.920	0.001	0.000	0.914	0.002	0.001
	ONR4	0.860	0.005	0.003	0.911	0.005	0.001
	ONR5	0.899	0.003	0.004	0.900	0.002	0.003
RDI2	ONR1	0.901	0.006	0.001	0.905	0.004	0.001
	ONR2	0.938	0.004	0.000	0.941	0.005	0.001
	ONR3	0.889	0.002	0.002	0.928	0.003	0.002
	ONR4	0.862	0.005	0.003	0.861	0.005	0.005
	ONR5	0.897	0.005	0.002	0.898	0.002	0.001
RDI3	ONR1	0.877	0.005	0.001	0.889	0.006	0.001
	ONR2	0.917	0.003	0.001	0.919	0.003	0.000
	ONR3	0.852	0.002	0.003	0.857	0.001	0.005
	ONR4	0.947	0.004	0.003	0.968	0.003	0.003
	ONR5	0.878	0.001	0.004	0.898	0.005	0.001
Overall		0.901			0.909		

RDI1: (100%FI); *RDI2*: (75%FI); *RDI3*: (50%FI); *ONR1*: (100%MN + 0%ON); *ONR2*: (75%MN + 25%ON); *ONR3*: (50%MN + 50%ON); *ONR4*: (25%MN + 75%ON); *ONR5*: (0%MN + 100%ON); *MN*: mineral nitrogen; *ON*: organic nitrogen; *RMSE*: root-mean-square error; *RCM*: the coefficient of residual mass
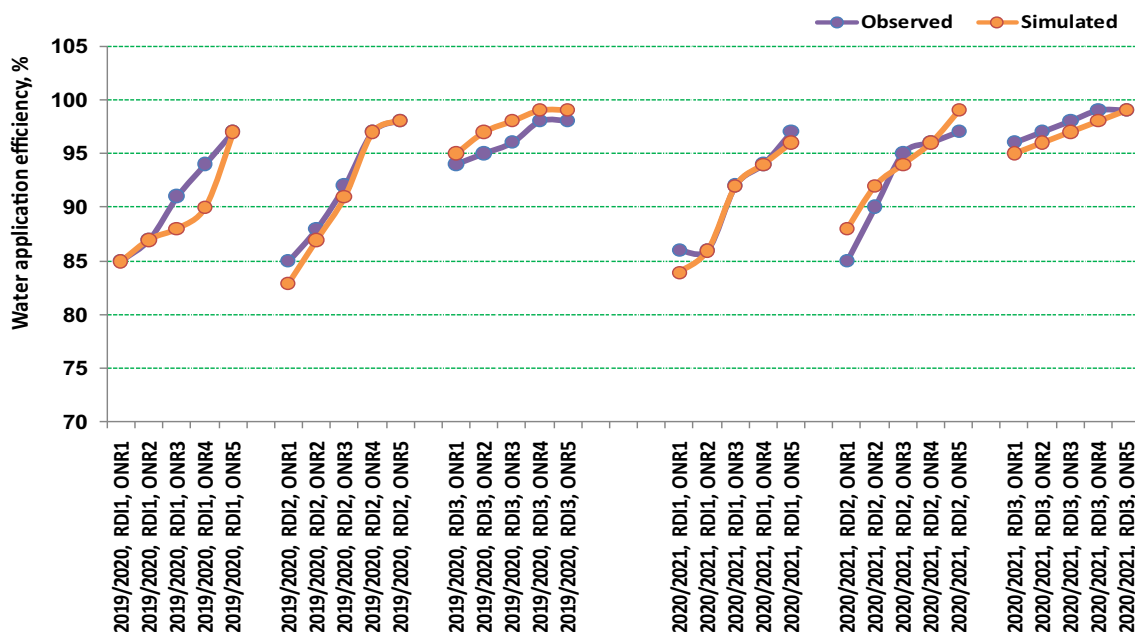
3.3 Water Application Efficiency

The WA_E is defined as the volume or depth of water that has been stored in the root zone to the volume or depth of water that has been added for irrigation.

Figure 10 indicates that the increasing of WA_E is caused by decreasing the volume of added irrigation water. The highest WA_E was observed when irrigating with 50% FI, while the lowest value was observed when irrigating with 100% FI. This was due to the increase in the volume of added water,

which increased the chance of water escaping below the root spread area by deep percolation; however, this did not happen during irrigation with 50% FI, as the small amount was stored in the root zone without any water loss. It is not demonstrable that the high water application efficiency created an environment with less water stress for the root propagation zone, but it is possible that the high water application efficiency created a dry environment with high water stress when irrigating with 50% FI, which can be observed when comparing soil moisture content in Fig. 8 and its proximity to the level of

Fig. 10 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed water application efficiency as compared to the simulated values for the average of the two seasons (RDI1 (100% FI); RDI2 (75% FI); RDI3 (50% FI); ONR1 (100%M_N + 0%O_N); ONR2 ($75\%M_N + 25\%O_N$); ONR3 ($50\%M_N + 50\%O_N$); ONR4 ($25\%M_N + 75\%O_N$); ONR5 ($0\%M_N + 100\%O_N$); M_N (Mineral Nitrogen); O_N (Organic Nitrogen))

permanent wilting when irrigating with 50% FI, as shown in Fig. 10.

