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Research Paper

Effects of sprinkler irrigation on physical properties of soil and on the yields of green gram

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Abstract. Field trials were conducted in the arid and semi-arid of the North West Kenya to assess the impact of sprinkler nozzle size on physical soil properties and subsequently on crop yield. Three different sprinkler sizes were tested under subsoiling and non subsoiling tillage field conditions. Green gram (*Vigna radiata syn. Phaseolus aureus*) was used as a test crop in each experimental plot. Soil particle distribution, penetration resistance, sprinkler characteristics and soil infiltration rates were assessed. Results indicated that the soil was sandy loam with a bulk density of 1.68 g/cm^3 and an optimum compaction moisture content of 17.53%. Compaction was 146 bars for Jalpari sprinkler type with more discharge at the end of the trials compared to Taiwan which had 142.5 bars. Naan sprinkler which had the least discharge caused compaction of 145 bars. Obtained results showed that there were no significant differences in crop yield due to sprinkler type. The trends however showed that sprinklers with high discharge resulted into lower yields. It was concluded that sprinklers with high discharge caused soil compaction and subsequently lower yield. The use of Taiwan sprinkler type and adoption of subsoiling tillage which gave the best yields were recommended for the project.

Keywords: Compaction, infiltration, penetration resistance.

INTRODUCTION

The main objective of irrigation is to supplement water to the crop's requirements for growth and development where rain water may be deficient (Kara et al., 2008). For sprinkler irrigation system, the application of water depends on the distribution of water, discharge rate of the sprinkler, spacing and other features of the sprinkler. The type and nozzles of the sprinkler are the most important features of the sprinkler irrigation system and they determine productivity and efficiency of the entire system (Keller and Bliesner, 1990).

Though sprinkler irrigation is one of the most efficient systems, it has shortfalls that compromise its efficiency and reduce crop yield. In irrigation set-ups in soils with poor physical properties there can be impairment of water infiltration into the soil, seedling emergence, root penetration, crop nutrient and water uptake, which result into low crop yield. For successful irrigation systems, continuous research is necessary to achieve improved crop production.

A study was conducted in West Pokot County in North Western Kenya at Wei Wei Irrigation Project to determine the performance of sprinkler irrigation and its effect on soil physical properties. The findings indicated that the soils were prone to compaction either by machinery or sprinkler water drops impact (Toromo et al., 2012; ISMES, 1987). The sprinkler water droplets energy causes compaction and decreases aggregate stability of the soil.

Silva (2006) found that the sprinklers with larger water droplets had higher impact energy over the soil surface, increasing surface sealing (compaction) and crust formation, which reduce infiltration and increase runoff.

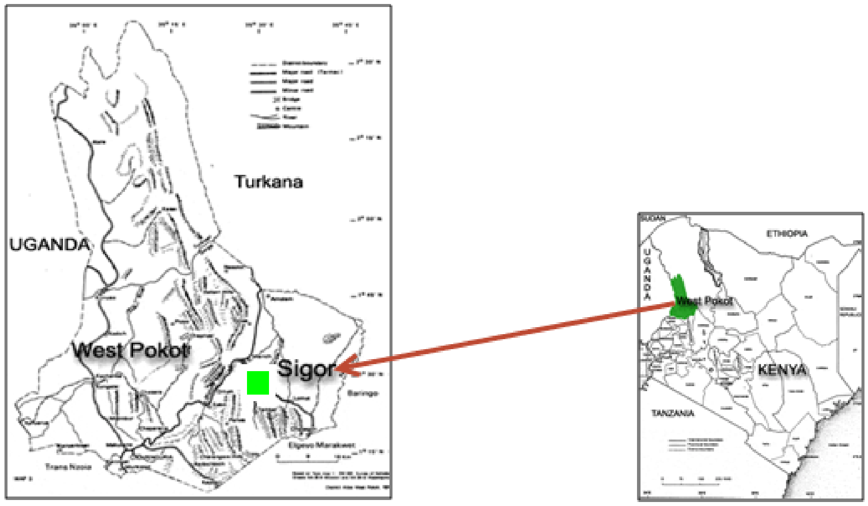

Figure 1. Wei Wei Integrated Development Project (WWIDP) in West Pokot County in Kenya.

