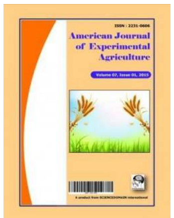

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Effect of Three Tillage Implements on Potato Yield and Water Use Efficiency

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Authors' contributions

This work was carried out in collaboration between all authors. Author SAAH managed the experiments, reviewed the measurements and the final manuscript. Author MFW participated in the field experiments, managed the literature review and wrote the first draft of the manuscript. Author AAS run the field experiments, made data analysis, managed the literature review and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The objective of this study was to evaluate the effect of tillage implements on potato yield and water use efficiency. The study was conducted at a private farm at Al-Kharj Governorate, Saudi Arabia during 2015 in randomize complete block design with three replications. Three primary tillage implements commonly used in Saudi Arabia for seedbed preparation with different configurations: disk harrow, chisel plow and moldboard plow were used. The potato variety used was Spunta. Centre pivot system was used to provide irrigation water. The statistical analysis indicated that tillage implement had significant effect on yield and water use efficiency. The highest yield of 37.19 t/ha was observed during plowing with moldboard plow and the lowest (32.33 t/ha) was observed during plowing with disk harrow. The highest water use efficiency of 7.91 kg/m^3 was observed during plowing with moldboard plow and the lowest (6.88 kg/m^3) was observed during plowing with disk harrow. The results could be helpful to develop comprehensive technology to increase potato yield and water use efficiency in semi-arid region like Saudi Arabia.

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Keywords: Chisel plow; moldboard plow; disk harrow; tillage; potato.

1. INTRODUCTION

Potato is one of the most important food crops worldwide. It comes in the forefront of tuber-crops and occupies the fourth position after wheat, sorghum and rice in the world [1]. The crop is grown in about 140 countries, more than 100 of which are located in the tropical and subtropical zones [2], with a production potential of about 327 million tons [3].

Saudi Arabia is currently 121% self-sufficient in potatoes [4], with an area of 17665 ha [5]. Over 75% of the total potato production in Saudi Arabia comes from small farmer groups in different regions [6]. Potato production is dependent on mechanization patterns, soil type and irrigation water quality. However, potato variety and fertilizer are the most important factors affecting its production [7].

Tillage is defined as the mechanical manipulation of the soil for the purpose of crop production [8]. Tillage produces enough loose soil to allow potato planter shoes to penetrate to the desired depth [9]. Many reports have been made on tillage implements regarding the effects on soil properties and yield [10]. Ogbodo [11] reported that tillage depth had significant effect on sweetpotato yield. Fresh tuber yields increased with soil tillage depth up to 40 cm from 1.2 t/ha to 12.9 t/ha [11]. Chandler et al. [12] and Aina [13] reported higher yields of potato and cassava on tilled plots than the untilled plots. Chandler et al. [12] also observed that higher plant shoot growth was enhanced by the increased root feeding area, created by increased depth of tillage. Ghazavi et al. [14] studied the effect of four plows (moldboard, chisel, disk, and a combination of chisel and disk plows) on potato and found significant differences in tuber yield. Mohammadi and Shamabadi [15] found crop yield differences among four tillage methods. Similar observation was made by Ati et al. [16].

In Saudi Arabia, potatoes are mainly produced on coarse textured soils and under centre pivot irrigation systems and average yields vary between 20 and 40 t/ha [17]. Moreover, in water-limited environments, efforts are needed from different research disciplines; agronomists, plant breeders, plant physiologists, plant biotechnologists, water engineers and others, to develop new approaches in water use in agriculture [18]. However, water productivity or water use efficiency is an efficient approach to describe the efficient use of water in crop production. Water use efficiency can be increased by two ways, either by increasing yield or by saving water. It is varied typically form 11 to 9 kg/m^3 [19]. Yavuz et al. [20] investigated the effects of different irrigation methods on yield and yield components of potato and water use. The methods were sprinkler, furrow and drip irrigation. The highest water use was obtained with drip irrigation plots while the lowest were obtained from sprinkler irrigation.