Figure 10 also shows that there was an increase in the WA_E with the increase in the ONR, until it reached its highest value with fully organic fertilization without any mineral fertilizers. This is considered logical due to the ability of the organic matter to retain added irrigation water in the root zone and maintain a high soil moisture content for the longest period of time. The lowest values for the WA_E were observed when no organic nitrogen fertilizers were added, and 100% mineral fertilizers were used.

The most significant results in Fig. 10 show that the highest WA_E values were observed when irrigating with 50% FI with the addition of the highest ONR from the compost, while the lowest values were seen when irrigating with 100% FI without adding mineral fertilizers.

The results in Figs. 10 and 11 and Table 7 show the strong correlation between the field-measured WA_E values and the values simulated using the SALTMED model. The R^2 correlation coefficient was 0.907 for the 2019/2020 season, while it was 0.908 for the 2020/2021 season. These results are consistent with those obtained by [7, 36] and [37]

3.4 Soil Organic Matter Content

Table 7 shows that the SOMC values significantly decreased as the amount of irrigation water added increased. The lowest values were observed for 100% FI, and the highest values were observed for 50% FI. Table 7 shows that the SOMC values during the growing season significantly increased as the amount of organic fertilizers applied increased. The lowest values were seen when no organic fertilizers were added and the highest values were seen with 100% ONR addition in both seasons. The SOMC values increased as the amount of organic fertilizers applied increased. The highest SOMC values were under 50% FI with the addition of 100% ONR, but the lowest SOMC value was under 100% FI with the addition of 0% organic N-fertilizers. This may be due to the fact that part of the organic matter was decomposed and lost with the excess irrigation water outside the root spread area.

The results in Figs. 12 and 13 and Table 7 show the strong correlation between the measured SOMC values and the values simulated using the SALTMED model. The R^2 correlation coefficient was 0.946 for 2019/2020 season, while R^2 was 0.989 for 2020/2021 season.

3.5 Grain Yield of Wheat

The results obtained for the effect of the studied factors on the productivity of hectares of DM $_{wheat}$ were very similar to
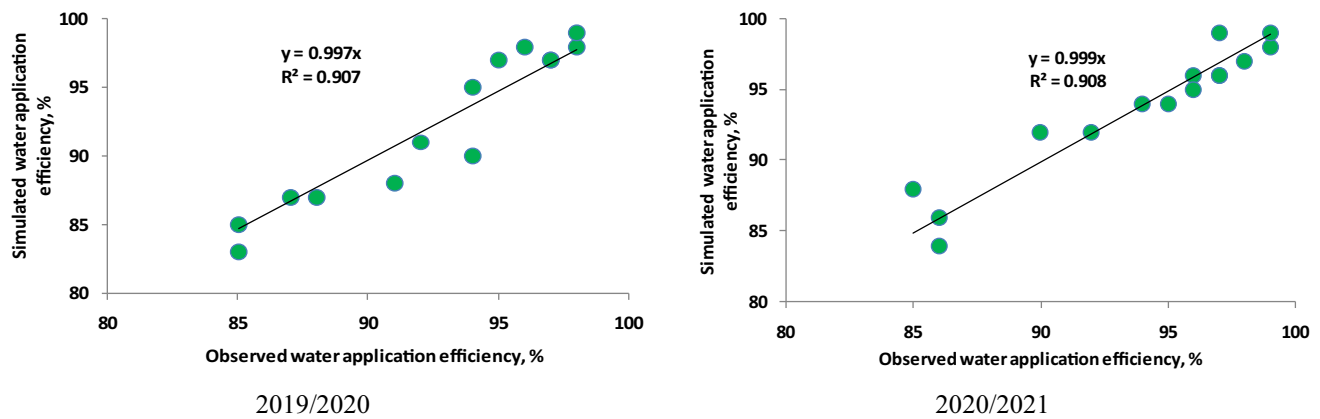
Fig. 11 Observed versus simulated water application efficiency for all treatments

those previously reported as regards the effect of the studied factors on the GY_{wheat}. Therefore, the focus of the following section is the effect of studied factors on GY_{wheat}.

In general, crop productivity decreased by the decrease in the volume of added irrigation water; however, sometimes we obtained the highest productivity when irrigating with 75% FI as compared to 100% FI. This may be due to the weak water stress when irrigating with 75% FI, which compensated for the high concentration of nutrients in the root zone. Moreover, many of the nutrients may have been washed away and diluted when irrigated with 100% FI. Figure 14 and Table 8 show that the lowest GY_{wheat} values were at 50% FI, and the highest values were at 75% FI, i.e., not when irrigating with 100% FI.

Figure 14 and Table 8 show that the GY_{wheat} values significantly increased when the amount of ONR applied was increased by up to 50%, and it decreased with the continued increase in ONR addition. This is due to the presence of two types of stress interacting dynamically: with an increase in one, the other decreases, i.e., when the soil moisture stress increases, the stress associated with nitrogen fertilization decreases. Mineral fertilization acts at the expense of organic fertilization. This resulted in increased moisture stress and decreased fertilization stress as the rate of nitrogen availability increased with mineral fertilization. The highest productivity was obtained when relying on the integrated fertilization of organic fertilizers with mineral fertilizers equally. This achieved a balance between water stress and fertilization stress and the availability of nutrients. The highest GY_{wheat} values were observed when adding 50% ONR with 50% mineral N-fertilizers, and the lowest GY_{wheat} values were seen when adding 100% ONR with no mineral N-fertilizers. These results are in agreement with those reported in [9, 12, 17, 19], and [13].

