

Research Article

Effect of Tillage, Irrigation, and Nutrient Levels on Growth and Yield of Sweet Potato in Rice Fallow

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A field experiment was conducted during the year 2007-2008 and 2008-2009 in Bhubaneswar, India to study the effect of tillage, irrigation and nutrient levels on growth and yield of sweet potato (*Ipomoea batatas* L.) in rice fallow. The results revealed that the conventional tillage system of sweet potato planting recorded maximum fresh root yield. During the year 2007-2008 and 2008-2009, the fresh root yield in this system was 4.6% and 30.3% higher than the minimum tillage treatment, respectively. Similarly 5.6% and 21.7% higher green fodder yields were obtained in conventional tillage compared to minimum tillage treatment during the year 2007-2008 and 2008-2009, respectively. But lower consumptive use and water use efficiency (WUE) were observed in conventional tillage than minimum tillage. Increasing irrigation and nutrient levels increased root and fodder yield significantly in both the years as well as reduced the soil compactness. The consumptive use and WUE were decreased with increasing irrigation levels, and increased with increasing levels of nutrients. Minimum tillage has advanced planting of sweet potato 15 to 17 days and produced 80–90% root and fodder yield of conventional tillage.

1. Introduction

Rice (*Oryza sativa* L.) is a staple food crop in many of the developing countries in the world. It is grown in all the ecosystems. Transplanted rice is most common in both rainfed and irrigated ecosystem. In rainfed lowlands, rice is mostly transplanted; occasionally direct seeded either in dry soil or drilled in puddled soil. This type of rice system represents 25% of the total rice area and 17% of world production, ranking second after irrigated rice [1]. In these lands, soils remain under saturated/swampy conditions after harvest of rice due to ponding of water during the cropping season. It takes 15–30 days to dry for tillable conditions. Hence, farmer grows long duration rice varieties or keeps the fields vacant. Pulses and oil seeds are sown after harvest of rice by preparing fine seed beds in rice-based cropping system. However, in certain Asian countries like India and Bangladesh winter delays sowing of pulses and oil seeds. The ever increasing human and animal populations are

exerting a lot of pressure on food and fodder production. As the land available for agriculture is shrinking, multiple cropping and enhancing productivity are the options left with the farmers to meet out the demand of food and fodder requirements.

Sweet potato (*Ipomoea batatas* L.), a tuberous root crop, is grown throughout the tropical and subtropical countries. In uplands, it is grown under rainfed conditions whereas in lowlands, it is grown after harvest of rice with few irrigations. The tuberous roots are rich source of carbohydrate and secondary staple in many developing countries in Asia, Africa, and Latin America [2]. The green vines serve as fodder for animals. Sweet potato is a dual purpose crop suitable for planting especially after rice harvest in marshy lowlands. Tillage is difficult/not possible in such marshy/wet soils immediately after harvest of rice. When the soil is wet, minimum or no tillage for upland crops after low-land rice is recommended. Under such ecosystem, upland crops such as pulses may suffer due to excess moisture in the soil. However,

sweet potato establishes well in marshy conditions and there is no need of seed bed preparation (tillage). It saves time, water, and energy inputs. Sweet potato can be harvested within 90–105 days after planting (DAP). Thus, the cropping intensity in lowlands can be increased by growing sweet potato.

In intensive cropping systems a minimal tillage system involving ploughing the land only for first crop is recommended (rice-wheat (*Triticum aestivum*) system) in India and elsewhere [3]. Wheat yield under zero-tillage or minimum tillage is found on par with conventional tillage system in most of the locations [4]. However, root and tuber crops respond differently to zero or minimum tillage. Jongruaysup et al. [5] reported that the fresh root yield of cassava (*Manihot esculenta* Crantz.) grown under zero-tillage system was significantly higher than that of cassava grown using conventional tillage on fine loamy soil (Oxic Paleustults) in Thailand. But in Khaw Hin Sorn and TTDI sites in Thailand, the cassava tuber yield was comparable whereas in Huay Pong and Rayong sites of the same country lowest yield was obtained. Tongglum et al. [6] observed no significant difference in cassava root yield between zero and conventional tillage planting in Thailand. In China, slight reduction in cassava root yield but not at significant level was noticed under zero-tillage system compared to conventional tillage system [7]. In compact soils, zero-tillage resulted in lower cassava root yield and experienced difficulty in weeding and harvesting [8]. In well-drained coastal alfisols of Uyo, Nigeria, no significant difference was observed in sprouting, growth, yield attributes, and yield of *Colocasia* and *Xanthosoma* between zero and other tillage practices [9]. In Hawaii, higher yields were recorded in taro (*Colocasia esculenta*) when planted in puddled soil with higher doses of fertilizers [10]. In rainforest zone of southwest Nigeria, reduced tillage techniques are as effective as conventional tillage for cocoyam (*Xanthosoma sagittifolium* (L.) Schott) cultivation [11].

