Arab Universities Journal of Agricultural Sciences
(2022) 30 (2) 1-9
Website: http://ajs.journals.ekb.eg

Effect of Different Nitrogen Rates on Gray Water and Water Footprint to Potato

Mai M Abd-Elsalam[1], Ahmed A Farag[1], Mohamed Z El-Shinawy[2], Ayman F Abou-Hadid[2]

1- Central Laboratory for Agricultural Climate, Agricultural Research Centre, Cairo, Egypt
2- Horticulture Dept, Fac of Agric, Ain Shams Univ, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt

*Corresponding author: mayclac@yahoo.com

DOI: 10.21608/AJS.2022.110065.1445

Received 15 February 2022 ; Accepted 15 August 2022

Keywords:

Potato,
Water footprint,
Nitrogen levels,
Crop water use

Abstract: The importance of water footprint (WFP) is providing information related to water resource management, especially for countries that have water scarcity and rely on irrigation to enhance food security. A field experiment was conducted during two winter seasons in 2018, and 2019. The current study sought to evaluate the impacts of various nitrogen levels (1.N1: 120, 2.N2: 150, and 3.N3: 180 kg /fed) on potato production as well as the water footprint and water requirement. Vegetative characteristics, yield parameters, N contents, and climate data were measured. The obtained results are clarified that increasing the nitrogen rate up to 180 kg/fed led to increase the vegetative growth characteristics, yield parameters, and water footprint of potato crop. The most significant vegetative growth values were obtained using a 180 kg/fed nitrogen level followed by 150 kg/fed. The greater marketable tuber yield was recorded at 180 kg/fed with 18117 & 17753 Kg/fed values, followed by 150 kg/fed with 16864 and 16545 Kg/fed values for the first and second seasons respectively. The water footprint of potato in Egypt ranges from 237 to 267.8 for nitrogen levels of 120 kg/fed and 180 kg/fed.

1 Introduction

Potato is the fourth farmed crop globally, taken the place after the main cereal crops (Hailu and Mosisa 2019). It is classified as a tuber food commodity (Rykaczewska 2013). Potato tubers are swollen, starchy tubers that grow underground. Potato are one of the most important consumed crop food for hundreds millions of people worldwide (FAO et al 2017). The potato production about 388191 thousand tons of potatoes are produced in all the world annually, contributing to food security. In Egypt, potato crops occupied 175,161 Fadden and produced 5, 07 8,374 kg of tubers in 2019 (FAO 2019).

In developing countries, potato is one of the cheapest nutrient sources, including proteins, vitamins C and B, polyphenols and carotenoids, thus playing a fundamental role in food security and ensuring income (Abebe et al 2017). Potatoes can be used to make ethanol, which is utilized in the paper industry, as well as to offer raw materials for the chemical industry (FAO et al 2017).

Nitrogen fertilizer enhances the canopy growth, like a plant length, number of shoots/plant, leaf area, dry matter and tuber yield (Sincik et al 2008). Nitrogen considers one of the essential nutrients for metabolism activity. It is needed for most important components, such as amino acids, nucleic acids, amino acids, and chlorophyll content (Najm et al 2012). Proper nitrogen application can result in optimal shoot growth and, as a result, increased tuber output. Increases the level of nitrogen in the plant growth parameters rather than tuber production, causing potato maturity to be delayed (Kumar et al 2007), and quality of tuber reduce (Zebarth and Rosen 2007). Moreover, (Ahmed et al 2009) reported that different nitrogen fertilizer rates influenced vegetative, yield, marketable tubers, and quality of tuber.

The agricultural water footprint measures water usage in agriculture by considering three water types used by crops: rainfall (green water), irrigation from diverse water resources (blue water), and water used to dilute pollutants (gray water). Each component of the overall water footprint is geographically and chronologically defined. Previous investigations on the leaching of agricultural chemicals during crop cultivation identified nitrate-nitrogen as the primary contaminant. The intensity and loads of pollutants are negligible, and their concentrations are often lower than the disclosure limit of available testing procedures (Mekonnen and Hoekstra 2011). Furthermore, the nitrate-nitrogen form would be the primary freshwater contaminant in water footprint analyses under various agricultural systems (Aldaya et al 2011). The gray water footprint balance is based mostly on a straightforward assumption, which yields the N lost through leaching from fertilizer. As a result, difficulties are discovered by monitoring nitrate leaching and water resource pollution (Chapagain et al 2006).

