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Management of Biogate-Fert Technique Based on a Simulation Model

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Abstract. Biogate-fert technique ensures to optimization of fertilizer and water units yield of the potato crop. There were two field tests conducted in the growing seasons. 2019-2020 and 2020-2021, at the research farm of the National Research Centre in Nubaria region, Egypt to study the management of biogate-fert technique based on a developed SALTMED model on potato crop under drip irrigation system in sandy soil conditions. According to the findings, the SALTMED model demonstrated its capacity to forecast soil moisture availability, yield, total dry matter, and nitrogen (ppm) for two growing seasons when using mineral and biogte- fert approaches., In order to maximize crop production and nitrogen levels, the model can calculate how much irrigation supply will be needed to move the soil moisture profile from a given soil moisture to a target soil moisture. Furthermore, accurate estimation of the solute and nutrient status and uptake at the same time is contingent upon accurate simulation of nitrogen and soil moisture.

1 Introduction

Biogation technique means the application of biofertilizers (bacterial inoculum broth) through the irrigation water system (drip irrigation). In this regard, [1] explained that applying biofertilizers via irrigation water, (biogation) induced improvement in tomato yield under sandy soil conditions with considerable increase over the traditional application (fertigation). [2] stated that bio-fertilizers are living life forms utilized as a part of the preparation of soil and help supplement the typical use of substance manures and help in improving the soil. In recent decades, surface fertigation has been identified as a technology to increase fertilizer distribution uniformity and application efficiency [3]. [4] mentioned that the highest values of cabbage head yield were obtained by treatment of 100% recommended fertilizers with seedlings treated with Pseudomonas fluorescens and humic acid as compared with the other treatments. Applying bio-fertilizers via irrigation water, i.e. biogation is thought to be an alternative technique for chemigation with the consideration of the use of an appropriate injector, properly designed and operated irrigation system, and optimized

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microbial dose. [5] mentioned that through increased irrigation system efficiency, computer simulation models could result in significant water savings. [6] noted that hydraulic modeling (or simulation modeling) in surface systems is the process of mathematically describing the hydraulic characteristics of water as it flows from one end of the field to the other. [7] for these kinds of general uses, equations for crop water uptake, evapotranspiration, and water and solute transport are used in the modeling data from the literature, the model has been run for one growing season with five examples of applications. The impact of the irrigation system, the kind of soil, the salinity of irrigation water, leaching requirements, and crop production were all well depicted by the model. The goal of this study was to calibrate and validation of the SALTMED simulation model (version of 2020) [8] by using the biogate-fert technique and to evaluate this fertilizer treatment on potato yield under sand soil condition. As well as, to improve the production capacity of the limited quality land while rationalizing the use of the water and fertilizer units. The consequences of this work may help in improving the development and nature of potato tuber expanding its yield and enhancing the soil fertility.

2 Materials and Methods

2.1 Location and Meteorological data

Field tests were carried out in two potato growing seasons from 5 Nov. to 5 March of 2019-2020 and 2020-2021 at the experimental farm of National Research Center, El-Nubaria governorate, Egypt (latitude 30.8667 N, and longitude 30.1667 E, and mean altitude 21 m above sea level). The data were obtained from Central Laboratory for Agricultural Climate (CLAC) from (2019-2021) as shown in Table 1.

Table 1. Average meteorological data at the experimental site during the months of cultivation **(CLAC, 2019-2021)**

Month	T_{max} (℃)	T_{min} (℃)	RH_{mean} (%)	u_2 (m s^{-1})	R_a (MJ m^{-2} d^{-1})
November	32.5	26.2	59.6	2.2	40.7
December	35.0	28.7	63.9	2.0	41.2
January	36.6	31.9	65.3	1.9	40.6
February	35.1	30.7	65.1	1.6	37.6
March	**32.6**	**27.8**	**68.8**	**1.4**	33.0

T_{max}: Maximum value of temperature; T_{min}:Minimum value of temperature; RH_{mean}:Relative humidity mean; wind speed; solar shine; maximum duration of sunshine achieva ble; N; and extraterrestrial radiation (R_a).

2.2 Soil properties analysis

Representative soil samples were taken at different soil layer depths (0-15, 15-30, 30-45, and 45-60 cm). Soil chemical characteristics were measured as follows: Soil pH and EC were measured in 1:2.5 (soil: water suspension) and in soil paste extract, respectively. **Table (2)** shows a few of the chemical characteristics of the soil at the experiment site.

Table 2. Several chemical properties of the soil at the experimental location

Depth, (cm)	pH 1:2.5	EC, dS/m	Soluble Cations, meq/L				Soluble Anions, meq/L			
			Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO_3^{--}**	**HCO_3^{-}**	**SO_4^{--}**	Cl^{-}
0-15	8.3	0.35	0.50	0.42	1.05	0.23	0	0.11	0.82	1.27
15-30	8.2	0.36	0.51	0.43	1.04	0.24	0	0.13	0.86	1.23
30-45	8.3	0.34	0.55	0.41	1.05	0.23	0	0.12	0.85	1.27
45-60	8.4	0.73	0.57	0.43	1.06	0.25	0	0.17	0.86	1.28

2.3 Irrigation system components

A 45 m^3/h centrifugal pump, a screen filter, a backflow prevention device, a pressure regulator, pressure gauges, control valves, and a flow meter made up the irrigation system. The primary water supply was delivered from the source to the primary control locations in the field via a 110mm outer diameter (OD) polyvinyl chloride (PVC) pipe. PVC pipes with a 75mm OD were used as sub-main lines to link to the main line. Control valves, discharge gauges, and the sub-main line were connected to manifold lines, which were 63 mm OD polyethylene (PE) pipes. The emitters were constructed as 16 mm OD, 50 m long lateral PE tubes. At 1.0 bar working pressure, the emitters' discharge rate was 4 l/h, and their spacing was 30 cm Fig. (1).