Figure 14 and Table 8 show that the interaction between RDI and ONR for GY_{wheat} had insignificant effects on wheat grain yield. Although most of the characteristics, especially

GY_{wheat}, decreased with the decrease in the amount of irrigation water added, in this study, there were no significant differences between irrigation with 100% or 75% FI. Therefore, a 75% decrease in FI may not have had any effect on the moisture stress. On the contrary, the majority of the studied characteristics were slightly higher with 75% FI, as compared with full irrigation. This may be due to nutrients not being lost to leaching, as is the case with 100% FI. The highest GY_{wheat} values were seen when adding 50% ONR with 50% mineral N-fertilizers and irrigating at 75% FI. The lowest GY_{wheat} values were observed when adding 100% ONR with no mineral N-fertilizers and irrigating at 50% FI in both seasons.

Figures 14, 15 and Table 8 show the good correlation between the observed and simulated values for dry matter and grain yield for all treatments during the 2019/2020 season, with R^2 values of 0.946 and 0.918 for all treatments, respectively. Moreover, the R^2 values for the 2020/2021 season for dry matter and grain yield were 0.924 and 0.863, respectively.

3.6 Water Productivity

The water productivity of wheat (WP_{wheat}) was calculated as the amount of grain yield produced in kg per cubic meter of irrigation water applied. The total water volume at 100% FI was 2400 $m^3 \cdot ha^{-1}$ for the 2019/2020 season and 2350 $m^3 \cdot ha^{-1}$ for the 2020/2021 season.

Table 9 shows that the WP_{wheat} values increased as the amount of irrigation water applied decreased. The lowest WP_{wheat} values were seen at 100% FI, and the highest values were seen at 50% FI. This is due to the productivity being divided by the volume of water when irrigated with 50% FI, i.e., this volume increased by double when irrigating with 100% FI.

Table 9 shows that the WP_{wheat} values significantly increased as the ONR ratio applied increased up to 50%; after

Table 7 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed water application efficiency and soil organic matter content as compared to the simulated values
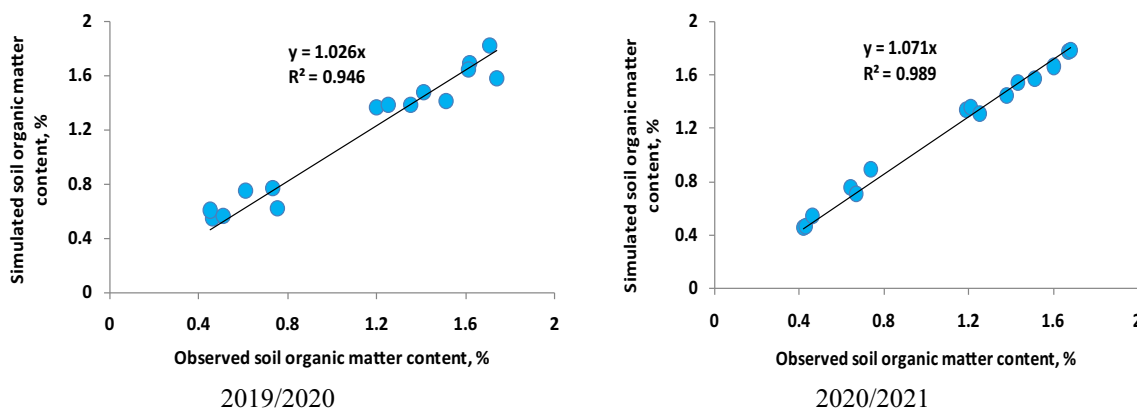
Regulated Deficit Irrigation, %	The ratio of organic nitrogen to the mineral nitrogen, "ONR" %	Water application efficiency, (%)				Soil organic matter content, (%)			
		2019/2020		2020/2021		2019/2020		2020/2021	
		O	S	O	S	O	S	O	S
RDI1	ONR1	85	85	86	84	0.46	0.55	0.42	0.46
	ONR2	87	87	86	86	0.61	0.75	0.64	0.76
	ONR3	91	88	92	92	1.20	1.37	1.19	1.34
	ONR4	94	90	94	94	1.41	1.48	1.38	1.44
	ONR5	97	97	97	96	1.62	1.69	1.60	1.66
RDI2	ONR1	85	83	85	88	0.45	0.61	0.43	0.47
	ONR2	88	87	90	92	0.73	0.77	0.74	0.89
	ONR3	92	91	95	94	1.25	1.38	1.21	1.36
	ONR4	97	97	96	96	1.51	1.41	1.51	1.57
	ONR5	98	98	97	99	1.74	1.58	1.67	1.77
RDI3	ONR1	94	95	96	95	0.51	0.57	0.46	0.55
	ONR2	95	97	97	96	0.75	0.62	0.67	0.71
	ONR3	96	98	98	97	1.35	1.38	1.25	1.31
	ONR4	98	99	99	98	1.61	1.64	1.43	1.54
	ONR5	98	99	99	99	1.71	1.82	1.68	1.78