Lehrsch and Kincaid (2006) found that sprinkler droplets energy degrades surface soil structure and decreased aggregate stability. Their findings ultimately recommended that the sprinkler kinetic energy of less than 10.6 J kg^{-1} is reasonable in minimizing surface structural breakdown of soil.

Compaction under intensive mechanized agriculture of dry and irrigated lands has not been addressed in the project due to limited technical knowledge by the farmers. This also has been aggravated by mechanical impact of irrigation water droplets and rain drops which enhance soil dispersion and further lowers infiltration capacity, particularly for high clay-silty contents. The basis of this study was hypothesised that sprinkler water drops size causes soil compaction during applications and subsequently results in runoff, soil erosion, poor soil drainage and reduction in crop yield. Despite this there has been an overall positive impact of the irrigation system on food production in the area albeit below the project potential.

The project was designed in 1987 to use sprinklers operating at 2.4 to 3.5 bars with twin nozzles of sizes 2.5 mm × 4.5 mm. This design was based on sandy loam soil with infiltration rates of 10 mm/h (ISMES, 1987). The sprinklers had distribution uniformity (DU) of 85% and coefficient of uniformity (CU) of 75%. Over the years and due to unreliable supply of specified sprinklers, farmers have used various types of sprinklers available locally. However, there are no sprinkler evaluations which have been conducted to determine their performance in terms of water application and effect on soil physical properties in West Pokot County in North Western Kenya. The objective of this study was to determine the effect of sprinkler type (nozzle size and discharge) under subsoiling tillage and no subsoiling tillage on soil compaction and hence soil infiltration and crop yield.

MATERIALS AND METHODS

Description of the study area

Wei Wei Integrated Development Project (WWIDP) is the focus of this study, which is situated in West Pokot County in Kenya (Figure 1). The project is situated 200 km North of Eldoret town and 200 km South of Lodwar town and lies at 35° 30′ E and 1°30′ N and at an elevation between 939 and 960 m above mean sea level. The current area under cultivation is 275 ha (Phase I and II) with an envisaged expansion by another 325 ha (Phase III). The project was established in 1987 in order to enhance food security, income generation, environmental conservation, transfer of modern farming technology and institutional capacity building (ISMES, 1987). The crops grown under the project irrigation system are maize, sorghum, cassava, mango, citrus, bananas and pawpaw. Other crops introduced recently include cowpea *(Vigna unguiculata* L.) and green gram (*Vigna radiata syn. Phaseolus aureus*).

The project area is classified as arid and semi-arid land (ASAL) with bimodal rainfall. The long precipitation season is between March and June and the short season is between September and November. The precipitation rates ranges from 700 mm in the lowlands to 1600 mm in the high altitudes annually with poor distribution during the year (Jaetzold et al., 2011). Temperatures are high and range from 15 to 30°C and the high evaporation rate (ETo = 2,289 mm/year) indicates that crops hardly survive without additional water supply through irrigation.

The project uses an overhead rotary sprinkler irrigation

Table 1. Irrigation schedule.

S/N	Sprinkler type	Application amount (mm/h)	Time schedule (days)	Duration (h)
1	Jalpari	11.6	5-6	5
2	Taiwan	9.0	5-6	5
3	Naan	7.8	5-6	5