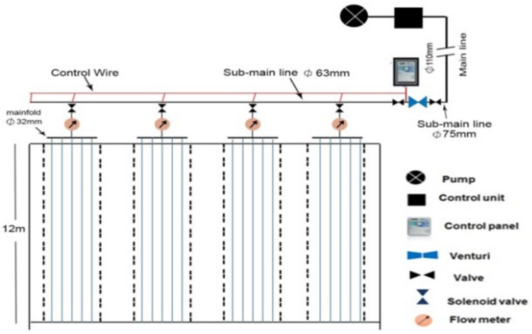

Fig. 1. Layout of the experiment.

2.4 Irrigation water analysis

An irrigation system using drip irrigation was used for the experiment. The irrigation channel that runs through the experimental site, known as Nile water, provides irrigation water with a pH of 8.3 and an electrical conductivity of 0.60 ds m-1. as shown in **Table (3).**

Table 3. Irrigation water chemical characteristics at the experimental site.

PH	**ECe dS/m**	**Soluble cations, meq/L**				**Soluble anions, meq/L**			
		Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO_3^{--}**	**HCO_3^{-}**	**SO_4^{--}**	**Cl^{--}**
8.3	**0.60**	**0.76**	**0.24**	**2.6**	**0.12**	**0**	**0.9**	**0.32**	**2.51**

2.5 Water application

Equation (1) was used to determine the amount of irrigation water needed each day for a drip irrigation system:

$$IR_g = \frac{(ET_O \times k_c \times K_r)}{E_i} - R + LR \qquad (1)$$

Where: ETO = Reference evapotranspiration, mm day-1; IRg = Gross irrigation requirements, mm day^{-1} According to [9], Kc = Crop factor. Ground cover reduction factor (Kr) and irrigation efficiency (Ei) as a percentage R = Water that a plant receives from non-irrigation sources, measured in millimeters (for instance, rainfall), LR = Water required for salt leaching, milliliters. According to [10], the gross irrigation requirements were changed from mm/ha/day to m^3/ha/day.

Table 4. Amount of irrigation water added throughout Potato growth season

Stage	stage days	Kc	ETo, mm stage^{-1}	ETc mm stage^{-1}	Total amount of irrigation water m^3 ha^{-1}
Initial	25	0.50	6.7	14.07	351.75
Development	30	0.63	5.6	14.82	444.6
Midseason	30	1.15	5.49	26.51	795.3
Late	35	0.75	6.8	21.42	744.9
Total	120		24.59	76.82	2336.5

2.6 Crop type

One crop type, Potatoes Spunta Netherland production has been selected. The plot has been applied with recommended fertilization and agronomic practices, which has been stated in the official agricultural bulletins. The experimental areas were cultivated from (5-Nov.:5-Mar.) at two seasons 2019-2020 and 2020-2021.

Table 5. Reference values of Lengths, the single crop coefficient (K_c), crop height (h), and root depth (Z_r) for the four growth stages of Potatoes [11].

Stage	Period	Days	K_c	h, m	Z_r, mm
Initial stage	5-Nov.:30-Nov.	25	0.50	0.14	0.20
Development stage	1-Dec.:30-Dec.	30	0.77	0.36	0.49
Mid-season stage	1-Jan.:30-Jan.	30	1.15	0.60	0.60
Late season stage	1-Feb.: 5-Mar.	35	0.75	0.51	0.60

2.7 Investigated techniques

2.7.1 Mineral fertilizer

Fertigation was carried out using the recommended amounts of chemical fertilizer, i.e., 288 kg ha^{-1} of nitrogen fertilizer (ammonium sulfate, 20.6 % N), 360 kg ha^{-1} of calcium super phosphate (15.5% P2O5), and 120 kg ha^{-1} of potassium sulfate (48 % K2O). Mineral fertilizers were applied by injection through the irrigation water. Fertigation applied through venture injector using 16 mm valves constructed on the opening mouse of irrigation line.

2.7.2 Bio-fertilizer

The bio-fertilizer was supported by Microbiology department Agricultural and Biological Research division, National Research Centre. It was containing a mixture of N_2-fixing bacteria (*Azotobacter chroococcum*) and (*Bacillus megaterium*) or phosphate mobilizing and (*Bacillus circulance*) or Potassium dissolving.

2.8 Treatments

1. Biogate-fert technique (bio-fertilizer during drip irrigation).
2. Mineral fertifgation technique (mineral fertilizer during drip irrigation).
3. Fertlization technique (bio+ mineral fertilizer during drip irrigation).

2.9 SALTMED Simulation model

2.9.1 Calibration procedure

The SALTMED model was fine-tuned to produce a good agreement between simulated and observed values of yield, total dry matter, soil moisture, and fertilizer distribution using data collected during the 2020–2021 season under drip irrigation and with mineral fertilizer treatment. The characteristics that were calibrated for the soil were mostly those that dealt with the upscaling of hydraulic properties applied at the field size and those assessed at the lab scale.