O: observed value; *S*: simulated; *FI*: full irrigation (RDI1 (100% FI); RDI2 (75% FI); RDI3 (50% FI); ONR1 (100%M_N + 0%O_N); ONR2 (75%M_N + 25%O_N); ONR3 (50%M_N + 50%O_N); ONR4 (25%M_N + 75%O_N); ONR5 (0%M_N + 100%O_N); M_N (Mineral Nitrogen); O_N (Organic Nitrogen))
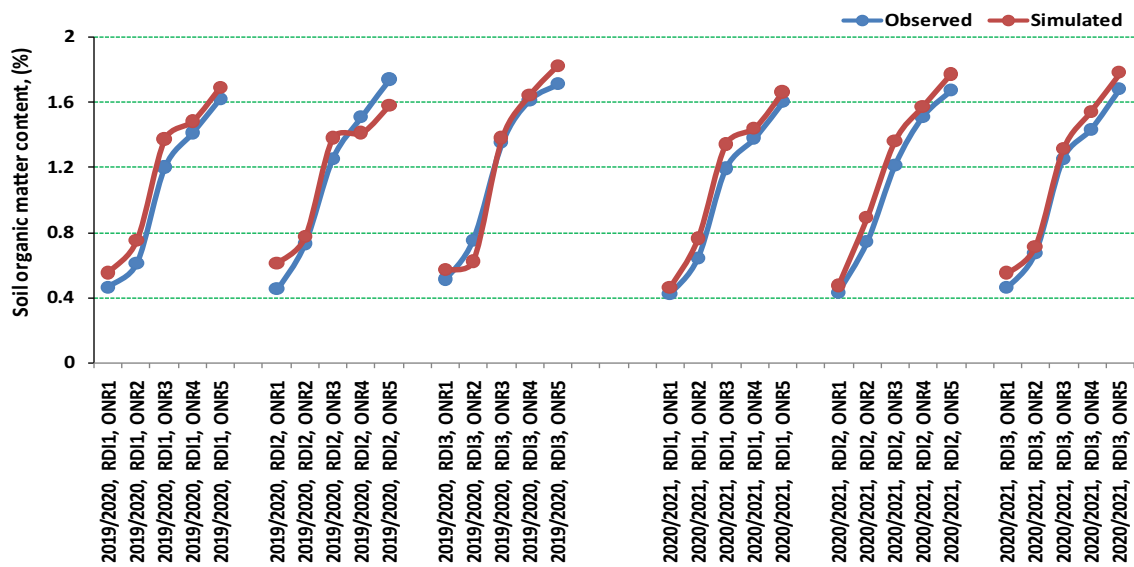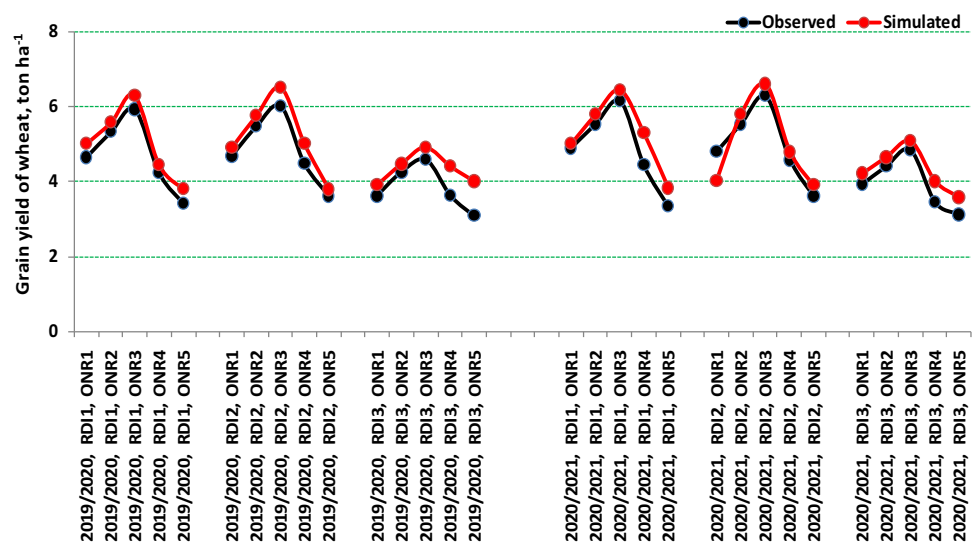
Fig. 12 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed soil organic matter content as compared to the simulated values [RDI1 (100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3 (50%MN + 50%ON); ONR4 (25%MN + 75%ON); ONR5 (0%MN + 100%ON); MN (Mineral Nitrogen); ON (Organic Nitrogen)]

