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Modeling the Effect of Planting Dates and Nitrogen Application Rates on Potatoes Water Productivity in Jordan Valley

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Abstract

Agricultural sector in Jordan is facing serious challenges in meeting the growing needs of food security because of its low water availability. Maintaining and enhancing agricultural water productivity under such prevailing environmental constraints are hard to achieve. Potatoes water productively in Jordan Valley was modeled using Decision Support System for Agrotechnology Transfer (DSSAT) under six nitrogen applications (0, 60, 80, 100, 120 and 140 kg/ha) and twelve planting dates every two weeks from October 1 to March 15 scenarios. The potatoes yield increased from 0% to 100% nitrogen treatment and then no considerable increase occurred. The potatoes' crop yield increased from October 1st to January 15 and then decreased after which until the last day of planting date. The seasonal cumulative crop evapotranspiration for potatoes about doubled from 0% to 60% nitrogen treatment and then kept increasing gradually until the last treatment. The growing season cumulative crop evapotranspiration for potatoes increased gradually from October 1 to March 1. The water productivity increased from 0% nitrogen treatment to 100% and then decreased. The potatoes' water productivity increased from October 1 until November 15 and then decreased to the end. From these results, we recommend that 100% of nitrogen requirements should be applied. The best window for potatoes' planting date is the last two weeks in November.

Keywords

Deficit Irrigation, Potatoes, DSSAT, Nitrogen Application, Planting Dates, Water Productivity

1. Introduction

Agricultural sector in Jordan is facing serious challenges in meeting the growing needs of food security. One crucial aspect of the challenges is water scarcity as Jordan is the second in water scarcity worldwide [1]. Jordan has a dry climate with low and erratic precipitation patterns thus imposing high pressures on the limited available water resources. Maintaining and enhancing agricultural sustainability and water productivity, under such prevailing environmental constraints, are hard to achieve especially because of the dramatic increase of the Jordanian population in the last decade mainly related to the high national growth rate coupled with the incoming refugees. The increasing gap between limited water supply and increasing demand in Jordan requires careful policies and programs to conserve and manage water properly. Water conservation is a means of enhancing water availability by managing both supply and demand. Generally, this can be addressed by enhancing the efficiency of use through the utilization of improved water-saving technologies and management practices, and the behavior modification of current practices through, in part, public awareness programs [2].

Improving water productivity is a critical aspect of comprehensive water resources management. Water productivity may be defined as the ratio between the crop yields achieved and crop water consumption or evapotranspiration [3]. The need to increase food crop productivity to feed a growing population under increasing scarcity of water increases the challenge of obtaining higher crop water productivity (CWP). This challenge can be formulated into two simpler objectives: increase crops yield and/or decrease irrigation water. The wide range of crop water productivity offers tremendous opportunities for maintaining or increasing agricultural production with 20% - 40% fewer water resources [4].

The variability of CWP can be ascribed to: climate; irrigation water management, soil (nutrient) management and varietal improvement [5] provided several strategies for enhancement of CWP by integrating varietal improvement and better resources management at plant level, field level and agro-climatic level. Examples of options and practices that can be taken to increase crop yield, improve drought tolerance and salinity tolerance (plant level), apply deficit irrigation, adjust the planting dates and tillage to reduce evaporation and to increase infiltration (field level), water reuse and spatial analysis for maximum production (agro-ecological level).

Climate change has become a challenge for most countries in the world especially the developing countries and according to the fourth assessment report of the Intergovernmental Panel on Climate Change [6]. Jordan is more vulnerable to these changes in light of the available resources, technological and institutional constraints. The main reasons for the high susceptibility to climate change are the dependency on agricultural sector, the lower per capita incomes and the low accessibility to technology. As a result of climate change in Jordan, due to increasing air temperature the agricultural water demand increases and due to decreasing precipitation the supply declines which enlarged the gap between water supply and demand.