2.10 Validation of the SALTMED model

Comparing data on dry matter, soil moisture, and fertilizer distribution for both experimental years under the various fertilizer treatments—mineral fertilizer, biofertilizer, and mineral plus biofertilizer treatments—was how the validation was done.

2.11 Model performance

Both quantitative (statistical) and qualitative (graphical) methods were used to assess the model's performance. The simulated and measured levels of soil moisture were plotted versus time in the graphical method. As a result, the model's response can be graphically measured. Utilizing the goodness of fit test, which was introduced by [12], the statistical method entailed comparing the model's projected outcomes with the observed data. The coefficient of determination (R^2), the coefficient of residual mass (CRM), and the root mean square error (RMSE) are the quality of fit expressions. The simulations' under- or overestimation of the measurements is indicated by the RMSE values.

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

Where:
N is the total number of observations, yo is the projected value, and ys is the observed value
The ratio between the average measurement value and the dispersion of simulated values is displayed by the R^2 statistics:

$$R^2 = \left\{\frac{1}{N} \quad \frac{\sum(y_o - \bar{y_o})\,(y_s - \bar{y_s})}{\sigma y_o - \sigma y_s}\right\} \tag{3}$$

Where:
y_o^- = averaged observed value, y_s^- = averaged simulated value, σy_o = observed data standard deviation and
σy_s = simulated data standard deviation.
The following defines the coefficient of residual mass (CRM):

$$CRM = \frac{(\sum y_o - \sum y_s)}{\sum y_o} \tag{4}$$

The CRM quantifies the model's propensity to overestimate or underestimate the measurements. CRM values that are positive suggest that the model undervalues the measurements, while those that are negative suggest that the model tends to exaggerate. 0.0, 0.0, and 1.0 should be the values of RMSE, CRM, and R2 for a perfect fit between the simulated and observed data, respectively. Every analysis was performed using Microsoft Inc. Excel.

3 Results and Discussion

3.1 Nitrogen calibration

The calibrated Nitrogen (ppm) content for soil layers 0-10, 10-20, and 20-40 cm was carried out using the data of mineral fertilizers, and was compared with the values measured in the 2019-2020 growth season. Fig. (2) present the relationship between measured and simulated nitrogen (ppm). In the case of soil layers 0–10, 10–20, and 20–40 cm, the correlation coefficient (R^2) obtained values of 0.93, 0.99, and 0.99, respectively. The soil layers' levels of nitrogen (ppm) did not differ much.

3.2 Soil moisture calibration

For every soil layer, there was a strong correlation between the measured and simulated soil moisture measurements. The link between simulated and observed soil moisture is shown in Fig. (3). The soil moisture content of the soil strata did not significantly vary. SALTMED demonstrated its remarkable sensitivity in simulating abrupt changes in soil moisture brought on by irrigation operations.

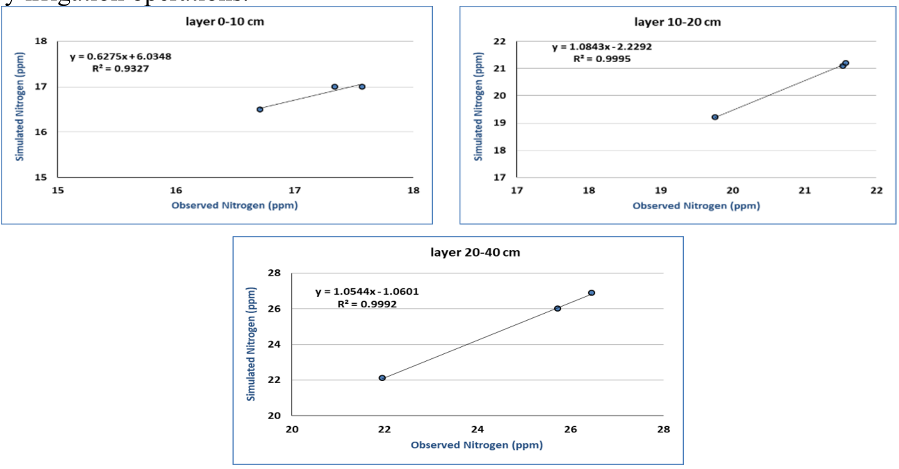

Fig.2. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for mineral fertigation during 2019-2020, simulated with SALTMED as calibration.

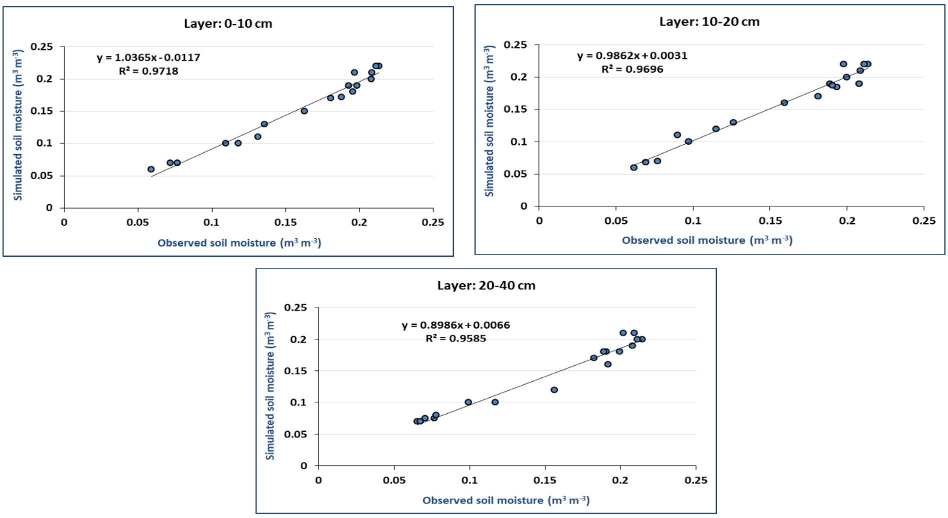

Fig. 3. Correlation between measured and simulated soil moisture in the layers from 0-40 cm for mineral fertigation during 2019-2020, simulated with SALTMED as calibration.

