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ACKNOWLEDGEMENTS. We thank the staff of the CC Shroff Research Institute, particularly Dr Podhar, and the Vivekanand Research and Training Institute, Mandvi for help, and the British Council for financial support.

Received 12 July 2017; accepted 16 November 2017

doi: 10.18520/cs/v114/i10/2142-2146

Effect of primary tillage implements on physical properties of harvested Spunta potato tubers

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We study the effect of implements on the physical properties of the produced potato tubers. These potatoes were classified as grade A. There was a significant difference in tuber shape index among the tillage implements. The results showed that the tuber weight of fresh potatoes was 179.28–201.64 g, and the bulk density was 1.066–1.068 g/cm^3. There were no significant differences among the physical properties. Thus, it is appropriate for a farm to select any of the studied tillage implements that are available.

Keywords: Physical properties, potatoes, tillage.

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IN many countries, potatoes are essential crops because they are a complete and inexpensive food[1,2]. Customers pay considerable attention to the appearance of potatoes. Soil tillage is required prior to potato seeding, because tuber crops require loose and deep soil that is permeable to air and water[3]. Thus, soil tillage is considered the most important operation affecting the shape and physical properties of a potato[4].

Mechanization consists of land preparation, planting, cultivation, harvesting and post-harvesting practices, all of which affect potato production[5]. Every mechanization process (soil tillage, for instance) affects the quantity and quality of produced potatoes[6]. However, soil tillage is a significant operation, because it provides a suitable environment for potato roots to enter the soil and maintains an adequate amount of water for plant consumption. Tillage implements directly affect planting depth, which is the primary factor influencing the yield and tuber quality of potatoes[7]. Also, tillage implements should loosen the soil as much as possible to support the ability of planter openers to easily reach the chosen planting depth[4]. A 10–15 cm planting depth is recommended for potatoes for most soil types in Saudi Arabia[8]. The tillage depth for potato production can be 15–18 cm when using minimum tillage, 22–25 cm when using conventional tillage and 33–35 cm when using deep tillage[9]. For soil tillage preceding potato seeding, reduced tillage at an 8 cm depth could achieved by a disk harrow, medium tillage at a 20 cm depth by a disk plow and a 30 cm depth by a moldboard plow[10].

The shape of potato tubers is one of the most important factors in classification and grading related to commercial quality and organoleptic properties[11]. The shape of Alpha potatoes is oval and that of Spunta potatoes is elongated[12]. Also, the average bulk densities of fresh Dimont and Santana tubers are 0.968–1.26 g/cm^3 and 0.924–1.221 g/cm^3 respectively[13]. Additionally, inter-row subsoiling does not significantly change the specific gravity of tubers[14].

Field preparation for potato planting is important, and using a suitable tillage implement can play a key role. However, the physical properties of agricultural products are the most important parameters in the design of grading, handling, processing and packaging systems. Among these physical properties, weight and volume are most important in handling systems[15]. Other important parameters are width, length and thickness. Knowledge of length, width, diameter, volume and weight may be applied for screening different potato varieties. Thus, based on the above mentioned points, we studied the influence of primary tillage implements on the physical properties of Spunta potatoes.

Experiments were conducted at a private farm in Al-Kharj Governorate (Saudi Arabia). Soil samples were analysed in the laboratory of the soil department, College of Food and Agriculture Sciences, King Saud University, Riyadh (Saudi Arabia). Irrigation water samples were collected from centre pivot nozzles and analysed in the IDAC laboratory, Riyadh (Saudi Arabia). Soil parameters such as sand, silt, clay percentages and organic matter percentage were obtained from laboratory analysis. Sodium adsorption ratios for soil and irrigation water were calculated based on sodium, calcium and magnesium concentrations. Soil samples were dried in an electric oven to determine soil moisture content and soil bulk density. Table 1 shows the soil and water characteristics at the experimental site.