The gray water footprint is an important indicator of the quality of different freshwater supplies and their influence on land use. The results reveal that assuming almost ten percent of N injected is leaching in the treated wastewater footprints balance of such a cropping system is erroneous. A validation approach with precise measurements is required for gray water footprint balance (Aldaya et al 2011). The study aimed to determine the effects of different N levels on potato production as well as estimate the water footprint for potato production.

2 Materials and Methods

2.1 Experimental site

The study was conducted during two successive winter seasons (2018 and 2019) in the Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Centre, Dokki, Giza, Egypt.

2.2 Plant materials

The potato tubers (*Solanum tuberosum L.*) cv. Spunta, originated in Denmark, with an average size of 35/60, and was treated with fungazilTM-100. Potato tubers were sprouted for about 10 days before cultivation under a well-aerated and shading area to guarantee sprouting and planting on January 18th and 20th in 2018 and 2019, respectively. The plants were grown in rows of 0.75 m between every two rows. The distance between in-row plants was 0.50 m.

2.3 The experimental treatments

The present experiment involved three nitrogen levels (N_1: 120 kg/fed, N_2: 150 kg/fed, and N_3: 180 kg/fed. Ammonium nitrate (33% N) was the nitrogen source used in this study. Nitrogen application was applied via drip irrigation using a venturi injector during the two growing seasons.

2.4 Soil samples

Soil samples were collected two weeks before cultivation. The physical and chemical properties were measured according to (Gee and Bauder 1986). The physical analysis was measured using the international pipette method, summarized in (**Table 1)**. The saturation point % (SP), field capacity % (FC), wilting point % (WP) and bulk density (g/cm^3) (BD) of the soil samples were estimated according to Grewal (1990). Chemical analysis of the soil, including the electrical conductivity (EC), pH and nutrient contents, was determined according to Westerman (1990).

2.5 Estimate the water needs of potatoes in two seasons

The Central Laboratory for Agricultural Climate (CLAC), ARC provided the climatic data of Dokki experimental site **(Table 2)**. The sum and average monthly weather parameters were measured and recorded by automated agro-metrology station model (iMetos 2, made in Austria, EU) during the two cultivated seasons, averages of total solar radiation (MJ/m2), minimum and maximum temperature (°C), minimum and maximum relative humidity (%), wind speed (m/s), total precipitations (mm), minimum and maximum soil temperature (°C) at 30 cm depth), during the two consecutive season. The evapotranspiration (ETo) during the experimental period was estimated by using the Penman–Monteith equation (Allen et al 1998). Total crop water used for potato in two seasons 2018 and 2019 was recorded in **(Table 3)**.

Table 1. Chemical and physical analyses of the soil sample at the Dokki experimental location

Soil depth	Chemical properties							
	ECe mmohs	**pH**	**Ca^{++}** meg/L	**Mg^{++}** meg/L	**Na^{+}** meg/L	**K^{+}** meg/L	**HCO_{3-}** meg/L	**Cl_{-}** meg/L
0 – 30 Cm	2.21	7.6	5.23	1.9	8.1	4.34	2.7	9.0
	Physical properties							
	Sand %	**Clay** %	**Silt** %	**Texture**	**SP** %	**FC** %	**WP** %	**BD** g/cm^3
	15.4	77.0	7.6	Clay	34.7	23.2	15.8	1.23

* SP = saturation point
* FC = field capacity
* WP = wilting point
* BD = bulk density