In developing countries, inappropriate agricultural practices in addition to the environmental impacts might be the major challenges to attain sustainable agriculture due to the lack of some modern agricultural knowledge of either investors or decision-makers [7]. Some of these inappropriate agricultural practices are an incorrect selection of suitable crops and varieties, lack of awareness of adapted management and techniques related to environmental changes, improper applications of fertilizers, pesticides and irrigation water and incongruous planning and erroneous decisions.

The generation of new data through traditional agronomic research methods and its publication is not possible to meet the increasing needs. Traditional agronomic experiments are conducted at particular points in time and space, making results site- and season-specific, time-consuming and expensive [8]. Therefore, using crop simulation models for predicting crop performance in different environments can be a helpful tool to attend the aims of those conventional researches in shorter time and less expensive manner.

Crop simulation models are tools for research that combine soil, plant, and climate systems together, which facilitates the understanding of the role of the different variables and their interaction. Recently, many researches had used these models to assess crop yield risk and the vulnerability of agriculture to climate change [9]. The Decision Support System for Agrotechnology Transfer (DSSAT) is a process-oriented crop simulation model for over 42 crops [10]. DSSAT simulates growth, development and yield as a function of the soil-plant-atmosphere dynamics. DSSAT is the most widely used crop simulation model in the world [11].

Potato (Solanum tuberosum L.) is the fourth crop produced worldwide after rice, wheat and corn with a total global potatoes production of 370 million tons in 2019 [12]. There has been a dramatic increase in potato production and demand in Asia, Africa and Latin America, where the yield rose from less than 30 million tons in the early 1960s to more than 381 million tons in 2019 (http://www.potatopro.com/world/potato-statistics). [13] showed that, for the first time, the developing world's potato production exceeded what was produced by the developed world. In Jordan, potatoes were the second in the area planted to vegetable after tomatoes in 2019. In Jordan, the total area planted with vegetables, in 2019, was 48 thousand ha. The total production of tomatoes, cucumber and potatoes were 597, 103 and 379 thousand tones, respectively.

The Decision Support System for Agro Technology Transfer (DSSAT) model was used to simulate the effects of deficit irrigation at different growth stages on potatoes yield and productivity in Jordan Valley however other factors such as planting date and nitrogen application were not studied [14]. A Field experiment was carried out during 2015/2016 season at the Agricultural Research Station–The University of Jordan in the Jordan Valley to calibrate DSSAT. The experiment had three irrigation treatments (WI 100%, WII 75%, WIII 50%) of the readily available water (RAW). Results of the field experiment showed that significant differences existed between the different irrigation treatments in the tubers yield, tubers weight, tubers number and plant height. The simulated SUBSTOR-Potato model of leaf area index, soil water content and tubers yield were in a close agreement with the measured ones.

This study aimed to model planting dates and nitrogen applications on potatoes productivity in Jordan Valley.

2. Material and Methods

Jordan Valley is the major agricultural productive area in Jordan, including crops such as vegetables, palm trees, and citrus. More than 60% of the irrigated area in the country is located in the Jordan Valley.

2.1. Experimental Site

The study was carried out at the Agricultural Experimental Station of Jordan University in the Jordan Valley. The Station is located at 32˚50'N, 35˚34'E and 255 m blow sea level. Climate is warm in winter and hot in summer. NASA power daily minimum and maxim air temperature, relative humidity, wind speed and solar radiation for one thirty years from 1990 to 2020 were used. The average annual rainfall and average temperature in the study area for these years was 368 mm/year and 19.4 C, respectively (Table 1). The high temperatures in Jordan Valley allows for planting summer crops in winter time, leading to higher area productivity and ability to grow more crops. Average relative humidity was 62% while average wind speed was 0.7 m/s which is low.