Under water-limited conditions, increasing water use efficiency is essential for successful crop production [21]. Consequently, any chosen tillage method for potato crop production in Saudi Arabia should aim at increasing water use efficiency. Therefore, the objective of this study was to evaluate the effect of different tillage implements on potato yield and water use efficiency.

2. MATERIALS AND METHODS

2.1 Experimental Site, Soil and Water Sampling and Analysis

The experiment was performed in a private farm at Al-Kharj Governorate, Saudi Arabia. No crop residues were found in the experimental field. Different soil and water samples were collected by soil sampling tool from the experiment site. The soil samples were analyzed in laboratory of Soil Department, College of Food and Agriculture Sciences, King Saud University. Irrigation water samples were also collected from centre pivot nozzles and water samples were analyzed in the laboratory of IDAC (الشركة العربية للخدمات الزراعية), Silliker, Riyadh, Saudi Arabia. Soil parameters like sand, silt and clay percentages, organic matter percentage, pH, EC, Na^+, K^+, Ca^{++} and Mg^{++} were obtained from the laboratory analysis. Soil samples were also dried in an electric oven to determine soil moisture content and soil bulk density. Irrigation water quality parameters like pH, EC, Na^+, TDS, Ca^{++}, Mg^{++}, SO_4 and NH_3 were obtained from the laboratory analysis.

2.2 Treatments and Experimental Design Used

The field was divided into different plots. The size of the plot was 12 m × 40 m and two meters between plots. Randomized block design was used with three replications. Treatments comprised of three different types of plows as follows:

Tillage treatment 1: Plowing using a disk harrow, one pass.
Tillage treatment 2: Plowing using chisel plow, one pass.
Tillage treatment 3: Plowing using moldboard plow, one pass.

The disk harrow was trailed hitched and consisted of 24 disks (12 disks in the front and 12 disks in the back), distance between two disks was 24 cm and diameter of the disk 56 cm. Plowing depth was 12 cm. The chisel plow was mounted hitched and consisted of 15 shares in two rows (8 shares in the front row and 7 in the back raw), the distance between two shares was 54 cm and the width of the plow was 3.377 m with a plowing depth was 12 cm. The moldboard plow was mounted hitched and the width of each share was 40 cm and the width of the plow was 80 cm. Plowing depth was 25 cm. All the plows operated at one tractor forward speed of 5.4 km/h. MF399 tractor (74 kW power) was used in the field experiments. Centre pivot was the main source of irrigation water to the experimental field.

In the beginning, a small block of approximately 10 m long by 12 m wide was used to enable the tractor and plow to reach a steady state condition of the required plowing speed and plowing depth. Plowing depth was measured as the vertical distance from the top of the undisturbed soil surface to the plow's deepest penetration. After finishing the first test plot, the tractor was again driven straight towards the second test plot with the same plow and the process was repeated. Similar procedure was repeated for all plows.

2.3 Potato Planting

Planting was done in autumn cycle on 2^{st} October, 2014 and harvested on the 14^{th} February, 2015. Spunta variety was used (growers No.1264, country of origin Netherland). The seeds size in mm was 35/55 and was treated with IMAZALIL. The planter TEKYATAGANLI, Turkey used had two rows and the distance between the rows was 90 cm with 40 cups. The distance between cups was 15 cm. Theoretical distance between seeds was 33.5 cm and the actual distance between seeds was 32 cm with a capacity of 0.48 m^3 and machine width was1.8 m. Its forward speed was 1.6 km/h. After sprouting of potato plants, a tractor drawn machine for potato rows building was used. The machine consists of an array of ridges and furrows. The ridges were about 20 cm high and 75 cm apart.