Table 2. Climate data for Dokki–Giza in two seasons 2018 and 2019

Month	Temperature		Relative humidity	Wind Speed (m/s)	Solar Radiation (MJ/m^2/day)	Precipitation (mm/day)	sun shin duration (h)
	Max (°C)	Min (°C)	(%)				
2018							
Jan	19.1	7.7	68.3	2.8	11.6	29.8	7.8
Feb	22.8	10.1	57	2	10.5	5.15	8.2
Mar	28.7	11.7	42.3	2.4	19.9	1.12	8.8
Apr	30.9	14.2	41	2.6	23.3	28.49	9.6
May	35.6	19.2	38	3.1	24.7	0.0	11.2
2019							
Jan	18.8	6.2	50.1	2.9	12.6	2.21	7.8
Feb	21	7.5	53.1	2.5	14.5	5.5	8.2
Mar	23.7	9	51.5	2.9	18.5	10.98	8.8
Apr	28.2	12.4	43	3.1	22.1	1.88	9.6
May	36.8	17.8	29.2	3.3	26.4	0.0	11.2

Table 3. Total crop water used for potato in two seasons 2018 and 2019

Month	ETo 2018	ETo 2019	Kc	CWU 2018 m^3/fed	CWU 2019 m^3/fed
Jan16–31	3.07	3.40	0.50	32	36
Feb 1–15	3.55	3.65	0.80	75	77
Feb 16–28	4.60	4.28	0.90	118	110
Mar1–15	5.66	4.91	1.15	258	224
Mar16–31	6.20	5.77	1.00	306	284
Apr1–15	6.75	6.63	0.90	321	315
April16–31	7.58	7.93	0.75	320	335
May1–15	8.41	9.23	0.60	89	98
Total				1519	1479

* ETo = Evapotranspiration (mm/day)
* CWU = crop water use
***** Kc **=** crop coefficient

The effect of climatic factors on germination of potato tuber seed and the number of germinated hills and seedlings per plot were detected 30 days after each cultivation date for germination of 50 %.

2.6 Vegetative growth characteristics

Plant height (cm), number of shoots per plant, and number of leaves per plant, average leaf area (cm^2), and total chlorophyll content (using digital chlorophyll meter (Spad)) were measured after 60 days and 90 days from the cultivation of seed tubers. Total chlorophyll content was measured in the fourth leaf according to Moran and Porath (1980).

2.7 Tubers yield parameters

No. of tubers /plant, total yield (g) /plant, tubers yield (ton/fed.) beside marketable tubers, unmarketable tubers (ton/fed and %).

2.8 Tubers quality

The specific gravity of the potato tubers was determined using the method described by Tuhin et al (2017)

$$\text{Specific gravity} = \frac{\text{Weight of tubers in air}}{\text{Weight of tubers in air} - \text{Weight of tubers under water}}$$

2.9 Water footprint calculation

2.9.1Green water footprint (GWF)

GWF was calculated as the ratio of the volume of rainfall water used for tuber production, CWUg (m^3/ fed.), to the quantity of tuber produced and Y (ton /acre).

$$WF_{green} = CWU_g\ /Y$$

CWUg = the ratio of the rainfall volume used for tuber production
Y = yield ton /fed.

2.9.2 Blue water footprint (BWF)

The blue water footprint (WFproc, blue, m^3/ton) was calculated as the irrigation water of crop water use (CWUblue, m^3/ha) divided by the potato tuber yield (Y, ton/ha). The amount of irrigation water (WFproc, m^3/ton) was calculated according to the following formula proposed by Aldaya et al (2011) as follows:

$$(WF_{blue} = WF_{blue}\ /\mathrm{Y}(\mathrm{m}^3/ton)$$

CWU blue, irrigation requirement
Y yield ton /fed

2.9.3 Gray water footprint (GWF)

GW was determined according to proposed formula by Aldaya et al (2011). The formula quantifying the necessary water required to leach the nutrients that reach ground water or surface water. Nonpoint source contamination of surface and subterranean water is mostly caused by agricultural natural drainage fields.

$$GWF = \frac{f \times Ln}{(cn.m_{ax} - cn.n_at) \times Y}$$

GWF = gray water footprint
f = fraction of nitrogen element that leaches or runs off
L_n = N fertilizer application rate
$C_{n,max}$ = maximum acceptable level of nitrogen element
$C_{n,nat}$ = natural level of nitrogen element
Y = actual crop yield

2.10 The Experimental design

A randomized complete block design was used for arranging the experiment factors. The experiment contains three treatments, and each contains three replicates.