The soil is classified as Hyperthermic, Typic Torriorfluents [15]. The soil texture of the experimental site is sandy clay loam with a pH ranging from 7.4 to 8.1 and electric conductivity (EC) from 0.46 to 0.63 ms/cm. Field capacity ranged from 0.285 to 0.298 while permanent wilting point from 0.129 to 0.139 cm^3/cm^3 (Table 2).

Table 1. Weather parameters in the experimental site.

Weather parameter	Average	Minimum	Maximum
Precipitation (mm)	368	240	443
Temperature (˚C)	19.4	−0.4	46.7
Relative Humidity (%)	62	10.7	98.6
Solar radiation ($Mj/day/m^2$)	19.2	0.9	31.8
Wind speed (m/s)	0.7	0.2	2.1

Table 2. Some soil physical and chemical properties of the experimental site.

Soil depth (cm)	Texture	FC (%)*	PWP (%)*	EC (ds/m)	$CaCO_3$ (%)	pH	Total N (%)	P Ppm	K ppm
0 - 20	Sandy clay loam	29.3	13.9	0.467	24.9	7.4	0.45	60.7	62.4
20 - 40	Sandy clay loam	28.5	12.9	0.627	25.6	8.01	0.51	40.6	56.1
40 - 60	Sandy clay loam	29.8	13.6	0.473	24.7	8.1	0.49	42	52.1

*: volumetric basis.

Potatoes water productively in Jordan Valley was modeled using Decision Support System for Agrotechnology Transfer (DSSAT) version 4.7.5 under six nitrogen applications (0, 60, 80, 100, 120 and 140 kg/ha) and twelve planting dates every two weeks from October 1 to March 15 scenarios using the genetic coefficients obtained from [14] study for 31 years from 1990 to 2020. 225 Kg/ha of nitrogen was used for the 100% nitrogen treatment. Irrigation in the simulation was set automatically to give enough water in order to avoid any water stress. In the planting date simulation, 225 kg/ha of nitrogen was used which is recommended in the area. For the different nitrogen treatments, planting date was set for December 20. Planting density was 5.1 tuber/m^2.

2.2. Method of Calculation Water Productivity

Water productivity (WP) for all treatments was calculated according to the following Equation (1).

$$WP\left(\text{kg/mm}\right) = Y\left(\text{kg}\right) / ETc\left(\text{mm}\right) \tag{1}$$

where (Y) is dry weight potato yield for each treatment, (ETc) is crop evapotranspiration to each treatment in mm. Water productivity (WP) describes the relationship between production and the amount of water used.

2.3. Model Description

The DSSAT-version 4.7.5 model is a product application program that comprises crop simulation models for more than 40 crops (WWW.DSSAT.net). It is used to predict crop development and growth, to help decision making. DSSAT-v4.7.5 SUBSTOR-potato was used to simulate potato production and water productivity. The model describes daily phonological development and growth in reaction with factors related to weather, soil and crop management. Crop models are controlling devices that illustrate crop advancement and development as utility of crop management, soil conditions and climate [16]. The SUBSTOR-potato model is part of a group of crop models in the DSSAT-CSM (Decision Support Systems for Agro-innovation Transfer—Crop Simulation Model) programming [8] [10]. The DSSAT also has the capability to simulate changes in soil water, carbon and N that occur during crop development phase. The DSSAT shell allows the user to input, store, and output information for crop simulations, sensitivity analyses, model calibrations, and model evaluation.

3. Results

3.1. Crop Yield

The potatoes yield ranged from 3002 kg/ha for 0% nitrogen treatment to 10477 kg/ha for 140% nitrogen treatment (**Table 3**). The potatoes yield increased from 0% nitrogen treatment to 100% nitrogen treatment and then no considerable increase occurred. The potatoes yield at 80% nitrogen treatment was 3 folds the potatoes yield at 0% nitrogen treatment while potatoes yield at 100% nitrogen

Table 3. Nitrogen impact on potatoes yield, cumulative evapotranspiration and water productivity.