The experimental set-up consisted of a completely randomized block design with three replications. For the tillage implements, three different types of plows were studied: a moldboard plow, a disk harrow and a chisel plow. All plows were operated at a forward tractor speed of 5.4 km/h. This speed was achieved by selecting an appropriate gear. Before tillage, the mean soil moisture content, soil bulk density and soil cone index were 8.24% dry base, 1.58 g/cm^3 and 2.19 MPa at a soil depth of 0–15 cm respectively. The adjusted tillage depth for all tillage implements was at 15 cm. However, particle density is the density of solid particles that collectively make up a soil sample. The value is commonly expressed in grams per cubic centimetre. The common range among soils is 2.55–2.70 g/cm^3. A value of 2.65 g/cm^3 is therefore used generally[16]. Thus in this study, soil particle density (ρ_s) was assumed to be 2.65 g/cm^3 and the soil porosity (%) was calculated using the formula

$$\text{Soil porosity} = \left[1 - \frac{\rho_d}{\rho_s}\right] \times 100, \qquad (1)$$

Table 1. Characteristics of soil and irrigation water at the experimental site

	Value
Soil characteristics	
Sand (%)	82.9
Silt (%)	13.08
Clay (%)	4.02
Soil texture	Loamy sand
Organic matter (%)	0.98
Irrigation water characteristics	
pH	7.57
EC (dS/m)	4.81
SAR	4.23

where ρ_d is the soil bulk density after tillage operations. Table 2 shows the mean of five readings of actual tillage depth, soil porosity and soil cone index at a soil depth of 0–15 cm and 15–30 cm, as affected by different tillage implements.

The size of the plots was 12 m × 40 m, and the distance between the plots was 2 m. A 78 kW tractor pulled the tillage implements during tillage experiments. The moldboard plow (mounted type) had two bottoms and a working width of 80 cm. The chisel plow (mounted type) had 15 shanks mounted in a staggered arrangement on two toolbars (eight shanks on the forward bar and seven shanks on the rear bar). The soil-engaging tools (shovel type) were 5 cm wide with a 45 cm shank space. The working width was 337.5 cm. The disk harrow (pull type) had 24 disks (56 cm in diameter) mounted on two gangs (12 disks on the forward gang and 12 disks on the rear gang). The working width was 280 cm. All studied tillage implements passed over the soil surface once. Details regarding seedbed preparation, fertilization, planting and potato yield are provided[17]. Planting was done in an autumn cycle on 2 October 2014 and harvested on 14 February 2015. The soil depth of the effective root zone was increased from about 15 cm at planting to about 35 cm in bulking and tuber enlargement stages.

Five randomized samples of potato tubers were carefully obtained during harvesting (fresh tubers). All measurements were conducted at our laboratory in King Saud University. For each potato, three mutually perpendicular axes were measured using a digital slide caliper. Each potato was laid on a flat surface and allowed to reach its natural resting position[18]. The longest intercept acted as the tuber length (L), the longest intercept normal to L acted as the tuber width (D), and the longest intercept normal to D and L acted as the tuber thickness (T). The tubers were weighed using an electrical digital balance. The moisture content (% wb) of the tubers was determined using an electric oven. Water activity (a_w) was determined using AOAC methods[19] using an AquaLab apparatus (Decagon Devices, Inc., Pullman, Washington). The shape index of potato tubers was calculated as[20]

$$\text{PSI} = \frac{L^2}{D \times T} \times 100, \qquad (2)$$

where PSI is the shape index, and L, D and T are the length, width and thickness of the potato tubers respectively. The calculated shape index was compared with recommended limits and the tubers were sorted into different classes (a PSI from 100 to 160 is round, from 160 to 240 is oval, from 240 to 340 is long, and over 340 is very long). The actual volume of potato tubers was measured by immersing each tuber instantaneously in a 1000 ml measuring cylinder filled with tap water up to a fixed height. The actual volume of potato tubers was determined using the equation[21]

$$V_{act} = W/S_p, \quad (3)$$

where V_{act} is the actual volume of the tuber (mm^3), W the mass of displaced water (g) and S_p is the specific density of water (g/mm^3). Density is calculated by dividing sample weight by volume obtained from the water displacement method[22]. Bulk density was determined using the mass–volume relationship by filling an empty plastic container of predetermined volume with samples, and then weighing the full container. The bulk density was then determined by dividing the weight of the samples by the container volume[23]. Bulk density is calculated as follows

$$P_d = M/V_{act}, \quad (4)$$

where P_d is the bulk density of a tuber (g/cm^3), M the weight of a tuber (g) and V_{act} is the actual volume of a tuber (cm^3).

An analysis of variance statistical test was performed as reported earlier[24]. The differences between the means of physical properties were compared using least significance difference tests.

The standard deviation and summary of analysis of variance for the length, width and thickness, shape index, moisture content, weight, actual volume, density and calculated volume and water activity of potatoes produced using different tillage implements are shown in Tables 3 and 4 respectively.