2.11 Statistical analysis

All experiment data were statistically analyzed using the SAS programme (SAS User's Guide: Statistics, SAS Institute Inc. Editors, Cary, NC). According to, the differences between means factors for all traits were assessed for significance at the 5% level (Waller and Duncan, 1969).

3 Results and Discussion

3.1. The effect of N levels on the vegetative growth

The effects of different nitrogen treatments on vegetative growth characteristics of potato are illustrated in **(Table 4)**. Increasing nitrogen levels, increased vegetative growth characteristics. The nitrogen level (180 kg/fed) resulted in the highest vegetative growth followed by the 150 kg/fed level. The lowest vegetative growth was obtained by 120 kg N per feddan.

These results are consistent with Saeidi et al (2009) who showed that increasing nitrogen application increases growth parameters, including tuber, up to a definite point, but beyond that, they decrease. This may be attributed that vegetative growth could be raised, therefore, prevent the transfer of photo-synthetically matter into the tubers. Mukta et al (2015) reported that increasing nitrogen fertilizer up to an appropriate level had a direct relationship with yield per area unit.

3.2 The effect of N levels on yield

Data presented in **(Table 5)**, showed the effects of N levels on marketable, unmarketable, and total yield through the two seasons investigated. Increasing N rates from 120 to 180 kg/fed increased total yield and marketable yield during the two studied seasons, with significant differences among nitrogen treatments. The highest marketable yield was obtained at 180 kg N per fed. with values of 18117 and 17753 Kg/fed., for the 1st and 2nd seasons, respectively. Using 150 N per fed. came in the second order with 16864 and 16545 Kg/fed for the 1st and 2nd seasons, respectively. The lowest marketable yield was obtained at 120 kg/fed with 15552 and 15355 Kg/fed values for the 1st and 2nd seasons, respectively. The highest unmarketable yield was obtained at 120 kg/fed with values of 1240 and 1219 Kg/fed., for the 1st and 2nd seasons, respectively, followed by 150 kg/fed with values of 1090 and 1050 Kg/fed for the 1st and 2nd seasons, respectively. The lowest unmarketable yield was obtained at 180 kg/fed with 980 and 940 Kg/fed values for the 1st and 2nd seasons, respectively.

According to Marguerite et al (2006) increasing applied nitrogen fertilizer to an appropriate amount enhanced tuber output per unit area. According to Farag et al (2014) the protein content of tubers increased linearly as nitrogen levels increased. The considerable impact on protein percentage of tubers could be attributed to nitrogen's crucial role in plants, which is directly or indirectly tied to protein synthesis. Erdoğan et al (2010) revealed that raising nitrogen dose significantly increased the protein in tubers.

3.4 The effect of different N- levels on nutrient content (%)

The effects of Nitrogen levels on the nutrient percentage of potato leaves are presented in **(Table 6)**. Data revealed that increasing N from 120 kg/fed to 180 kg/fed increased in N percentage of potato leaves content from 4.35% to 4.99%. The highest nutrient content was gained at 180 Kg/fed followed by 150 Kg/fed with significant differences between the all seasons. The lowest nutrient content of potato leaves was obtained at 120 Kg/fed with 4.350% and 4.416% values in first and second seasons, respectively. The same results were reported by McPharlin and Rachel (2005) who found that applied nitrogen at 200 kg /fed significantly increased the nitrogen content percentage and uptake (kg/fed) potato aerial parts and tubers.

3.5 Estimation of the blue water footprint

Table 7 shows the crop water use (CWU) and crop yield and blue water footprint value. The lowest blue water footprint value for potato in two seasons (2018 and 2019) were 78 and 78, 2 m^3/ton for the first and second seasons, respectively, at a nitrogen level of 180Kg/fed, and the highest potato blue water footprint were 91, 9 and 90, 8 m^3/ton for the first and second seasons, respectively, at a nitrogen level of 120Kg/fed. The average nitrogen levels of 120,150 and180 Kg/fed were calculated, and the values were 78, 84.3, and 91 m^3/ton, respectively, as potato blue water footprint values.