2.4 Irrigation

The centre pivot was the main source of irrigation water in the experiment site. Operation parameters for the centre pivot are shown in Table 1. The centre pivot was evaluated based on the ASAE (American Society of Agricultural Engineers) standard S436.1 [22]. The centre pivot was operated at 50% speed rate to apply a reasonable average depth of water. The irrigation was conducted for about 60 days from planting prior to harvesting. The applied water was added based on the practical experience of cultivation potato in the experiment site.

Table 1. Operation parameters for the centre pivot in the experiment site

Item	Value
Ambient temperature	13
Relative humidity	63%
Wind speed	Km/h
Type	Lockwood crop
Age	15 years
No. of towers	7
No. of nozzles	210
Speed at 50%	1.036
Cycle time at 50%	6 hr
Area	22 ha

2.5 Fertilizers, Chemicals and Harvesting

Urea was spread on the field experiment with 350 kg/ha. Diammonium phosphate (DAP) was also spread with 200 kg/ha. Dissolved fertilizer was also spread with 25 kg/ha. In addition, potassium was also spread with 200 kg/ha and liquid pesticide with 2 kg/ha was spread by manual sprayer. The potato digger machine was CARTTO with two rows.

2.6 Yield and Statistical Analysis

To determine potato yield, the five middle plants in each plot were harvested by hand and weighed. Then tubers were separated from the plants, weighed and tuber yield was recorded in tons/ha. Analysis of variance (ANOVA) was performed on the data. The statistical analysis was performed by SAS software [23]. The significant differences of the yield and water use efficiency means were compared using least significance difference (LSD) tests.

3. RESULTS AND DISCUSSION

3.1 Soil and Water Analysis Data

Table 2 illustrates both soil and water characteristics based on laboratory analysis. It is clear that soil texture was loamy sand. The soil was poor in organic matter as it was 0.98%. Soil moisture content and soil bulk density were 7.09%, db and 1.67 g/cm^3, respectively. The studied soil tends to be alkaline as pH value was 8.5. Soil SAR was calculated as recommended by Lesch and Suarez [24] from concentration of Na^+, Ca^{++} and Mg^{++}. SAR commonly used as an index for evaluating the sodium hazard. The SAR for the studied soil was 1.08. Electric conductivity (EC) of the soil was 4.6 dS/m. Meanwhile, concentrations of SO_4, Cl and NH_3 in the studied soil were 55.06 ppm, 41.72 ppm and 19.61 ppm, respectively as depicted in Table 2. For irrigation water, SAR was 4.23 and pH was 7.57, meanwhile electric conductivity (EC) was 4.81 dS/m.TDS, SO_4 and NH_3 concentrations in the irrigation water were 3204.79, 1237.6 and 8.11 mg/l, respectively as shown in Table 2.

3.2 Field Evaluation of Centre Pivot Irrigation System

Uniformity of a system is a measure of its ability to apply the same depth of water to every unit area. Without good uniformity, it is impossible to irrigate adequately and efficiently; parts of the field will be either over-irrigated or under-irrigated. Four uniformity measurements were considered in the evaluation; Coefficient of Uniformity, Distribution Uniformity and Potential Application Efficiency of Low Quarter and Application Efficiency. A Coefficient of Uniformity rating of 90%-95% is considered excellent and would only require regular maintenance. 85%-90% is considered good and would not need major adjustments; regular maintenance and inspection are required. 80%-85% the system requires inspection and sprinkler package check. 80% or less the system requires an adjustment to the sprinkler package, change the default system, sprinkler pressure and conduct full maintenance for the whole system [25]. Distribution Uniformity is useful as an indicator of the magnitude of the distribution problems. It is calculated by dividing the weighted average of the lowest 25% of the catch cans by the weighted average of the entire catch cans. A of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered poor and unacceptable [26]. The evaluation parameters (Coefficient of Uniformity, Distribution Uniformity, Application Efficiency and Potential Application Efficiency of Low Quarter) of the studied centre pivot are shown in Table 3. The obtained data of evaluation parameters indicate that the system needs maintenance due to its lower evaluation parameters.