Castroverde [12] stated that minimum tillage is necessary to obtain a loose and well-aerated soil for the development of storage roots. This was confirmed by Pardales [13] who showed that conventional tillage (ploughing and harrowing the entire area) or minimum tillage (row ploughing only) were better than zero-tillage. Sustainability of reduced tillage was also reported by Liebig et al. [14] and Sharma et al. [15].

Soil conditions of puddled low-land rice ecosystem are quite different from upland ecosystem. Puddling, which is done to reduce percolation rate causes soil compaction. This poses problem to the following arable crops [15]. Sweet potato being root crop, may respond differently in puddled low-land rice fields. Soil compaction may affect root bulking. Irrigation can loosen the soil [16] and can improve the root bulking.

We hypothesize sweet potato can be established in saturated/marshy soils under zero-tillage and subsequent earthing up at appropriate moisture level would create favourable conditions for root bulking. Few numbers of irrigation can reduce compactness of the soil. Sweet potato responds very well to fertilizer application. Hence present investigations were carried out to find out the effect of tillage methods,

number of irrigations, and levels of nutrients on sweet potato in rice fallow.

2. Materials and Methods

2.1. Site Characteristics. A field experiment was conducted during the years 2007-2008 and 2008-2009 at Regional Centre of Central Tuber Crops Research Institute (20° 14' 50'' N and 85° 47' 06'' E), Dumduma, Bhubaneswar, Orissa, India. The soil of the experimental site was a sandy clay loam with bulk density of 1.53 g cm⁻³. The soil was acidic (pH 5.8), low in available N (205 kg ha⁻¹), P (18 kg ha⁻¹), and K (155 kg ha⁻¹). The climate of the region is warm and humid in summer and cool and dry in winter.

2.2. Rice Planting. Rice was the preceding crop of sweet potato. Rice (var. Naveen) was grown during rainy season (*kharif*) by transplanting 20–22-day-old seedlings in puddled soil on 7 August 2007 and 5 August 2008. No treatment was imposed on rice, and it was grown as per recommended package of practices as follows: FYM at 5 t ha⁻¹ and N-P₂O₅-K₂O at 60-30-30 kg ha⁻¹. The rice crop was harvested on 2 November 2007 and 30 October 2008. The rice crop produced 5.6 and 4.9 t ha⁻¹ grain yield during 2007 and 2008, respectively.

2.3. Sweet Potato Planting. Immediately after harvest of the rice, sweet potato was planted (dry/winter season) in the rice field. The following treatments were imposed in sweet potato in split-split plot design with three replications. Minimum tillage (crop stand establishment in zero-tillage, and earthing up between 15 to 20 DAP, and 60 DAP) and conventional tillage (one pass of disc plough, three passes of cultivator followed by forming ridge and furrows, and earthing up between 15 to 20 DAP, and 60 DAP) were taken in main plots. The treatment and number of irrigations (3, 5, and 7) were allotted in subplots. In sub-subplots, nutrient levels at 0-0-0, 37.5-25-37.5, and 75-50-75 N-P₂O₅-K₂O kg ha⁻¹ were imposed. The plot size for sweet potato planting was 6 m × 3 m and spacing of 1.5 m was kept between the plots. Sweet potato under zero-tillage was planted on 3 November 2007 and 31 October 2008. During 2008, 5 cm of water was applied to simulate saturated conditions for zero-tillage planting of sweet potato (minimum tillage treatments). This was done as there was no water on the surface of the soil due to low rainfall in the month of October 2008. Under conventional system sweet potato was planted on 20 November 2007 and 15 November 2008. In conventional tillage, planting was done on ridges after making ridge and furrow. In minimum tillage system sweet potato was planted on flat beds and later converted into ridge and furrows.

Lateral pipelines, 7.5 cm diameter PVC pipes were laid out all along the treatments with outlet and lid in each plot. Whenever irrigation was scheduled to a plot, the outlet was opened and the remaining plots outlets were closed with the lid. All the lateral pipelines were connected to main pipeline. A water meter was installed in the main pipeline to monitor the amount of water applied. Irrigation was

scheduled as per treatment and each irrigation of 4 cm of water was applied. In conventional tillage system, 4 cm of water was applied immediately after planting to ensure good establishment. Later, irrigation treatments were imposed. In fertilizer treatment, half of N and K and full P were applied as basal dose immediately after planting; the remaining half of N and K was applied one month after planting (MAP). Weeding-cum-earthing up was carried out at 15–20 and 60 DAP in minimum tillage treatment and 30 and 60 DAP in conventional tillage. Need-based plant protection measures were followed against sweet potato weevil (*Cylas formicarius* L.). The crop was harvested 105 DAP.