3.6 Estimation of the gray water footprint (GWF)

Table 8 shown that, the most important parameter in calculating (GWF) of potato is the fraction of N that leaches or runs off into surface waters. Mekonnen and Hoekstra (2011) consider the leaching rate to be ten percent of crop water requirements taken from previous literatures for all countries and crops. Unfortunately, this is a broad assumption because leaching fraction *f* is affected by crop type, crop-specific nitrogen fixation, soil composition and conditions, agro-meteorological factors such as precipitation, local climate and topography, and relief. Gray water is sensitive to *f* value, according to the sensitivity study done herein, which included resuming the balance of the (GWF) for variant off values.

Logically, the nitrogen level of 120 had the lowest gray water footprint for potato with 145.2 and 147 m^3/ton for the first and second seasons. In contrast, the nitrogen level of 180 had the highest potato blue water

Table 4. The effect of different (N) rates on vegetative characteristics of potato at 90 days during the two seasons 2018 and 2019.

Treatment	First Season 2018					
	Number of leaves	number of shoots	Plant height(cm)	Chlorophyll (SPAD)	Plant dry weight (g)	Plant fresh weight (g)
N 120	72.3	6.0	76.6	33.3	95.5	657.2
N 150	78.3	7.6	81.6	37.3	113.4	736.8
N 180	85.3	8.3	85.0	41.3	126.2	783.3
L.S.D	4.88	1.76	4.66	3.82	40.32	6.23
	Second Season 2019					
N 120	70.0	6.6	74.1	30.6	85.6	645.3
N 150	75.0	7.0	79.1	34.3	97.8	708.8
N 180	82.3	8.0	85.3	38.0	106.3	758.5
L.S.D	4.66	1.49	4.89	3.51	44.85	11.61

Table 5. The effect of different rates of (N) fertilization on total Marketable yield of potato tubers, unmarketable and total yield during two seasons, 2018 and 2019

	First Season 2018		
	Marketable yield (Kg/fed.)	Unmarketable yield (Kg/fed.)	Total yield (Kg/fed.)
N 120	15552	1240	16792
N 150	16864	1090	17954
N 180	18117	980	19097
L.S.D	1249	76	100,66
Second Season 2019			
N 120	15355	1219	16574
N 150	16545	1050	17595
N 180	17753	940	18693
L.S.D	1224	74	92,55

Table 6. The effect of different rates of nitrogen fertilization on nitrogen content in leaves during two seasons, 2018 and 2019

Treatments	Nitrogen content in leaves (%)	
	Frist season (2018)	Second season (2019)
N 120	4.350	4.416
N 150	4.736	4.716
N 180	4.993	5.016
L.S.D at 5%	0.245	0.1792

Table 7. Blue water footprint assessment under Different Nitrogen rates in seasons 2018 and 2019

N 120			
Year	**CWU (m^3/fed)**	**Yield (ton\fed)**	**WF BLUE (m^3/ton)**
2018	1519	16.5	91.9
2019	1479	16.3	90.8
Average	**1499**	**16**	**91**
N 150			
2018	1519	17.9	84.6
2019	1479	17.6	84.1
Average	**1907.5**	**17.8**	**84.3**
N 180			
2018	1519	18.9	78.0
2019	1479	19.2	78.2
Average	1479	18.972	78.0

CWU irrigation requirement WF BLUE Blue water footprint

Table 8. Gray water footprint assessment under different nitrogen rates in seasons 2018 and 2019

Treatment	Gray water footprint		
	2018	2019	Average
N 120	145.2	147	146.2
N 150	167.1	170.5	168.8
N 180	186	189	187.9