3.3 Dry matter calibration

The third step in calibration aimed to optimize crop growth factors that influence biomass production, such as photosynthesis. The calibrated dry matter (ton ha^{-1}) for potato crop was completed in order to compare the mineral fertigation data with the measurements made in 2019-2020. As shown in Fig. (4). the correlation coefficient (R^2) between measured and simulated dry matter reached values of 0.98. It is evident that the dry matter did not vary significantly. There is good agreement between the simulated and observed dry matter, as indicated by the estimated RMSE of 0.06 and the CRM of -0.02.

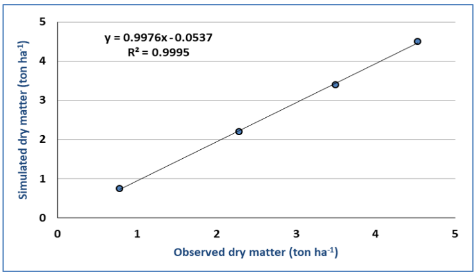

Fig. 4. Correlation between observed and simulated dry matter (ton ha^{-1}) for mineral fertigation during 2019-2020, simulated with SALTMED as calibration.

3.4 Nitrogen Validation

3.4.1 Model validation for nitrogen for season 2019-2020

The model was validated following the calibration. for nitrogen fertilization, with biogat-fet and mix (Bio-fert + mineral) fertilization techniques In the two simulation years (without adjustment). Figures 5 and 6 shows the correlation between measured and simulated nitrogen values. R^2 for biogat-fet and mix (Bio-Fert and mineral fertigation) fertilization were (0.99, 0.99 and 0.99) and (0.99, 0.99 and 0.99) respectively, for the soil layers 0-10, 10-20, and 20-

40 cm respectively. RMSE for the validated data were (0.082, 0.141 and 0.051) and (0.061, 0.066 and 0.105) and the CRM were (-0.002, -0.030 and 0.003) and (0.001, -0.023 and -0.03) with biogat-fet and mix (Bio-Fert and mineral fertigation) fertilization techniques, respectively for 0-10, 10-20 and 20-40 cm soil layers, respectively. The simulated and measured values agreed fairly well.

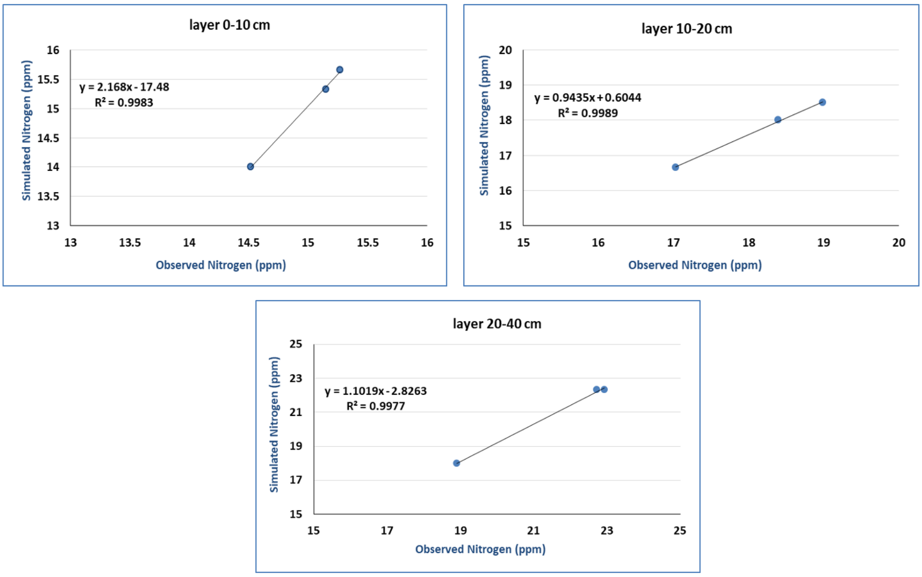

Fig. 5. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for Bio-Fert. during 2019-2020, simulated with SALTMED as validation.