Treatments	Yield (kg/ha)	Cumulative evapotranspiration (mm)	Water productivity (kg/mm)
0	3002	153	19.6
60	7832	299	29.1
80	9068	309	29.3
100	10,399	328	31.7
120	10,028	359	27.9
140	10,477	373	28.1

treatment was about 3.5 folds the potatoes yield at 0% nitrogen treatment.

Similar results were found in a two-year experiment conducted in Sicily, Italy with three 3 N-P-K fertilization rates (low: 50, 25 and 75 kg·ha^{-1}, medium: 100, 50 and 150 kg·ha^{-1} and high: 300, 100 and 450 kg·ha^{-1} of N, P_2O_5 and K_2O) [17]. They found that high rate of N-P-K fertilization was the best treatment and gave higher aboveground biomass, tuber yield, and sink/source ratio. Also, similar findings were reported in field trials carried out at the State Priekuïi Plant Breeding Institute from 2009 till 2012 [18]. Nine fertilization treatments were applied: no fertilization; PK dose to provide potato yield of 40 t·ha^{-1}; and the remaining seven treatments s with a PK dose plus increasing N amount from 30 to 210 kg·ha^{-1} by 30 increments. The results of the four-year experiment years indicated that an increase in nitrogen fertilizer rate up to N120 kg·ha^{-1} increased the potato yield.

Countries with high-input agriculture, such as the USA and France can reach an average potato yields more than double that for countries with low input [19]. Nitrogen has the highest effect on potato yield formation among all essential macronutrients. That is why this quite increases of potatoes yield with increasing nitrogen application until the 100% nitrogen treatment is expected because nitrogen is a primary macronutrient and is needed more during vegetative growth stage and tuber bulking [17]. During the first half of the vegetation period, when the tops grow intensively, potatoes are demanding for nitrogen. Usually, better vegetative growth in potatoes leads to more yield and better tube bulking leads to larger potatoes [19].

The potatoes' crop yield went from 454 kg/ha for planting date of October 1st to 7382 kg/ha for 15th of January treatment (**Table 4**). The potatoes' crop yield increased from October 1st to January 15 and then decreased after which until the last day of planting date March 15th. The potatoes yield on January 15th was more than 16 times that on October 1.

Similar results were found in a study using SIMDualKc model to simulate the effect of four planting dates namely 16 February, 3 March, 17 March and 1 April on potato yields in Italy [20]. They showed that yields varied a lot with the

Table 4. Planting dates impact on potatoes yield, cumulative evapotranspiration and water productivity.

Treatments	Yield (kg/ha)	Cumulative evapotranspiration (mm)	Water productivity (kg/mm)
1/10	454	104	13
15/10	584	122	16
1/11	738	137	15
15/11	772	151	39
1/12	2444	176	33
15/12	4642	212	24
1/1	7131	268	18
15/1	7382	312	8
1/2	6976	337	10
15/2	7143	357	3
1/3	6671	360	3.1
15/3	5824	352	3.3

planting date with higher yields for the first two dates. In another study in China, APSIM-Potato model was used to model the impact planting date on yield [21]. They found that optimal planting dates were May 20 and May 30 in the, middle and western APE, respectively. Yield of potato could be increased by 12.5% in the middle APE and 23.3% in the western APE.

In general, early planting of potato would lead to slow emergence and seedling growth rate due to low soil temperature and may face frost while delayed planting decreases the growing season as a result of higher temperature, harvest index and leaf area index (LAI), yield and water productivity of potato [21].

3.2. Crop Evapotranspiration

The cumulative crop evapotranspiration for potatoes ranged from 153 mm for 0% nitrogen treatment to 373 mm for 140% nitrogen treatment (**Table 3**). The cumulative crop evapotranspiration for potatoes about doubled from 0% to 60% nitrogen treatment and then kept increasing gradually until the last treatment.