Table 9. Total water footprint of potato under different nitrogen rates in seasons 2018 and 2019

treatment	Blue water	Gray water	water footprint
	First Season 2018		
N 120	91.9	145.2	237.08
N 150	84.6	167.1	251.71
N 180	78.5	186	264.47
	Second Season 2019		
N 120	90.8	147.3	238.1
N 150	84.1	170.5	254.6
N 180	78.0	189.8	267.8

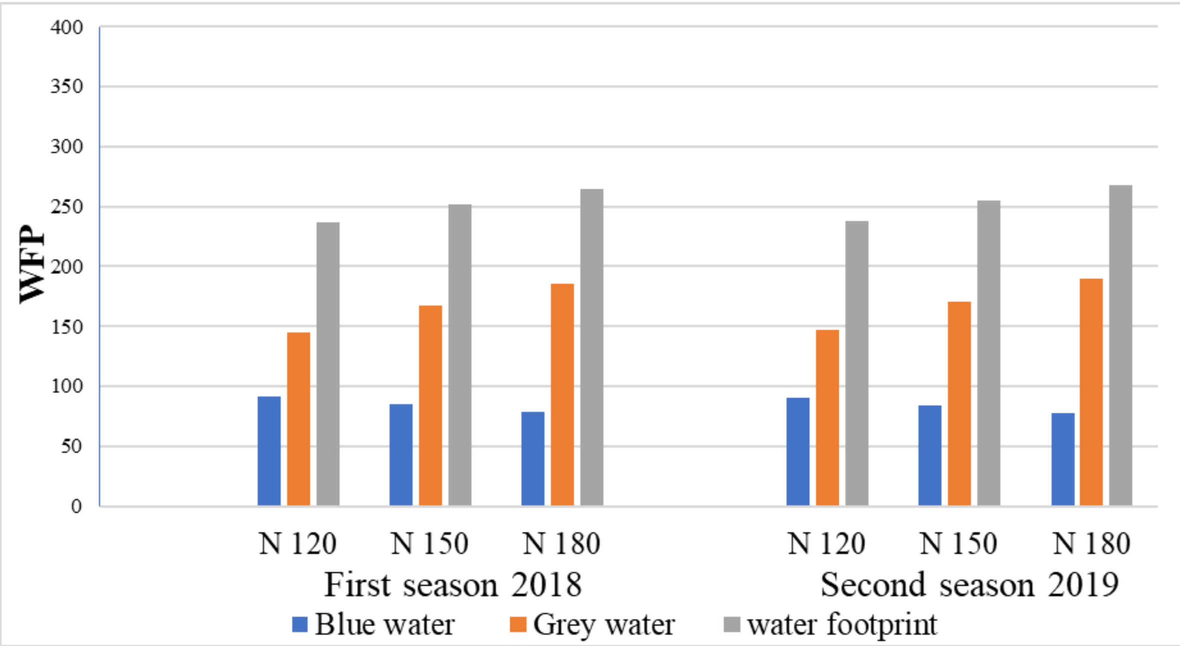

Fig 1. The average blue water, gray water, and water footprint of potato under different nitrogen rates in seasons 2018 and 2019

footprint, measuring 186 and 189 m^3/ton for the all seasons. These results agree with Luciana et al (2021) who reported that the dose of nitrogen was the main factor that affected gray water footprint. Delin and Stenberg (2014) reported that the essential source of freshwater contamination caused by fertilizers and surface run-off of P and N. Pollution levels are determined by a variety of factors, including soil texture, terrain, and, most importantly, crop and farm management.

3.7 Water footprint

Data in **Table 9 and Fig 1** illustrate the blue and gray water footprints and total footprint for different nitrogen levels in two seasons. The lowest value of water footprint was 181,5–184,1 m^3/ton for first and second seasons, respectively, at a nitrogen level of 120 Kg/fed and the highest value was (232,5 and 237,2 m^3/ton, for first and second seasons, respectively) at a nitrogen level 180 Kg/fed. These results agree with those of Hossain et al (2021) who discussed that tomatoes consumed 212.24 cubic meters of water for produce one ton and potato crop consumed 226.3cubic meter per ton of tuber. According to Rodriguez et al (2015) the potato water footprint was 323.99 m^3/ton in the southeast of Argentina. The evaporations use (irrigation and rainfall water) was about 56 percentage. Mekonnen and Hoekstra (2011) found that the global average water footprint for potato is 287 m3 /ton.