2019/2020

2020/2021

Fig. 13 Observed versus simulated soil organic matter content for all treatments
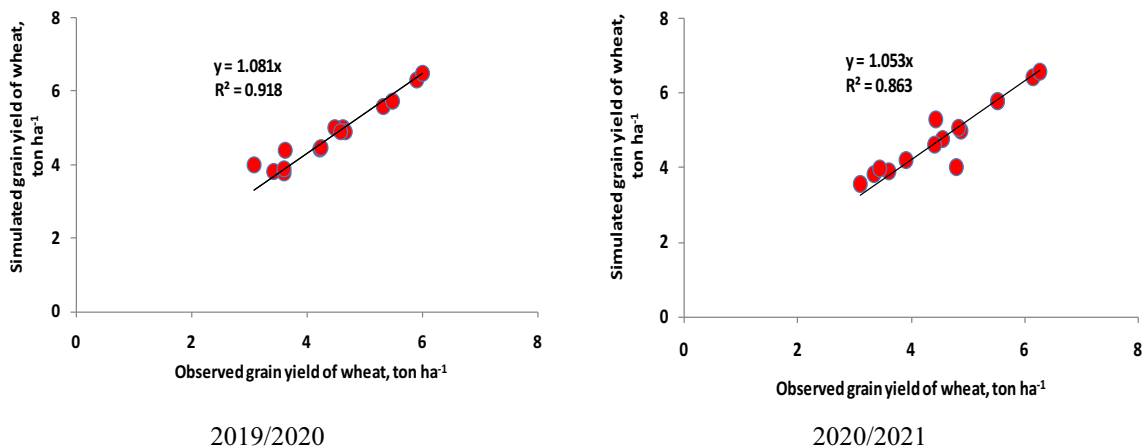
Fig. 14 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed grain yield of wheat as compared to simulated values (RDI1 (100% FI); RDI2 (75% FI); RDI3 (50% FI); ONR1 (100%M_N + 0%O_N); ONR2 (75%M_N + 25%O_N); ONR3 (50%M_N + 50%O_N); ONR4 (25%M_N + 75%O_N); ONR5 (0%M_N + 100%O_N); M_N (Mineral Nitrogen); O_N (Organic Nitrogen))

Table 8 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed dry matter and grain yield of wheat as compared to the simulated values

Regulated Deficit Irrigation, %	The ratio of organic nitrogen to the mineral nitrogen, "ONR" %	Dry matter, (ton/ha.)				Grain yield, (ton/ha.)			
		2019/2020		2020/2021		2019/2020		2020/2021	
		O	S	O	S	O	S	O	S
RDI1	ONR1	10.11	11.21	10.71	11.63	4.63	5.00	4.88	5.00
	ONR2	11.76	12.31	12.27	12.42	5.32	5.58	5.53	5.80
	ONR3	13.18	14.14	13.73	14.48	5.91	6.30	6.14	6.44
	ONR4	9.12	9.62	9.65	10.52	4.22	4.43	4.44	5.30
	ONR5	7.26	8.19	7.04	8.36	3.42	3.81	3.35	3.82
RDI2	ONR1	10.28	10.66	10.49	9.68	4.67	4.90	4.79	4.02
	ONR2	12.15	12.83	12.24	12.79	5.48	5.75	5.52	5.79
	ONR3	13.49	14.65	14.07	15.01	6.00	6.50	6.28	6.59
	ONR4	9.75	11.08	9.94	10.49	4.48	5.00	4.56	4.78
	ONR5	7.64	8.01	7.66	8.16	3.60	3.78	3.61	3.90
RDI3	ONR1	7.66	8.26	8.40	9.19	3.61	3.90	3.92	4.21
	ONR2	9.25	9.77	9.58	10.81	4.25	4.46	4.41	4.63
	ONR3	9.91	10.73	10.61	11.19	4.58	4.91	4.84	5.08
	ONR4	7.58	9.46	7.28	8.68	3.62	4.40	3.45	4.00
	ONR5	6.29	7.73	6.46	7.56	3.08	4.00	3.11	3.57
LSD at 5%						0.11		0.15	
Equation		$Y = 1.085X$		$Y = 1.064X$					
R^2		0.946		0.924					

O: observed value, *S*: simulated value, *FI*: full irrigation [RDI1 (100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3: (50%MN + 50%ON); ONR4: (25%MN + 75%ON); ONR5 (0%MN + 100%ON); *MN* (mineral nitrogen); *ON* (organic nitrogen)]

2019/2020   2020/2021

Fig. 15 Observed versus simulated grain yield of wheat for all treatments

Table 9 Effect of regulated deficit irrigation and organic nitrogen ratio on the observed water productivity and protein content of grain wheat as compared to the simulated values

Regulated Deficit Irrigation, %	The ratio of organic nitrogen to the mineral nitrogen, "ONR" %	Water productivity of wheat (kg/m^3)				Protein content of grain wheat (%)			
		2019/2020		2020/2021		2019/2020		2020/2021	
		O	S	O	S	O	S	O	S
RDI1	ONR1	1.93	2.08	2.08	2.13	10.15	9.84	10.50	10.00
	ONR2	2.22	2.33	2.35	2.47	10.5	10.68	10.72	10.39
	ONR3	2.46	2.63	2.61	2.74	10.57	10.25	10.79	10.46
	ONR4	1.76	1.85	1.89	2.26	9.43	9.74	9.69	9.39
	ONR5	1.43	1.59	1.43	1.63	7.59	6.36	9.00	8.55
RDI2	ONR1	2.59	2.72	2.72	2.28	10.35	10.03	10.59	10.00
	ONR2	3.04	3.19	3.13	3.28	10.54	10.22	10.64	10.32
	ONR3	3.33	3.61	3.56	3.74	10.59	10.77	10.95	10.62
	ONR4	2.49	2.78	2.59	2.71	9.55	9.29	10.00	8.51
	ONR5	2.00	2.10	2.05	2.21	9	8	8.89	8.22
RDI3	ONR1	3.01	3.25	3.34	3.58	8.74	8.47	8.53	8.27
	ONR2	3.54	3.72	3.75	3.94	8.91	8.64	9.28	9.00
	ONR3	3.82	4.09	4.12	4.32	9.31	9.33	10.00	9.17
	ONR4	3.02	3.67	2.94	3.4	7.27	7.55	8.27	8.02
	ONR5	2.57	3.33	2.65	3.04	6.26	6.17	6.00	6.10
Equation		$Y = 1.094X$		$Y = 1.057X$		$Y = 0.976X$		$Y = 0.951X$	
R^2		0.938		0.929		0.911		0.924	