In a two-year experiment conducted in Sicily, Italy, they found that irrespective of the rate of fertilization, the cumulative crop evapotranspiration was similar for the different treatments. However, for the 100% irrigation treatment, the cumulative crop evapotranspiration significantly increased for the higher fertilization rate compared to low and medium fertilization rates [17].

The cumulative crop evapotranspiration for potatoes went from104 mm for 1st of October to 360 mm for March 1 (**Table 4**). The cumulative crop evapotranspiration for potatoes increased gradually from October 1 to March 1. The cumulative crop evapotranspiration for potatoes for March 1 was about three and half folds that of October 1.

Similar results were obtained for the effect of planting dates on the cumulative crop evapotranspiration which increased with delaying planting date in all three regions in the China study using SIMDualKc model [20].

3.3. Water Productivity

The potatoes' water productivity ranged from 19.6 kg/mm for 0% nitrogen treatment to 31.7 kg/mm for the 100% nitrogen treatment (**Table 3**). The water productivity increased from 0% nitrogen treatment to 100% and then decreased. The water productivity of the 100% nitrogen treatment was more than one and half that of 0% nitrogen treatment.

In a two-year experiment conducted in Sicily, Italy, they found that water productivity was similar for the 100% irrigation treatment for the different fertilization treatments, however, it increased considerably for the higher fertilization rate compared to low and medium fertilization for the 50% irrigation treatments [17].

The potatoes' water productivity went from 13 kg/mm for date of planting on 15 February to 39 kg/mm for November 15 date of planting treatment (**Table 4**). The potatoes' water productivity increased from October 1 until November 15 and then decreased to the end. The potatoes' water productivity for November 15 was threefolds of that of October 1.

Similar results were obtained for the effect of planting dates on water productivity which increased with delaying planting date in all three regions in the China study using SIMDualKc model [20].

4. Conclusion

The effect of different nitrogen amounts from 0 to 140 % of nitrogen requirements and planting dates every two weeks from October 1st to March 15th on potatoes' water productivity was studied. The potatoes yield was lowest at 0% nitrogen treatment while it was at 80% nitrogen treatment 3 folds that of 0% nitrogen treatment while at 100% nitrogen treatment was about 3.5 folds at 0% nitrogen treatment. The minimum potatoes yield was at October 1st treatment and increased more than 16 times on January 15. The cumulative crop evapotranspiration for potatoes about doubled from 0% to 60% nitrogen treatment and then kept increasing gradually until the last treatment. The cumulative crop evapotranspiration for potatoes increased gradually from October 1 to March 1. The water productivity of the 100% nitrogen treatment was more than one and half that of 0% nitrogen treatment which had the lowest water productivity. The potatoes' water productivity for November 15 was threefolds of that of October 1 which was the minim. The 100% nitrogen requirements and the last two weeks in November as planting dates are recommended because they had the highest yield water productivity.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] United Nations International Children's Emergency Fund (2021). https://www.unicef.org/jordan/water-sanitation-and-hygiene

[2] Haener, P. (2018) The Handbook of Water Information Systems, Administration, Processing, Exploitation of Water Related Data.

[3] Pereira, L.S., Cordery, I. and Iacovides, I. (2012) Improved Indicators of Water Use Performance and Productivity for Sustainable Water Conservation and Saving. *Agricultural Water Management*, **108**, 39-51. https://doi.org/10.1016/j.agwat.2011.08.022

[4] Zwart, S.J. and Bastiaanssen, W.G.M. (2004) Review of Measured Crop Water Productivity Values for Irrigated Wheat, Rice, Cotton and Maize. *Agricultural Water Management*, **69**, 115-133. https://doi.org/10.1016/j.agwat.2004.04.007

[5] Kijne, J.W., Tuong, T.P., Bennett, J., Bouman, B. and Oweis, T. (2003) Ensuring Food Security via Improvement in Crop Water Productivity. Challenge Program on Water and Food.