4 Conclusions

In Egypt, the water footprint of potato ranges from 299 (nitrogen level of 120 kg/fed) to 336, 4 (nitrogen level of 180 kg/fed).

The positive relationship between nitrogen level and potato yield had a limit regarding the reverse response of excessive nitrogen fertilization on potato growth and yield in general. Increasing nitrogen level increased the potato yield and water footprint; the grates gained yield was at a nitrogen level 180 Kilograms /fed. Nitrogen over-fertilization leads to an increased water footprint and production problems.

The water footprint is a multidimensional indicator that encompasses the water consumption and the volume and type of pollution produced by production processes.

References

Abebe CA, Shunka E, Solomon A, et al (2017) Participatory potato seed production: a breakthrough for food security and income generation in the central highlands of Ethiopia. *Open Agriculture* 2, 205-212. https://doi.org/10.1515/opag-2017-0021

Ahmed MS, Quadri, SMK (2009). Decision support systems: concepts, progress and issues, a review. In: Lichtfouse, E. (Ed.), Climate Change, Intercropping Pest Control and Beneficial Microorganisms, Sustainable Agriculture Review 2. Springer, Dordrecht, Netherlands. 373-399. https://doi.org/10.1007/978-90-481-2716-0_13

Aldaya MM, Chapagain AK, Hoekstra AY, et al (2011) The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan, London, Washington DC. https://doi.org/10.4324/9781849775526

Allen RG, Pereira LS, Raes D, et al (1998) Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements; FAO Irrigation and Drainage. FAO: Rome, Italy: paper No. 56.

Chapagain AK, Hoekstra AY, Savenije HHG, et al (2006) The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, *Ecological Economics* 60, 186-203. https://doi.org/10.1016/j.ecolecon.2005.11.027

Delin S, Stenberg M (2014) Effect of nitrogen fertilization on nitrate leaching in relation to grain yield response on loamy sand in Sweden. *European Journal of Agronomy* 52, 291-296. https://doi.org/10.1016/j.eja.2013.08.007

Erdoğan Öztürk, Zühal Kavurmacı, Kemalettin Kara, Taşkın Polat, (2010) The effects of different nitrogen and phosphorus rates on some quality traits of potato. *Potato Research* 53, 309-312. https://doi.org/10.1007/s11540-010-9176-8

FAO (2019) World Food and Agriculture Statistical Pocketbook (2019), Food and Agriculture Organization of the United Nations Rome, 248 p. https://doi.org/10.4060/ca6463en

FAO, IFAD, UNICEF, et al (2017) The state of food security and nutrition in the world, Building resilience for peace and food security. ISBN 978-92-5-109888-2 DOI:https://www.fao.org/3/I7695e/I7695e.pdf

Farag AA, Abdrabbo MA, Abul-Soud M (2014) Maximizing potato production via nitrogen fertilizer and plant spacing. *Arab Universities Journal of Agricultural Sciences* 22, 29-41. https://dx.doi.org/10.21608/ajs.2014.14694

Grewal KS, Buchan GD, Tonkin PJ (1990) Estimation of field capacity and wilting point of some New Zealand soils from their saturation percentages. *New Zealand Journal of Crop and Horticultural Science* 18, 241-246. https://doi.org/10.1080/01140671.1990.10428101

Gee GW, Bauder JW (1986) Particle-Size Analysis, In: A. Klute, Ed., Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, 2nd ed., American Society of Agronomy and Soil Science Society of America, Madison, WI, 383-411. https://doi.org/10.2136/sssabookser5.1.2ed.c15

Hossain I, Imteaz MA, Khastagir A (2021) Water footprint: applying the water footprint assessment method to Australian agriculture. *Journal of the Science of Food and Agriculture* 101, 4090-4098. https://doi.org/10.1002/jsfa.11044