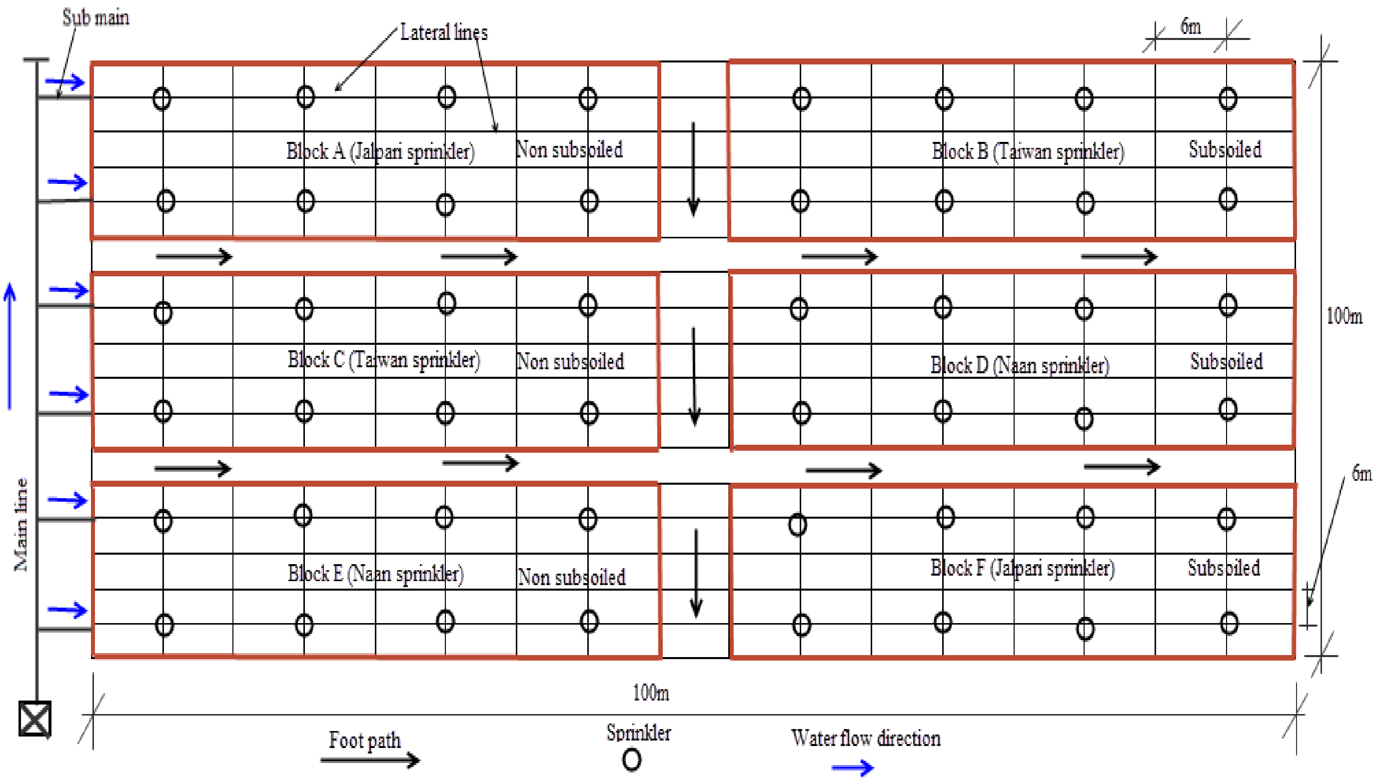

Figure 2. Field layout.

system with design pressures of a maximum 3.5 bar and sprinkler emissions of 0.3 l/s powered by gravity (ISMES, 1987). The project gets its irrigation water from Wei Wei River which originates from the adjacent Cherangany hills. Water is abstracted by a Weir into 1000 mm diameter steel pipeline. This is further distributed within the farm by the use of *u*PVC pipes. The wind in the area varies in intensity and direction and affects the efficiency, uniformity and distribution of the irrigation system.

According to Miller (1956) and IAO (1999), the valley in Wei Wei River composed young alluvial sediments, while the adjacent plains and foot slopes consist primarily of basement system rocks, namely fine grained hornblende gneisses (Viz: rocks rich in ferromagnesian minerals). The physiographic features of the area are closely related to the geology. It comprises the foot slopes of the Cherangany hills, the piedmont plain (or coalescing alluvial fanlands), the alluvial valley of the Wei Wei River, and minor valleys with young alluvial fans.

Experimental details

Experimental design and experimentation

Field trials were conducted during dry season of February to April, 2013 in a total area of 1 ha with a complete set of hand moved sprinkler irrigation equipment. Completely randomized design (Kothari, 2004) was used and the treatments were replicated two times in the field of 1 ha. The treatments were the sprinkler size discharges of 9, 11.6 and 7.8 mm/h for three types namely Taiwan, Jalpari and Naan, respectively (Table 1). The experimental field had six plots in which the trial was installed (Figure 2). Three plots were subsoiled and other three were prepared under normal project operations of ploughing and harrowing. Each plot had two lateral positions for uniformity of applying irrigation water. The laterals had four risers each fitted with sprinkler heads and the three sprinkler head types used had twin nozzles of two sizes