[6] Intergovernmental Panel on Climate Change (2014) To the Fourth Assessment Report.

[7] The Organization for Economic Co-Operation and Development (OECD) (2021) Report.

[8] Jones, J.W., Hoogenboom, G., Porter, C.H., Boote ,K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T. (2003) The DSSAT Cropping System Model. *European Journal of Agronomy*, **18**, 235-265. https://doi.org/10.1016/S1161-0301(02)00107-7

[9] Morissette, R., Jego, G., Belanger, G., Cambouris, A.N., Nyiraneza, J. and Zebarth, B.J. (2016) Simulating Potato Growth and Nitrogen Uptake in Eastern Canada with STICS Model. *Agronomy Journal*, **108**, 1853-1868. https://doi.org/10.2134/agronj2016.02.0112

[10] Hoogenboom, G., Porter, C.H., Boote, K.J., Shelia, V., Wilkens, P.W., Singh, U., White, J.W., Asseng, S., Lizaso, J.I., Moreno, L.P., Pavan, W., Ogoshi, R., Hunt, L.A., Tsuji, G.Y. and Jones, J.W. (2019) The DSSAT Crop Modeling Ecosystem. In: Boote, K.J., Ed., *Advances in Crop Modeling for a Sustainable Agriculture*, Burleigh Dodds Science Publishing, Cambridge, 173-216. https://doi.org/10.19103/AS.2019.0061.10

[11] Arshad, M.N., Ashfaq Ahmad, A. and Wajid, S.A. (2017) Adapting DSSAT Model for Simulation of Cotton Yield for Nitrogen Levels and Planting Dates. *Agronomy Journal*, **109**, 1-10. https://doi.org/10.2134/agronj2017.04.0233

[12] FAO (Food and Agriculture Organization), (2019) Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). https://www.fao.org/statistics/en

[13] FAO (Food and Agriculture Organization) (2017) The Future of Food and Agriculture—Trends and Challenges. Rome.

[14] Taleb (2018) Modeling of Potatoes Growth and Development for Different Deficit

Irrigation Management Treatment. Master Thesis, University of Jordan, Amman.

[15] Ababsa, M. (2013) Atlas of Jordan (History, Territories and Society). Beyrouth, Publication. https://doi.org/10.4000/books.ifpo.4560

[16] Haverkort, A. and Top, J. (2011) The Potato Ontology: Delimitation of the Domain, Modelling Concepts, and Prospects of Performance. *Potato Research*, **54**, 119-136. https://doi.org/10.1007/s11540-010-9184-8

[17] Ierna, A. and Mauromicale, G. (2018) Potato Growth, Yield and Water Productivity Response to Different Irrigation and Fertilization Regimes. *Agricultural Water Management*, **201**, 21-26. https://doi.org/10.1016/j.agwat.2018.01.008

[18] Ruþa, A., Skrabule, I. and Vaivode, A. (2018) Influence of Nitrogen on Potato Productivity and Nutrient Use Efficiency. *Agricultural Water Management*, **195**, 11-24.

[19] Koch, M., Naumann, M., Pawelzik, E., Gransee, A. and Thiel, H. (2020) The Importance of Nutrient Management for Potato Production Part I: Plant Nutrition and Yield. *Potato Research*, **63**, 97-119. https://doi.org/10.1007/s11540-019-09431-2

[20] Paredes, A.P., Daniela, D., Mahdi, A., Mladen, A., Todorovic, B. and Pereira, S. (2018) Assessing Potato Transpiration, Yield and Water Productivity under Various Water Regimes and Planting Dates Using the FAO Dual Kc Approach. *European Journal of Agronomy*, **98**, 82-94. https://doi.org/10.1016/j.agwat.2017.09.011

[21] Syas, S. (2013) The Effects of Different Regimes on Potato Yield and Quality Characteristics under Unheated Greenhouse Conditions. *Bulgarian Journal of Agricultural Science*, **19**, 87-95.