O: observed value, *S*: simulated value, *FI*: full irrigation [RDI1 (100%FI); RDI2 (75%FI); RDI3 (50%FI); ONR1 (100%MN + 0%ON); ONR2 (75%MN + 25%ON); ONR3: (50%MN + 50%ON); ONR4: (25%MN + 75%ON); ONR5 (0%MN + 100%ON); *MN* (mineral nitrogen); *ON* (organic nitrogen)]

that, it decreased with the continued increase in the ONR. The lowest WP$_{wheat}$ values were observed when adding 100% ONR with no mineral N-fertilizers, and the highest WP$_{wheat}$ values were seen when adding 50% ONR with 50% MN-fertilizers.

Table 9 shows that RDI and ONR had significant effects on the WP$_{wheat}$, i.e., the highest WP$_{wheat}$ values occurred under 50% FI with the addition of 50%M$_N$ + 50%O$_N$. Furthermore, the lowest WP$_{wheat}$ values were seen at 100%M$_N$ + 0%O$_N$. The highest values as regards the water productivity of the wheat crop were observed at 50% FI; however, there were highly significant differences for the highest grain yield values when irrigating with 75% FI with the addition of 50% ONR with 50% mineral N-fertilizers. These results are consistent with those obtained by [22–24] and [25]

The correlation analysis for the observed and the simulated water productivity was in good agreement, with an R^2 of 0.938 for all treatments during the 2019/2020 season and 0.929 during the 2020/2021 season (Table 9).

3.7 Protein Content of Grain Wheat

Table 9 shows that the lowest protein content values for wheat (PC$_{wheat}$) were observed at 50% FI, and the highest values occurred at 75% FI. There were no significant differences between 75 and 100% FI.

Table 9 shows that the PC$_{wheat}$ values significantly increased as the ONR applied increased by up to 50%, after which it decreased with the continued addition of ONR. The lowest values were obtained when adding 100% ONR, and the highest PC$_{wheat}$ values were achieved when adding 50% ONR with 50% mineral N-fertilizers.

Table 9 shows that the PC$_{wheat}$ values increased as the amount of ONR applied increased by up to 50%, after which it decreased with the continued increase in ONR. This is due to the presence of two types of stress interacting dynamically: with an increase in one, the other decreases, i.e., when soil moisture stress increases, the stress associated with nitrogen fertilization decreases. Mineral fertilization acts at the expense of organic fertilization; this resulted in increased moisture stress and decreased fertilization stress as the rate of nitrogen availability increased with mineral

fertilization. Although most of the characteristics, especially crop yield, decreased with the decrease in the amount of added irrigation water, in this study, there were no significant differences between irrigation with 100% and 75% FI; therefore, a decrease of 75% FI may not have had any effect on moisture stress. On the contrary, the majority of the studied characteristics were slightly higher when irrigating with 75% FI as compared with full irrigation. This may be due to nutrients not being lost through leaching, as was the case with 100% of FI. These results are in agreement with those reported in [10, 18, 19], and [8].

The correlation analysis for the observed and the simulated protein contents of wheat were in good agreement, with an R^2 of 0.911 for all treatments during the 2019/2020 season and 0.924 during the 2020/2021 season (Table 9).

4 Conclusion

It can be concluded that the addition of 50% organic and 50% mineral fertilization with irrigation at 75% of full irrigation, i.e., saving 25% of the irrigation water, did not have any significant impact on the productivity and quality characteristics of wheat in sandy soil conditions in arid regions. Moreover, wheat productivity increased by 28.5% in the first season and 56% in the second season. The model simulated the water stress inside the root zone, soil moisture, water application efficiency, soil organic matter, dry matter, yield, and water productivity of wheat for all treatments for the two seasons relatively well. In summary, the field and modeling results indicate that the use of organic waste in sustainable water management in dry areas has various benefits that include a higher yield and reduced use of chemical fertilizers by up to 50%. These can be replaced with 50% organic nitrogen fertilizer from compost produced from agricultural waste, which is abundant on farms. This increases the benefits and income for farmers and reduces environmental pollution.

In arid regions, under limited water resource conditions where the effects of climate change are being felt, it is necessary to adopt sustainable farming techniques. The integrated management of fertilization is one of the most important of these. Integrated fertilization management is defined as organic fertilization in combination with mineral fertilization. It is well-known that organic fertilization includes all forms of organic agricultural waste in its production (as these wastes represent a huge loss of resources and are a severe environmental pollutant if they are not used correctly). In view of the increasing volume of agricultural waste in most developing countries, in this study, we converted this waste into compost, which is a source of organic fertilization to be used in combination with mineral fertilization. In addition, it exhibited a good ability to hold irrigation water in the area of root spread and reduce water stress on the roots of cultivated plants. In summary, organic waste, which poses a threat to the environment in the event of its repeated use, was converted into a useful and environmentally safe source of fertilization with the ability to reduce water stress in cultivated plants in areas that lack irrigation and are suffering the impact of climate change.