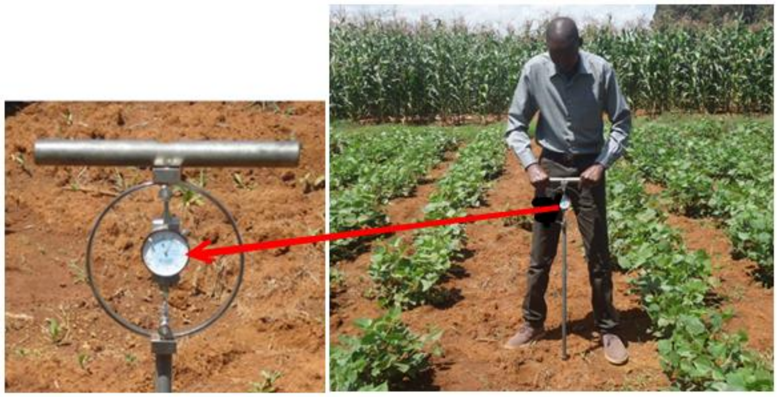

Figure 3. Cone Penetrometer and measurements of soil penetration resistance.

of 4.67 mm × 3.19 mm for Taiwan, 5.31 mm × 2.99 mm for Jalpari and 3.2 mm × 2.5 mm for Naan.

The laterals used in this experiment were the movable sets and were regularly shifted from one position to the next after attaining the set irrigation duration. In WWIDP irrigation water is applied at five hour duration with intervals of 5 to 6 days for green gram. This irrigation schedule was adopted in the cropping season for the field trials.

Sowing of green gram

Green gram variety KF20 was sown to all six trial plots at a spacing of 40 cm × 15 cm and used as a test crop in this experiment.

Data collection

Determination of physical properties of soils

Soil samples were collected from the trial plots at depths of 0 to 40 cm, ploughing depth. The properties of the studied soil were only considered for this depth of soil which was the approximate crop rooting depth and which had direct effect on yield. Soil calculator (Saxton, 2003) was used to determine the soil hydraulic properties.

Data on applied irrigation water

The applied irrigation water was measured alternately for each set of sprinkler type with catch cans spaced at 3 m squared grid between each other evenly distributed in the trial plots. The amount of water collected in the catch cans which had rim surface areas of 37.44 cm^2 was measured in mm using a graduated cylinder. The sprinkler water data collected from the catch cans was standardized to that of a normal rain gauge of surface area of 118.82 cm^2. The measurements were carried out at a pressure of 4.5 bars which was determined using a standard pressure gauge mounted on similar positions of the riser pipe with the sprinkler heads.

The data collected was processed using MS Excel computer software. The coefficient of uniformity (CU) and distribution uniformity (DU) which are common indices describing uniformity were determined as described by Keller and Bliesner (1990). The CU was calculated using Christiansen's formula given by Vories and von Bermuth (1986) thus:

$$CU = 100[1 - \frac{\sum X}{mn}] \quad (1)$$

Where, CU is the coefficient of uniformity (%), $\sum x$ is summation of absolute deviations from the mean depth of observations (mm), m is the mean depth of observations (mm) and n is the number of observations.

Also, DU is defined as the ratio of the least amount of infiltrated water to the average amount, which was determined using equation given by Hanson (2005) thus:

$$DU = 100[\frac{M_4}{M}] \quad (2)$$

Where, DU is the distribution uniformity (%), M_4 is the mean depth of the lowest quartile of the observations (mm) and M is the mean depth of all observations (mm).

Data on soil penetration resistance

The effect of sprinkler water drops on soil compaction was measured using a Penetrometer with a 30 degree steel cone (Figure 3) at the end of a steel shaft and a pressure gauge on the other end. The Penetrometer was pushed into the soil at a rate of 2.5 cm per second to

Table 2. Physical properties of the studied soils.

S/N	Parameter	SI Unit	Quantity
1	Particle Size Distribution		
	Clay	%	3.95
	Sand	%	58.55
	Silt	%	37.5
	Textural Class	Sandy Loam (SL)	
2	Bulky density	g/cm^3	1.68
3	Particle density	g/cm^3	1.83

depths of 0 to 20 cm during the measurements. The penetration resistance was measured before application of irrigation water and repeated thereafter at a time interval of six days. This was repeated for subsequent irrigation regimes until crop harvest and the degree of compaction determined from the differences in penetration resistances between the measurements. The penetration resistance due to long term machinery operations was taken as the average of resistances measured in the first irrigation schedule when compaction due to sprinkler was insignificant.