Table 5 shows mean values of potatoes produced using different tillage implements. As seen in Table 5, tuber length varies depending on tillage implement, and ranges from 90 to 106 mm. This variation in the length of tubers could be attributed to soil aggregated. However, well-aggregated soils provide better moisture retention, adequate aeration, easy penetration for roots, and good permeability[25]. Moreover, the size of aggregates and aggregation state are affected by soil tillage implements[25].

The mean tuber widths are 62, 63 and 63 mm for potatoes produced using the disk harrow, chisel plow and moldboard plow respectively. The mean thicknesses are 50, 52 and 52 mm for potatoes produced using disk harrow, chisel plow and moldboard plow respectively. Thus, based on Suliman *et al.*[12], the produced potatoes belong to grade A, because the longest dimension of the tubers is more than 45 mm. Table 4 shows that the type of tillage implement had a significant effect on tuber length. As indicated in Table 5, tuber length is lower for potatoes produced using chisel plow compared to those produced using other tillage implements. The reductions in tuber length are 18.18% and 16.69% when compared to tubers produced using disk harrow and moldboard plow respectively. These changes may be related to tillage depth and this was in agreement with Akinboye *et al.*[26], who reported significant effects of land preparation methods on tuber length, with the longest tuber length recorded for sweet potato grown on plots with plowing using a disk harrow.

Statistical analysis in Table 4 shows no significant difference in tuber width between the tillage implements. As indicated in Table 5, tuber width is lower for potatoes produced using disk harrow when compared with those produced using other tillage implements. The reductions in tuber width are 2.4% and 2.35% when compared to chisel plow and moldboard plow respectively. Additionally, the statistical analysis shows no significant difference in tuber thickness among the tillage implements. As indicated in Table 5, tuber thickness is lower for potatoes produced using disk harrow when compared to those produced using other tillage implements. The reductions in tuber thickness are 3.66% and 2.9% when compared to chisel plow respectively.

As shown in Table 5, the tuber shape index values range from 250.04% to 370.37%, indicating long to very long shapes[20]. However, Gamea *et al.*[13] concluded that the shape of Spunta potato variety was long. Table 3 shows that the standard deviations for shape index are 14.23–21.23%, higher than those for length, width and thickness. These results contradict the expectation that a higher standard deviation would be observed for an index summing all dimensions in one number. Additionally, as seen in Table 4, significant shape index value differences are observed for various tillage implements. As indicated in Table 5, the shape index is lower for potatoes produced using chisel plow when compared to those produced using other tillage implements. The reductions in the shape index are 48.12% and 36.88% compared to disk harrow and moldboard plow respectively. These changes may be related to tuber dimensions.

As seen in Table 5, the mean water activities were 0.977, 0.977 and 0.976 for potatoes produced using the disk harrow, chisel plow and moldboard plow respectively. Additionally, as seen in Table 4, there is no significant difference in water activity among the tillage implements. As indicated in Table 5, water activity is slightly higher for potatoes produced using the moldboard plow when compared to those produced using other tillage implements.

As seen in Table 5, the mean values of the moisture content of potato tubers are 82.20%, 82.46% and 81.45% for potatoes produced using disk harrow, chisel plow, and moldboard plow respectively. As seen in Table 4, there is a significant difference in the moisture content of potato tubers among the tillage implements. Moreover, as indicated in Table 5, the moisture content of potato tubers is slightly low for potatoes produced using moldboard plow when compared to those produced using other tillage implements.

The tuber weight for fresh potatoes ranges from 179.28 g to 201.64 g (Table 5). It can thus be concluded that the use of a disk harrow or moldboard plow

Table 2. Mean* actual tillage depth, soil porosity and soil cone index at a soil depth of 0–15 cm and 15–30 cm as affected by different tillage implements

Tillage implements	Tillage depth (cm)	Soil porosity (%) at a soil depth of 0–15 cm	Soil cone index (MPa)	
			Soil depth 0–15 cm	Soil depth 15–30 cm
Disk harrow	14.5c	43.24a	1.37a	1.47a
Chisel plow	15.3b	42.27a	1.42a	1.50a
Moldboard plow	16.4a	42.79a	1.41a	1.55a
LSD⁺ (5%)	0.7	1.99	0.08	0.11

*Means followed by different letters in each column are significantly different at $P = 0.05$. ⁺LSD, Least significant difference.