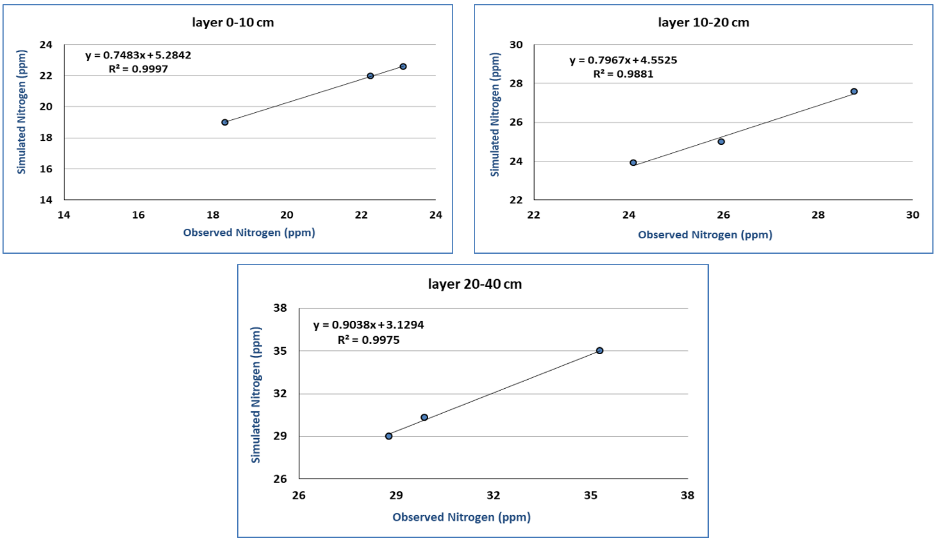

Fig. 6. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for Bio-Fert and mineral fertigation fertilization technique, during 2019-2020, simulated with SALTMED as validation.

3.4.2 Model validation for nitrogen for season 2020-2021

The model was validated following the calibration for nitrogen fertilization, with mineral, Biogt-fert and mix (Bio-Fert and mineral fertigation) fertilization techniques In the two simulation years (without adjustment). Figures 7, 8 and 9 demonstrates the relationship between the simulated and measured nitrogen values. R^2 for mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization techniques were (0.99, 0.99 and 0.99), (0.99, 0.99 and 0.99) and (0.98, 0.99 and 0.98) respectively, for the soil layers 0-10, 10-20 and 20-40 cm respectively. RMSE for the validated data were (0.048, 0.037 and 0.061), (0.069, 0.1 and 0.05) and (0.065, 0.04 and 0.073) and CRM were (0.011, 0.001 and -0.013), (-0.01, -0.006 and 0.000) and (-0.01, -0.008 and 0.005) with mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization, respectively for 0-10, 10-20 and 20-40 cm soil layers, respectively. The simulated and measured values agreed fairly well.

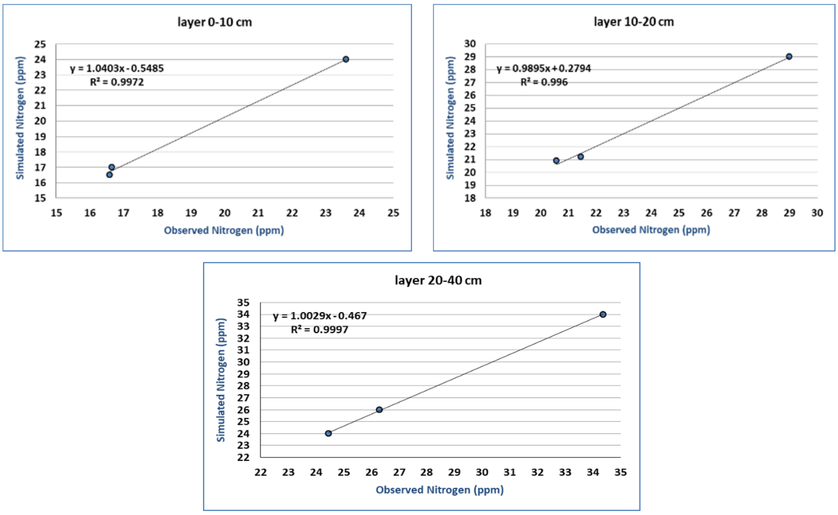

Fig. 7. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for mineral fertigation during 2020-2021, simulated with SALTMED as validation.

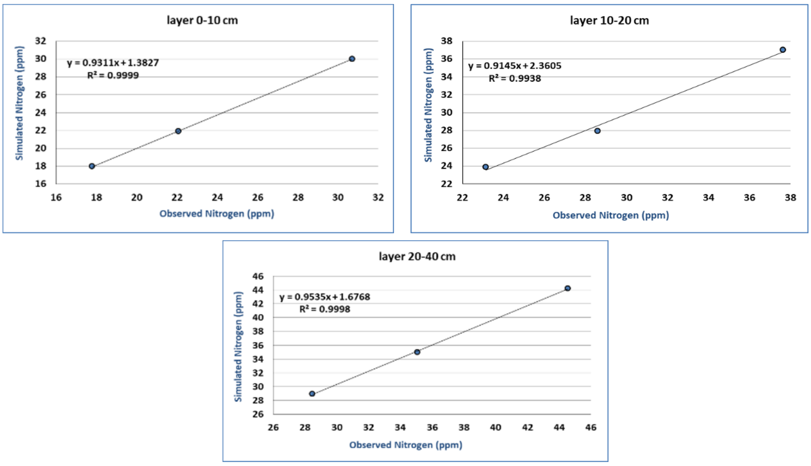

Fig. 8. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for Bio-Fert and mineral fertigation during 2020-2021, simulated with SALTMED as validation.