Data on water infiltration rates

The effect of soil compaction on water infiltration rates was measured using a double ring infiltrometer according to ASTM D-3385 standard procedure. The infiltrometer was made of 16-gauge metal sheet cylinders of inner and outer diameters of 30 and 60 cm, respectively. The two rings were driven into the ground to a depth of 5 cm without disturbing the soil and partially filled with water to a depth of 10 cm (Akinbile, 2010). The rates of infiltration were measured by first noting the time and the water level in the inner ring (reference level) as indicated on a measuring rod (graduated transparent ruler). The drop in the water level in the inner ring was measured first at short intervals of 1 to 2 min and thereafter at appropriate longer intervals of 20 to 30 min. The tests were taken at various irrigation schedules and the levels of compaction by the three types of sprinklers with different nozzle sizes. In the baseline and actual trials data collection, soil moisture content was viewed as a factor influencing infiltration rate uniformly across the trial plots. Initial infiltration rates were determined on the farm before land preparation to establish the behaviour of the soil under dry and undisturbed conditions.

Data on crop yield

At harvest, green gram crop was sampled from an area of 24 m × 6 m from each plot and the selected area for sampling did not have overlap of water application with any other sprinkler. The crop from the plots was harvested after attaining maturity and the grains were dried to 12.5% moisture content. The dry green gram grains from each plot was then weighed and analyzed.

Data analysis

The data was analyzed using two-way ANOVA statistical technique and differences were tested at 5% significance level (Kothari, 2004). MS-Excel computer software was used in this analysis.

RESULTS AND DISCUSSION

Soils physical properties

Results of particle size distribution from the studied soils had average percentage clay, silt and sand of 3.95, 37.50 and 58.55%, respectively, hence sandy loam (Table 2). In addition the soil bulk density was 1.68 g/cm^3. This bulk density is slightly greater than the average value for crop growth of most of the arable soils which ranges from 1.4 to 1.6 g/cm^3 (Ross and Mckenzie, 2010). The maximum particle density for the same soils was 1.83 g/cm^3. This particle density was greater than 1.6 g/cm^3, which is the upper limit for plant growth. The high particle density indicates the impacts of high loads on the soil bulk densities above the recommended values which are detrimental to plant growth.

Effect of sprinkler water drops on soil compaction

Results indicated that the initial soil penetration resistance measurements at depths of 0 to 20 cm had average value of 160 bars. The trial values ranged from as low as 108 bars at irrigation event 1 to 146 bars at irrigation event 5 (Table 3). These values were greater than the maximum root restricting soil resistance values of 10 bars (Taser and Kara, 2005; Hamza, 2005) and 20.68 bars (Duiker, 2002). The penetration resistances of subsoiled plots were lower at the start of the trials

Table 3. Soil resistance to penetration for different sprinkler types and irrigation schedules.

S/N	Sprinkler type	Block	Initial penetration resistance (bar)	Penetration resistance per irrigation schedule (bar)					Penetration resistance increase (bar)
				1	2	3	4	5	
1	Jalpari (*SS)	F	146	108	133	140	143	146	38
2	Jalpari (*NS)	A	165	134	140	143	146	146	12
3	Taiwan (SS)	B	160	127	136	143	143	143	16
4	Taiwan (NS)	C	168	135	142	142	145	145	10
5	Naan (SS)	D	160	131	140	140	145	145	14
6	Naan (NS)	E	160	141	143	140	144	141	0

*NS - Non subsoiled; *SS - Subsoiled

Table 4. Initial and base infiltration rates for each irrigation schedule.

S/N	Block	Initial (mm/h)	Schedule 1 (mm/h)	Schedule 2 (mm/h)	Schedule 3 (mm/h)	Schedule 4 (mm/h)
1	A	36	92	63	64	64
2	B	24	109	116	63	61
3	C	24	91	63	63	63
4	D	22	90	53	75	68
5	E	26	231	120	92	79
6	F	12	82	58	79	70

Table 5. Sprinkler characteristics.

S/N	Sprinkler type	Discharge (mm/h)	Coefficient of uniformity, CU (%)	Distribution uniformity, DU (%)
1	Jalpari	13.85	72.2	57.85
2	Taiwan	9.83	83.2	75.88
3	Naan	6.04	71.2	58.46

compared to non subsoiled plots. Similarly, penetration resistance was low with high discharge sprinklers and slightly high in low discharge sprinklers both in subsoiled and non subsoiled plots during the first irrigation schedules. The penetration resistance of the highest discharge sprinkler (Jalpari) continued to rise and exceeded other sprinklers in the fifth irrigation schedule at 146 bars. The increase in soil resistance to penetration was associated with gradual impact of sprinkler water drops on the compaction of the soil.