References

1. Siavoshi, M.; Nasiri, A.; Shankar, L.: Laware: effect of organic fertilizer on growth and yield components in rice (Oryza sativa L.). J. Agric. Sci. (2011). https://doi.org/10.5539/jas.v3n3p217

2. Abdelraouf, R.E.; El-Habbasha, S.F.; Hozayn, M.; Hoballah, E.: Water stress mitigation on growth, yield and quality traits of wheat (Triticum aestivum L.) using biofertilizer inoculation. J. Appl. Sci. Res. **9**(3), 2135–2145 (2013)

3. Okasha, E.M.; Abdelraouf, R.E.; Abdou, M.A.A.: Effect of land leveling and water applied methods on yield and irrigation water use efficiency of maize (Zea mays L.) grown under clay soil conditions. World Appl. Sci. J. **27**(2), 183–190 (2013)

4. Vengadaramana, A.; Jashothan, P.T.: Effect of organic fertilizers on the water holding capacity of soil in different terrains of Jaffna peninsula in Sri Lanka. J. Nat. Prod. Plant Resour. **2**(4), 500–503 (2012)

5. Amanullah, H.: Influence of organic and inorganic nitrogen on grain yield and yield components of hybrid rice in northwestern pakistan. Rice Sci. **23**, 326–333 (2016)

6. Ouédraogo, E.; Mando, A.; Zombré, N.P.: Use of compost to improve soil properties and crop productivity under low input agricultural system in west Africa. Agric. Ecosyst. Environ. **84**, 259–266 (2001)

7. Eid, A. R. and Negm, A.: Improving Agricultural Crop Yield and Water Productivity via Sustainable and Engineering Techniques. Book Chapter in "Conventional Water Resources and Agriculture in Egypt. Hdb Env Chem 74, 561–592 (2019), https://doi.org/10.1007/698_2018_259, Springer International Publishing AG 2018, Published online: 1 June 2018. Springer Verlag, (2019), 561–591

8. Vliegen-Verschure, A.: Fumigation using mustard seed meal instead of mustard. *EFM* **2,** 6 –7. (2013) (in Netherlands). Water Resour. Res., 44, W00E04, https://doi.org/10.1029/2007WR006200

9. Gasparatos, D.; Roussos, P.; Christofilopoulou, E.; Haidouti, C.: Comparative effects of organic and conventional apple orchard

management on soil chemical properties and plant mineral content under Mediterranean climate conditions. J. Soil Sci. PlantbNutr. **11**(4), 105–117 (2011) (**In Greece**)

10. Yih-Chi, T.; Jihn-Sung, L.; Adhikari, K.R.; Shakya, S.M.; Shukla, A.K.; Sharma, K.R.: Efficacy of mulching, irrigation and nitrogen applications on bottle gourd and okra for yield improvement and crop diversification. Irrig. Drain. Syst. **23**, 25–41 (2009)

11. NFDC : National Fertilizer Development Centre, Annual fertilizer review 2007–08. Planning and Development Division, Islamabad, Pakistan (2008)

12. Bodruzzaman, B; Meisner, C.A.; Sadat, M.A. and Hossain, M.I.: Long term effects of applied organic manures and inorganic fertilizers on yield and soil fertility in a wheat-rice cropping pattern. World Congress of Soil Science, Australia, 142–145 (2010)

13. Tadesse, T.; Dechassa, N.; Bayu, W.; Gebeyehu, S.: Effects of farmyard manure and inorganic fertilizer application on soil physic-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. Am. J. Plant Sci. **4**, 309–316 (2013). https://doi.org/10.4236/ajps.2013.42041

14. Sultani, M.I.; Gill, M.A.; Anwar, M.M.; Athar, M.: Evaluation of soil physical properties as influenced by various green manuring legumes and phosphorus fertilization under rain fed conditions. Int. J. Environ. Sci. Technol. **4**, 109–118 (2007). https://doi.org/10.1007/BF03325968

15. Akhtar, N.; Ali, A.; Ali, Z.; Iqbal, J.: Effect of integrated use of organic manures and inorganic fertilizers on grain yield of wheat. J. Agric. Res. **49**, 181–186 (2011)

16. Naeem, M.; Khan, M.M.A.; Moinuddin, K.; Siddiqui, M.H.: Triacontanol stimulates nitrogen-fixation, enzyme activities, photosynthesis, crop productivity and quality of hyacinth bean (*Lablab purpureus L.*). Sci. Hortic. **121**, 389–396 (2009). https://doi.org/10.1016/j.scienta.2009.02.030

17. Hussainy, S.: Integration of different organic manures and nitrogenous fertilizer and its effect on the growth and yield of rice. J. Pharmacogn. Phytochem. **8**, 415–418 (2019)

18. Shah, J.A.; Depar, N.; Memon, M.Y.; Aslam, M.; Sial, N.A.: Integration of organic and mineral nutrient sources enhances wheat production. Pak. J. Agri. Agril. Eng. Vet. Sci. **29**, 106–113 (2013)