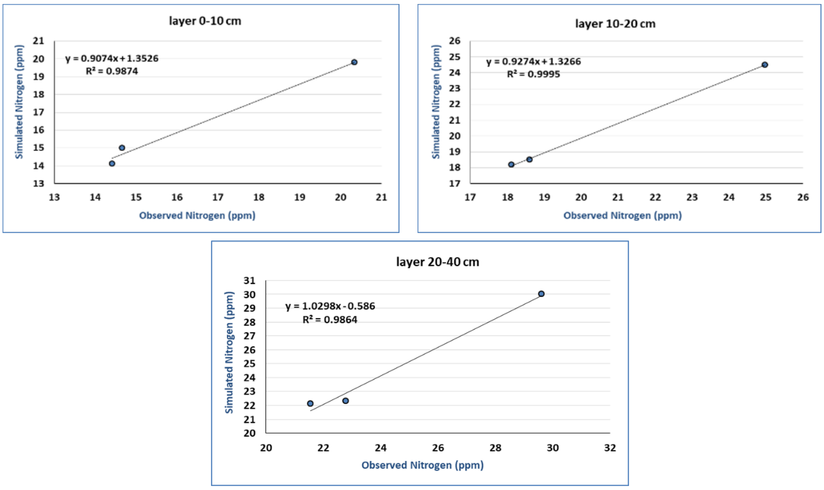

Fig. 9. Correlation between measured and simulated nitrogen in the layers from 0-40 cm for Bio-Fert., during 2020-2021, simulated with SALTMED as validation.

3.5 Model validation for soil moisture

3.5.1 Model validation for soil moisture for season 2019-2020

Following calibration, soil moisture for Biogat-Fet and mix (Bio-fert + mineral) fertilization approaches was confirmed by the model. The correlation between the simulated and measured soil moisture values is displayed in Figures 10 and 11. R^2 for biogat-fet and mix (Bio-Fert and mineral fertigation) fertilization were (0.97, 0.97 and 0.98) and (0.95, 0.97 and 0.90) respectively, for the soil layers 0-10, 10-20 and 20-40 cm respectively. RMSE for the validated data were (0.008, 0.01 and 0.01) and (0.009, 0.008 and 0.011) and CRM were (-0.01, 0.01 and 0.002) and (-0.01, -0.007 and 0.04) with Biogat-Fet and mix (Bio-Fert and mineral fertigation) fertilization techniques, respectively for 0-10, 10-20 and 20-40 cm soil layers, respectively.

The outcomes showed that the simulated and measured values agreed fairly well

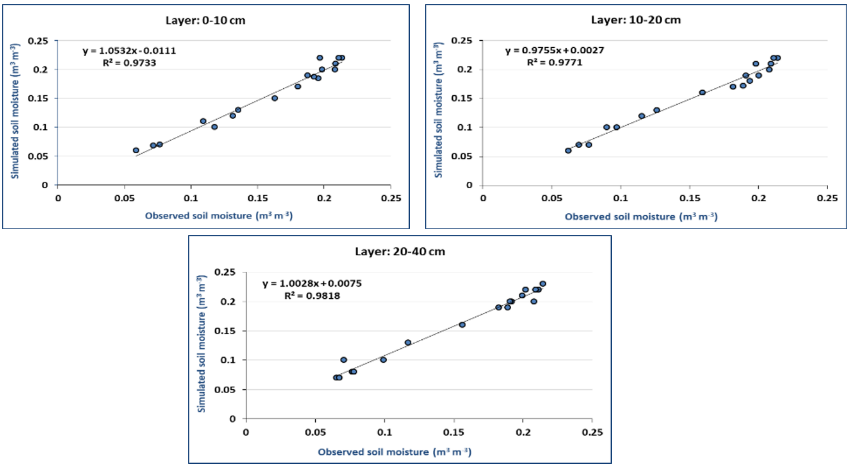

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Fig. 10. Correlation between simulated and measured soil moisture in the 0–40 cm strata for Biogate–fert. in 2019–2020, with SALTMED simulation serving as validation.

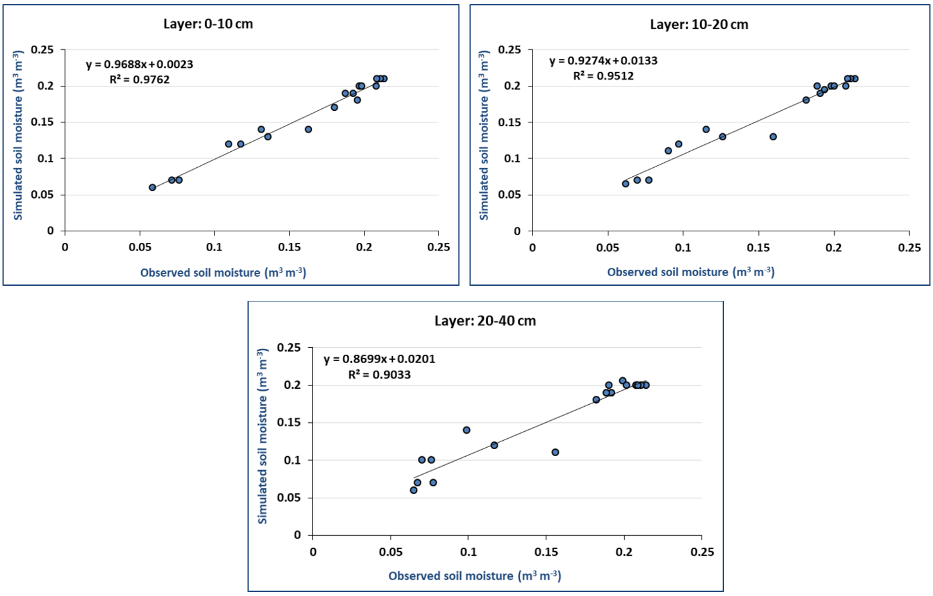

Fig. 11. Correlation between the simulated and measured soil moisture in the 0–40 cm strata for mineral fertigation and Bio-Fert in 2019–2020, validated using SALTMED simulation.