Table 2. Characteristics of soil and water in the experiment site

	Unit	Value
Soil parameters		
Sand	(%)	82.9
Silt	(%)	13.08
Clay	(%)	4.02
Soil texture	(---)	Loamy sand
organic matter percentage	(%)	0.98
Soil moisture content	(%,db)	7.09
Soil bulk density	(g/cm^3)	1.67
Calcium carbonate percentage	(%)	6.85
pH	(---)	8.5
EC	(dS/m)	4.6
Na^+	(ppm)	48.66
K^+	(ppm)	4.91
Ca^{++}	(ppm)	140.59
Mg^{++}	(ppm)	8.76
SO_4	(ppm)	55.06
Cl	(ppm)	41.72
NH_3	(ppm)	19.61
Water parameters		
pH	(---)	7.57
EC	(dS/m)	4.81
Na^+	(mg/l)	372.07
TDS	(mg/l)	3204.79
Ca^{++}	(mg/l)	404.75
Mg^{++}	(mg/l)	109.78
SO_4	(mg/l)	1237.6
NH_3	(mg/l)	8.11

3.3 Yield and Water Use Efficiency

The total applied water during season was 4700 m^3/ha. The ANOVA analysis (Table 4) indicated that tillage implement had significant effect (at 5%) on yield and water use efficiency. The highest yield of 37.19 t/ha was observed during plowing operation with moldboard plow and the lowest (32.33 t/ha) was observed during plowing operation with disk harrow as shown in Table 5. However, Ati et al. [16] reported that potato yield recorded 32700 kg/ha using moldboard plow for tillage purposes compared to chisel plow. Additionally, Amel et al. [27] reported that average yield of the potato was 39121.9, 24945.7, 19504.3 and 22010.15 kg/ha based on irrigation water quality.

Table 3. Evaluation parameters of the studied centre pivot in the experiment site

Coefficient of uniformity (%)	Distribution uniformity (%)	Application efficiency (%)	Potential application efficiency of low quarter (%)
79.96	72.04	88.94	64.07

Table 4. Analysis of variance (ANOVA) for potato yield and water use efficiency as affected by tillage implements

Source of variation	Degree of freedom	Anova SS		Mean square		F value		Pr > F	
		Yield	WUE[+]	Yield	WUE	Yield	WUE	Yield	WUE
R[++]	2	1.36	0.061	0.68	0.031	27.57		0.0046**	
TI[+++]	2	41.89	1.89	20.95	0.95	848.55		<0.0001**	

[+]WUE=Water use efficiency; [++]R= Replicates; [+++]TI= Tillage implements

Table 5. Mean[+] potato yield and mean water use efficiency as affected by tillage implements

Tillage implement	Mean yield (t/ha)	Mean water use efficiency (kg/m^3)
Moldboard plow	37.19a	7.91a
Chisel plow	32.95b	7.01b
Disk harrow	32.33c	6.88c
LSD$	0.36	0.08

+ Means followed by different letters in each column are significantly different at P ≤ 0.05
$ LSD = Least significance difference (5%)

The highest water use efficiency of 7.91 kg/m^3 was observed during plowing operation with moldboard plow and the lowest (6.88 kg/m^3) was observed during plowing operation with disk harrow as shown in Table 5. However, Abdeldagir et al. [17], found mean water use efficiency to be 8.32 kg/m^3 under drip irrigation and 6.09 kg/m^3 under sprinkler irrigation. It could be concluded that the obtained results could be helpful to develop comprehensive technology to increase potato yield and water use efficiency in semi-arid region like Saudi Arabia.

4. CONCLUSION

Tillage implement had significant effect on potato yield and water use efficiency. The highest yield and water use efficiency were 37.19 t/ha and 7.91 kg/m^3, respectively, and were obtained from moldboard plow.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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