Hailu DM, Mosisa CA (2019) Role of Nitrogen on Potato Production: A Review. *Journal of Plant Sciences* 7, 36-42. doi: 10.11648/j.jps.20190702.11

Kumar P, Pandey SK, Singh BP, et al (2007) Effect of nitrogen rate on growth, yield, economics and crisps quality of Indian potato processing cultivars. *European Potato Journal* 50, 143-155. https://doi.org/10.1007/s11540-008-9034-0

Luciana T, Alejandro P, Pamela S (2021) Water footprint of soybean, maize and wheat in Pergamino, Argentina. *Agricultural Sciences* 12, 305-323. https://doi.org/10.4236/as.2021.123020

Mukta S, Rahman MM, Mortuza MG (2015) Yield and nutrient content of tomato as influenced by the application of vermicompostand chemical fertilizers. *Journal of Environmental Science and Natural Resources* 8, 115-122. https://doi.org/10.3329/jesnr.v8i2.26877

Mekonnen MM, Hoekstra AY (2011) The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences* 15, 1577–1600. https://doi.org/10.5194/hess-15-1577-2011

Marguerite O, Jean-Pierre G, Jean-Francois L (2006) Threshold value for chlorophyll meter as decision tool for nitrogen management of potato. *Agronomy Journal* 98, 496-506. https://doi.org/10.2134/agronj2005.0108

McPharlin IR, Rachel L (2005) Applied nitrogen effects on yield and crisping quality of ´atlantic´, ´bliss´ and ´dawmor´ potatoes. *Acta Horticulturae* 684, 119-126. https://doi.org/10.17660/ActaHortic.2005.684.16

Moran R, Porath D (1980) Chlorophyll determination in intact tissues using N, N dimethylformamide. *Plant Physiology* 65, 478-479. https://doi.org/10.1104/pp.65.3.478

Najm AA, Paknejad F, Haj SH, et al (2012) Effect of integrated management of nitrogen fertilizer and cattle manure on the leaf chlorophyll, yield and tuber glycoalkaloids of Agria potato. *Communications in Soil Science and Plant Analysis* 43, 912-923. https://doi.org/10.1080/00103624.2012.653027

Rodriguez CI, Ruiz de Galarreta VA, Kruse EE, (2015) Analysis of water footprint of potato production in the pampeanregion of Argentina. *Journal of Cleaner Production* 90, 91-96. https://doi.org/10.1016/j.jclepro.2014.11.075

Rykaczewska K (2013) The impact of high temperature during growing season on potato cultivars with different response to environmental stresses. *American Journal of Plant Sciences* 4, 2386-2393. http://dx.doi.org/10.4236/ajps.2013.412295

Saeidi M, Tobeh A, Raei Y, et al (2009) Evaluation of tuber size and nitrogen fertilizer on nitrogen uptake and nitrate accumulation in potato tuber. *Research Journal of Environmental Sciences*, 3, 278-284. https://dx.doi.org/10.3923/rjes.2009.278.284

Sincik M, Turan ZM, Goksoy AT (2008) Response of potato (*Solanum tuberosum L.*) to green manure cover crops and nitrogen fertilization rates. *American Journal of Potato Research* 85, 158. http://dx.doi.org/10.1007/s12230-008-9043-1

Tuhin SR, Rajesh C, Maruf M, et al (2017) Yield, Dry Matter and Specific Gravity of Exportable Potato: Response to Salt. *Universal Journal of Agricultural Research* 5, 98-103. DOI:10.13189/ujar.2017.050203

Westerman RL (1990) Soil Testing and Plant Analysis, 3rd ed., SSSA Book Series Number 39 Soil Science Society of America, Madison, WI. DOI:10.2136/sssabookser3.3ed

Waller RA, Duncan, DB (1969) A Bayes rule for the symmetric multiple comparison problem, *Journal of the American Statistical Association* 64, 1484-1504. https://doi.org/10.1080/01621459.1969.10501073

Zebarth BJ, Rosen CJ (2007) Research perspective on nitrogen BMP development for potato. *American Journal of Potato Research* 84, 3-18. https://doi.org/10.1007/BF02986294