19. Abdelraouf, R.E.; Abou-Hussein, S.D.; Abd-Alla, A.M.; Abdallah, E.F.: Effect of short irrigation cycles on soil moisture distribution in root zone, fertilizers use efficiency and productivity of potato in new reclaimed lands. J. Appl. Sci. Res. **8**(7), 3823–3833 (2012)

20. Feller, C.; Prestel, M.; Hartmann, H.; Straub, T.; Soding, J.; Becker, P.B.: The MOF-containing NSL complex associates globally with housekeeping genes, but activates only a defined subset. Nucleic Acids Res. **40**, 1509–1522 (2012)

21. Abdelraouf, R.E.; El-Shawadfy, M.A.; Ghoname, A.A.; Ragab, R.: Improving crop production and water productivity using a new field drip irrigation design. Plant Arch. **20**(1), 3553–3564 (2020)

22. El-Habbasha, S.F.; Okasha, E.M.; Abdelraouf, R.E.; Mohammed, A.S.H.: Effect of pressured irrigation systems, deficit irrigation and fertigation rates on yield, quality and water use efficiency of groundnut. Int. J. ChemTech. Res. **15**(01), 475–487 (2014)

23. Marwa, M. A.; Abdelraouf, R.E.; Wahba, S. W.; El-Bagouri, K. F. and El-Gindy, A. G.: Scheduling Irrigation using automatic tensiometers for pea crop. Agric. Eng. Int. CIGR J. Special issue 174–183 (2017)

24. Hozayn, M.; Abd El-Wahed, M.S.A.; Abd El-Monem, A.A.; Abdelraouf, R.E. and Ebtihal, M. Abd Elhamid: Applications of Magnetic Technology in Agriculture, A Novel Tool for Improving Water and Crop Productivity: 3. Faba Bean., Res. J. Pharm. Biol. Chem. Sci. 7(6), 1288–1296

25. Abdelraouf, R.E.; Okasha, E.M.; Tarabye, H.H.H.: Modified design for drip irrigation system to improve the productivity of irrigation water and fertilizers distribution. Int. J. ChemTech Res. **9**(9), 40–52 (2016)

26. El-Metwally, I.; Abdelraouf, R.E.; Ahmed, M.; Mounzer, O.; Alarcón, J.; Abdelhamid, M.: Response of wheat (Triticum aestivum L.) crop and broad-leaved weeds to different water requirements and weed management in sandy soils. Agriculture **61**(1), 22–32 (2015)

27. Shiferaw, B.; Smale, M.; Braun, H.J.; Duveiller, E.; Reynolds, M.; Muricho, G.: Crops that feed the world 10. Past successes and future challenges tothe role played by wheat in global food security. Food Secur. **5**, 291–317 (2013)

28. FAO: Global Information and Early Warning System. Crop prospectsand food situation. Rome, Italy: Food and Agriculture Organization of the United Nations, (2016)

29. Del Pozo, A.; Yanez, A.; Matus, I.A.; Tapia, G.; Castillo, D.; Sanchez-Jardon, L.: Physiological traits associated with wheat yield potential andperformance under water-stress in a Mediterranean environment. Front. Plant Sci. **7**, 987 (2016)

30. Bakry, A.B.; Abdelraouf, R.E.; Ahmed, M.A.; El Karamany, M.F.: Effect of drought stress and ascorbic acid foliar application on productivity and irrigation water use efficiency of wheat under newly reclaimed sandy soil. J. Appl. Sci. Res. **8**(8), 4552–4558 (2012)

31. Abdelraouf, R.E.; El-Shawadfy, M.A.; Hashem, F.A.; Bakr, B.M.M.: Effect of deficit irrigation strategies and organic mulching on yield, water productivity and fruit quality of navel orange under arid regions conditions. Plant Arch. **20**(1), 3505–3518 (2020)

32. Evans, R.G.; Sadler, E.J.: Methods and technologies to improve efficiency of water use. Water Resour. Res. (2008). https://doi.org/10.1029/2007WR006200

33. Terry, A.H.: Enhancing water use efficiency in irrigated agriculture. Agron. J. **93**, 281–289 (2001). https://doi.org/10.2134/agronj2001.932281

34. Dumas, J.B.A.: Procedes de l'analyse organique. Ann. Chim. Phys. **T47**, 198–213 (1831)

35. Kjeldahl, J.: Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. Fresenius' J. Anal. Chem. **22**, 366–382 (1883). https://doi.org/10.1007/BF01338151

36. Ragab, R.: A holistic generic integrated approach for irrigation, crop and field management: the SALTMED model. Environ. Model. Softw. **17**, 345–361 (2002)

37. Ragab, R.; Battilani, A.; Matovic, G.; Stikic, R.; Psarras, G.; Chartzoulakis, K.: SALTMED model as an integrated management tool for water, crop, soil and N-fertilizer water management strategies and productivity: field and simulation study. Irrig. Drain. **64**, 13–28 (2015)

38. Allen, R.; Pereira, L.; Raes, D. and Smith, M.: FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations 56, (1998)

39. Hozayn, M.; Abd El Monem, A.A.; Abdelraouf, R.E.; Abdalla, M.M.: Do magnetic water affect water use efficiency, quality and yield of sugar beet (Beta Vulgaris L.) plant under arid regions conditions? J. Agron. **34**, 1–10 (2013)