3.5.2 Model validation for soil moisture for season 2020-2021

The soil moisture model was verified with mineral, Biogat-fert and mix (Bio-Fert and mineral fertigation) fertilization techniques in both years of simulation (without adjustment). Figures (12, 13 and 14) demonstrate the relationship between the simulated and measured soil moisture levels. R^2 for mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization techniques were (0.91, 0.93 and 0.96), (0.95, 0.95 and 0.94) and (0.93, 0.92 and 0.94) respectively, for the soil layers 0-10, 10-20 and 20-40 cm respectively. were (0.01, 0.01 and 0.01), (0.01, 0.01 and 0.02) and (0.01, 0.01 and 0.01) and CRM were (0.000, 0.047 and -0.012), (0.02, 0.03 and 0.09) and (0.02, 0.05 and 0.03) with mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization, respectively for 0-10, 10-20 and 20-40 cm soil layers, respectively.

Generally, through the calculations of the [12] statistical method for estimating the fit test quality, which compares measured data with model-predicted outcomes. The outcomes demonstrated that the simulated and measured values agreed fairly well.

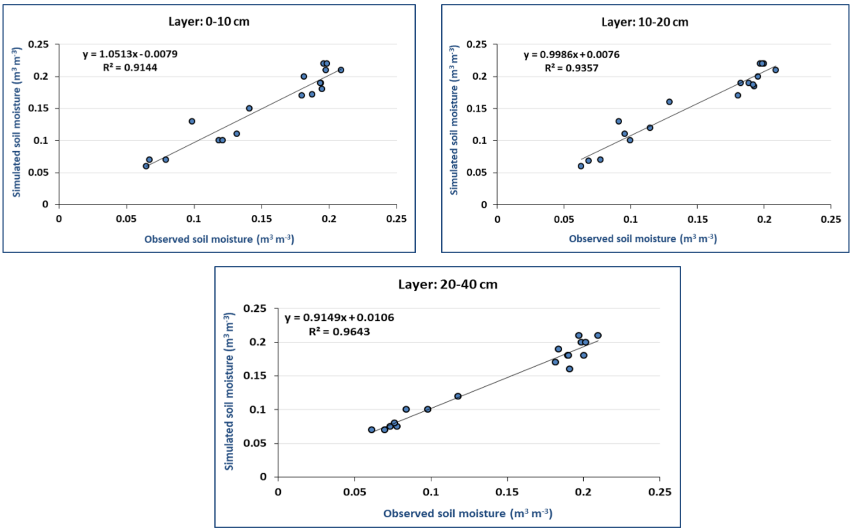

Fig. 12. Correlation between simulated and measured soil moisture in the 0–40 cm strata for mineral fertigation in 2020–2021, validated by simulation using SALTMED.

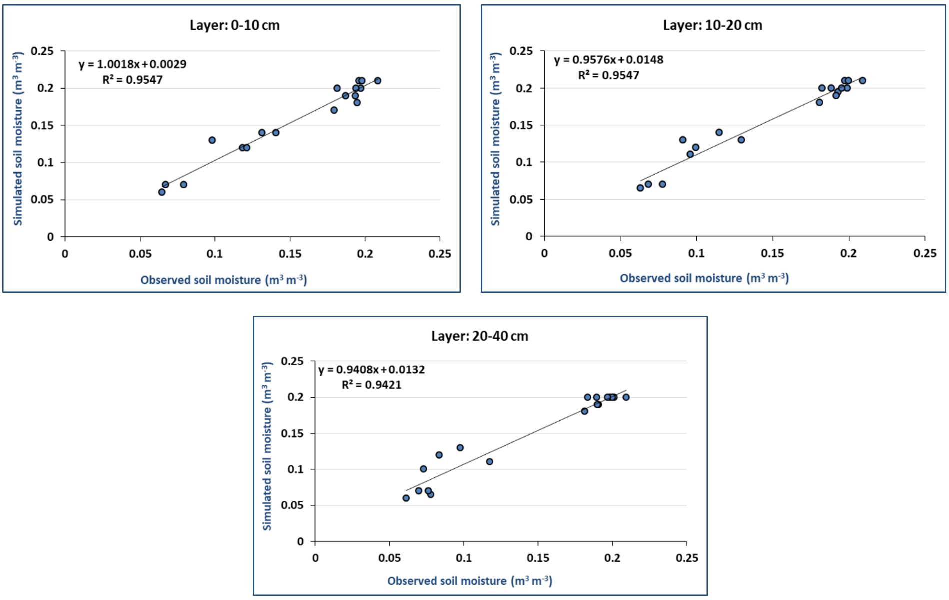

Fig. 13. Correlation between the simulated and measured soil moisture in the 0–40 cm range for mineral and bio-fert fertigation during 2020-2021, simulated with SALTMED as validation.

3.6 Model validation for total dry matter (ton ha^{-1})

Fig. 15 demonstrates the relationship between the estimated and actual total dry matter of potato (ton ha^{-1}) for mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization techniques during the two seasons. The R^2 for Total dry matter both simulated and observed was 0.99 and 0.99, RMSE was 0.11 and 0.12 and CRM was -0.02 and -0.01 for first and second seasons respectively. The simulated and measured results showed a strong degree of agreement, demonstrating the SALTMED model's effectiveness in yield prediction for hypothetical scenarios.