Table 3. Standard deviation of physical properties of potato tubers produced using different tillage implements

Physical properties of potato tubers	Tillage implements		
	Disk harrow	Chisel plow	Moldboard plow
Length (mm)	9.77	5.69	5.56
Width (mm)	3.02	1.69	4.76
Thickness (mm)	2.55	6.7	4.34
Shape index	78.64	39.61	48.69
Water activity	0	0	0
Moisture content (% wb)	0.36	0.14	0.21
Weight (g)	33.91	28.59	23.54
Actual volume (cm^3)	31.7	26.81	22.61
Bulk density (g/cm^3)	0.01	0.01	0.01

Table 4. Summary of the analysis of variance for length, width, thickness, shape index, moisture content, mass, actual volume, density and calculated volume, and water activity of potatoes produced using different tillage implements

Source of variation	DF	Pr > F								
		Length	Width	Thickness	Shape index	Water activity	Moisture content	Mass	Actual volume	Bulk density
Replicates	4	0.93	0.62	0.27	0.99	0.53	0.59	0.45	0.44	0.19
Tillage implements	2	0.03	0.76	0.79	0.05	0.52	0.0009	0.41	0.38	0.208

Table 5. Mean* length, width, thickness, shape index, moisture content, mass, actual volume, density and calculated volume, and water activity of potatoes produced using different tillage implements.

Tillage implements	Length (mm)	Width (mm)	Thickness (mm)	Shape index	Water activity	Moisture content (%wb)	Mass (g)	Actual volume (cm^3)	Bulk density (g/cm^3)
Disk harrow	106a	62a	50a	370.37a	0.977a	82.20a	201.64a	188.98a	1.068a
Chisel plow	90b	63a	52a	250.04b	0.977a	82.46a	179.28a	167.02a	1.074a
Moldboard plow	105a	63a	52a	342.27ba	0.976a	81.45b	201.63a	189.10a	1.066a
LSD⁺ (5%)	12	5	6	34.21	0.003	0.39	42.18	39.57	0.009

*Means followed by different letters in each column are significantly different at $P = 0.05$. ⁺LSD, Least significant difference.

significantly affects tuber weight and that such plows can be used in loamy sand soil. However, Abrougui *et al.*[10] found that medium tillage produced 30% large tubers and 37% small tubers. Medium tubers comprised an average of 32% of potato tubers. With a maximum tillage depth of 30 cm, the researchers obtained large tubers. Moreover, there is no significant difference in average tuber weight among the tillage implements, at a 5% level of probability, as indicated in Table 4. In contrast, Ghazavi *et al.*[4] reported significant differences in tuber weight among the tillage implements, at a 5% probability level.

As seen in Table 5, the actual volume of fresh potato tubers ranged from 167.02 cm^3 to 189.10 cm^3. It can be concluded that, using moldboard plow significantly affects the actual volume of tubers, and that it can be used in loamy sand soil. There is no significant difference in the actual volume of tubers among tillage implements, at a 5% probability level, as shown in Table 4.

The bulk density of fresh potato tubers ranged from 1.066 g/cm^3 to 1.068 g/cm^3, and it can be concluded that using chisel plow significantly affects tuber bulk density. There is no significant difference in bulk density of potato tubers among tillage implements, at a 5% probability level. The present results show that soil preparation practices for Spunta potato planting can be achieved using the tested tillage implements. However, there were no significant differences among the studied physical properties. Thus, it is appropriate for a farm to select any of the studied tillage implements that are available.

This study reported the physical properties of fresh Spunta potato tubers. Three different tillage implements were used to prepare seedbeds of loamy sand soil. A centre pivot irrigation system was utilized for irrigation. The studied physical properties were weight, length, width, shape index, bulk density, moisture content, actual volume and water activity. The results show significant differences among different tillage implements in tuber moisture content, length and shape index. The tuber shape index values ranged from 250.04% to 370.37%, indicating long and very long shapes. Soil tillage for Spunta potato planting could be achieved using tested tillage implements. However, no significant differences were observed in the physical properties of potatoes produced using different implements.

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ACKNOWLEDGEMENTS. We thank the Deanship of Scientific Research, King Saud University and Agriculture Research Center, College of Food and Agriculture Sciences for the financial support, sponsorship and encouragement.

Received 19 March 2017; revised accepted 14 November 2017

doi: 10.18520/cs/v114/i10/2146-2150