Soil infiltration

Results indicated that soil base infiltration rates were 24 mm/h for initial measurements, 52.8 mm/h for soil hydraulic calculator and 60 to 79 mm/h for measurements taken after installation of trials (Table 4). These soil infiltration rates were moderate (20 to 60 mm/h) to moderately rapid (60 to 90 mm/h) as described by Landon (1991). ISMES (1987) recommended the water application rate for the project soils as 10 mm/h. The infiltration rates of the soil measured decreased with the increase in irrigation schedules. This decrease could be due to available moisture in the soils at subsequent irrigation schedules and effects of soil compaction as a result of sprinkler water drops. Compared to the two sprinklers, Jalpari sprinkler generally had lower infiltration rates at every subsequent irrigation event.

Sprinkler performance

Results (Table 5) indicated Jalpari sprinkler with a discharge of 13.85 mm/h, CU of 72.2% and a DU of 57.85% at a spacing of 12 m × 18 m applied more water and did not meet the recommended characteristics of DU >75% and CU >84% described by Keller and Bliesner (1990). On the other hand, Taiwan sprinkler displayed the best characteristics of water application of CU 83.2%, DU 75.88% and water application rate of 9.83 mm/h which is closer in magnitude to the project's recommended value of 10 mm/h (ISMES, 1987). Furthermore, Naan sprinkler with CU 71.2%, DU 58.46% and lower water application

Table 6. Green gram yield and cost benefit analysis.

S/N	Plot	Sprinkler type/block	Yield (kg/ha)	Total revenue (kshs/ha)	Production cost (kshs/ha)	Surplus (kshs/ha)
		Jalpari (Block A)	552.08	82,812.00	98,224.10	-15,412.10
1	Non subsoiled	Taiwan (Block C)	437.50	65,625.00	98,224.10	-32,599.10
		Naan (Block E)	208.33	31,249.50	98,224.10	-66,974.60
		Jalpari (Block F)	1,027.78	154,167.00	98,224.10	55,942.90
2	Subsoiled	Taiwan (Block B)	1,190.97	178,645.50	98,224.10	80,421.40
		Naan (Block D)	507.94	76,191.00	98,224.10	-22,033.10

rate of 6.04 mm/h required long duration to supply sufficient moisture to the soil. This sprinkler was inefficient under the project operational conditions because it provided longer water scheduling periods associated with time loss and high evaporation losses due to small water drops discharged by the sprinkler.

Green gram yield

The yield determined for each sprinkler type with subsoiled plots exceeded that in the non subsoiled plots (Table 6). The yield exceeds were by 475.7, 753.47 and 299.61 kg/ha for Jalpari, Taiwan and Naan sprinklers, respectively. The cost benefit analysis on yield resulted in negative surpluses for all non subsoiled plots and in that for Naan sprinkler in the subsoiled plots.The negative surplus in yield for Naan sprinkler was associated with its low water application (6.04 mm/h) as opposed to the recommended application rate of 10 mm/h (ISMES, 1987). On the other hand, Jalpari and Taiwan sprinklers in the subsoiled plots had positive net income of yields of Kshs 55,942.90 and Kshs 80,421.40 per hectare, respectively. The highest yield was achieved with the use of Taiwan sprinkler which had water application rate of 8.5 mm/h, DU of 75.88% and CU of 83.2% which are close to values recommended by Keller and Bliesner (1990) and Kara et al. (2008). The yield with Jalpari sprinkler type was lower because of poor performance characteristics, high penetration resistance, low infiltration and hence reduced crop yield. These findings suggest that subsoiling improve water infiltration, nutrient uptake, aeration, penetration resistance of the soil and ultimately yield.

CONCLUSIONS

Results from this study indicate that sprinklers especially with high discharge increase soil compaction and reduce crop yield. Sprinkler water drops cause soil compaction because the sprinkler with the highest dicharge such as Jalpari with 13.85 mm/h had the highest penetration resistance of 146 bars. Taiwan and Naan sprinklers had lower penetration resistances.Taiwan sprinkler had the best characteristics with DU of 75.88% and CU of 83.42% and this was recommended for use in the project and strategies for continous supply to the farmers in the project area should be developed.

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