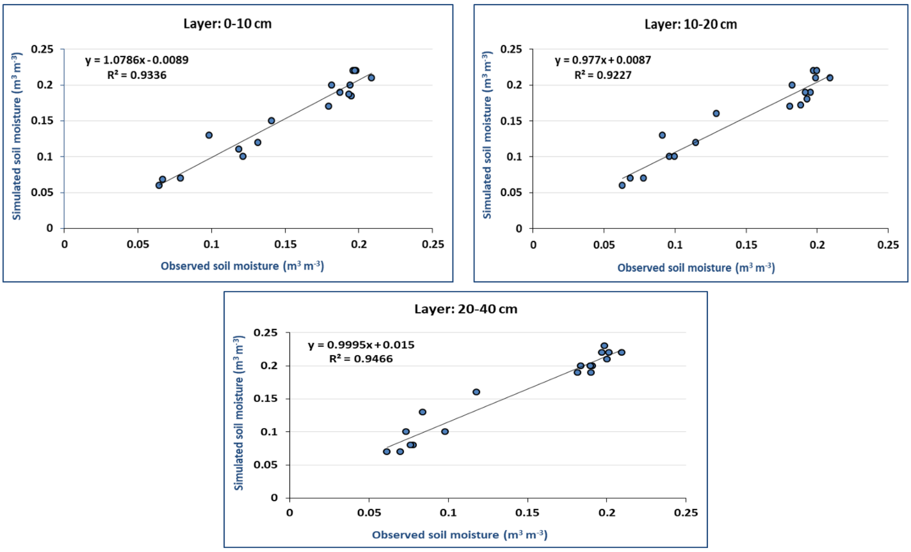

Fig. 14. Correlation between measured and simulated soil moisture in the layers from 0-40 cm for Bio-Fert., during 2020-2021, simulated with SALTMED as validation.

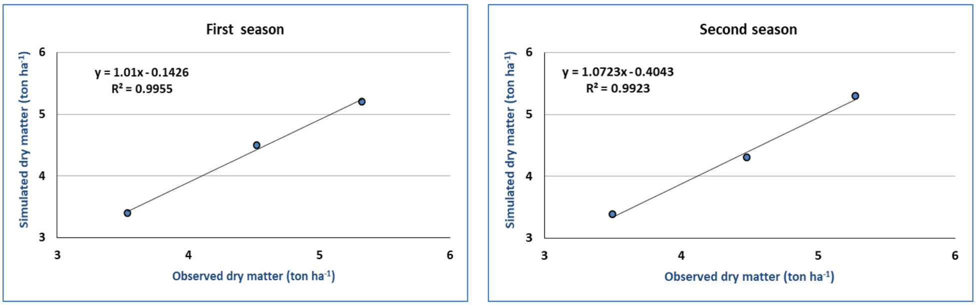

Fig. 15. Correlation between measured and simulated total dry matter of potato under mineral and biogate-fert technique for two years simulated with SALTMED as validation.

3.7 Model validation productivity (ton ha^{-1})

Fig. (16) demonstrates how the simulated and measured values correlate for potato yield (ton ha^{-1}) with mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization techniques during the two seasons. The R^2 for simulated and measured productivity was 0.99 and 0.99, RMSE was 0.3 and 0.4 and CRM was -0.002 and -0.005 for first and second seasons respectively. A strong correlation was found between the simulated and observed values, indicating the effectiveness of the SALTMED model in yield prediction for theoretical scenarios.

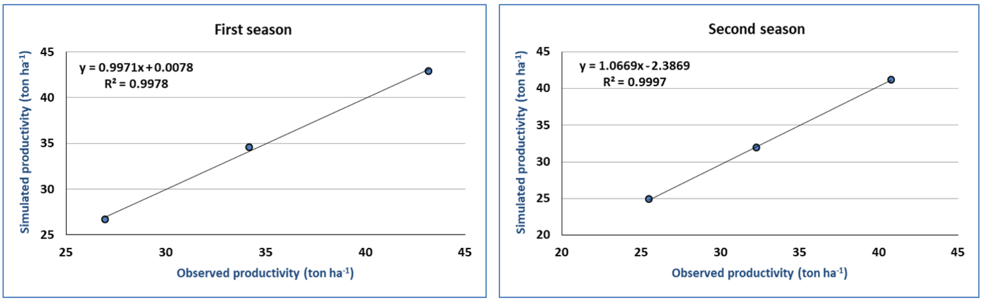

Fig. 16. Correlation between measured and simulated yield under different fertilization treatments for two years simulated with SALTMED as validation.

4 Conclusion

The SALTMED model demonstrated its capacity to forecast total dry matter, yield, soil moisture availability, and nitrogen (ppm) over the course of two growing seasons under mineral, mix (Bio-Fert and mineral fertigation) and Biogt-fert fertilization techniques With a respectable level of confidence, the SALTMED model can be utilized in prediction mode with "what if" field management scenarios. The outcomes verified that the model is capable of managing many simultaneous hydrodynamic processes occurring in the soil, crop, water, and atmosphere continuum. Practical consequences arise from accurate model prediction of soil moisture content and nitrogen (ppm). It indicates that the model can calculate how much irrigation is needed to raise the soil moisture profile from a given soil moisture to a target soil moisture in order to maximize both the amount of nitrogen and crop production. Furthermore, accurate estimation of the solute and nutrient status and uptake at the same time is contingent upon accurate simulation of nitrogen and soil moisture.

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