2.4. Plant Measurements. Three consecutive plants were randomly selected and uprooted carefully during each sampling. The roots of the uprooted plants were washed thoroughly with tap water, and the adhering soils around the roots were removed. Roots, vine, and leaves were separated and averaged, and the averages, were expressed per plant. Vine length was measured from base of the vine to the tip at harvest. Leaf area index (LAI) was estimated at 90 DAP and harvest. The LI-COR Model LI-3000 portable leaf area meter with the transparent belt conveyor (Model LI-3050A) and an electronic digital display was used for measuring leaf area. The area was integrated and displayed in cm² as the excised leaves were fed into conveyor belt assembly. The LAI was calculated by dividing the total leaf area with the corresponding land area [17].

$$\text{LAI} = \frac{\text{total leaf area}}{\text{unit land area}} \quad (1)$$

Number of roots per plant, root length, root diameter, and root weight per plant were measured at harvest. Root diameter was measured with Vernier calipers. Net plot yield at harvest was converted into per ha.

2.5. Soil Moisture Studies and Penetration Resistance. Moisture status of various layers, namely, 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm of soil profile treatment-wise was determined gravimetrically at planting, before and after irrigation. The moisture contents were converted to volumetric moisture contents by multiplying with respective bulk density values. Consumptive use (Cu) of water was calculated by using the formula

$$\text{Cu} = \sum_{i=1}^n (\text{E}_p \times 0.6) + \sum_{i=1}^n \left(\frac{M_{ai} - M_{bi}}{100} \right) \times \text{BD}_i \times D_i + \text{ER}, \quad (2)$$

where E_p is pan evaporation value for the period from the date of irrigation to the date of soil sampling after each irrigation, 0.6 is pan factor, n is number of soil layers considered in root zone depth D , M_{ai} is soil moisture percentage after irrigation in i th layer, M_{bi} is soil moisture percentage before irrigation in i th layer, BD_i is bulk density of i th layer, D_i is depth of i th layer, and ER is effective rainfall. E_p was measured from open pan evaporimeter (USDA Class A open pan evaporimeter) installed at 200 m away from the

experimental site. Pan factor 0.6 is determined based on the wind velocity and solar radiation values of the location [18]. The distribution of soil water content was determined in different layers, namely, 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm and the results were summed up and presented as M in the equation. The experiment was conducted in dry season and the rainfall received was less during the cropping season (Table 1). Irrigation water was applied less frequently (3, 5, and 7 number of irrigations) with 4 cm of water in each irrigation. Hence percolation losses were presumed zero. Effective rainfall was calculated by the soil moisture balance method [19]. The water storage capacity of the soil was 151 mm in 600 mm depth. Irrigation and rainfall were noted on credit side and soil moisture depletion was noted on debit side. Any amount of rainfall in excess of soil storage capacity was considered as surplus.

Water use efficiency (WUE) was calculated by the following formula:

$$\text{WUE} = \frac{\text{root yield (kg)}}{\text{consumptive use of water (mm)}} \quad (3)$$

Penetration resistance of soil was measured with hand-held penetrometer as described by Black [20].

2.6. Statistical Analysis. The data were subjected to analysis of variance (ANOVA) using Genstat. The significant differences between treatments were determined using least significant difference.

3. Results

3.1. Weather Conditions. The mean temperature ranged between 22.0 and 29.6°C in the year 2007–2008 and 23.4 and 29.2°C in the year 2008–2009 during rice-sweet potato cropping period (Table 1). A total rainfall of 1275.3 and 1180.4 mm was observed between July to March of 2007–2008 and 2008–2009, respectively. During 2007–2008 rice-sweet potato cropping period received more rainfall than 2008–2009 rice-sweet potato cropping period. Maximum rainfall was received between July and September in each year which was corresponding to rice cropping period. During 2007–2008, 83.5% of total rainfall was received between July and September whereas during 2008–2009, 96.8% of total rainfall was received between July and September. The mean relative humidity was ranged from 62 to 88% during 2007–2008 and from 66 to 87% during 2008–2009 rice-sweet potato cropping period (Table 1).

3.2. Growth. Statistically significant difference in vine length was observed at harvest (Table 2). The longest vines were observed in conventional tillage system than minimum tillage. Number of irrigations had significant influence on vine length. The longest vines were noticed with highest frequency of irrigation (7 irrigations) during both the years of study. The shortest vines were observed with minimum irrigation level (3 irrigations). Influence of nutrient levels on vine length was also noticed (Table 2). Longer vines were registered with higher levels of fertilizer application.

TABLE 1: Weather conditions during crop growing period.

Month	Mean temperature (°C)		Mean relative humidity (%)		Rainfall (mm)	
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
July	29.6	29.1	83	85	183.3	227.3
August	28.9	28.5	86	87	346.4	297.6
September	28.2	28.5	88	86	535.3	617.8
October	27.6	28.0	76	76	131.1	31.8
November	25.5	24.9	78	70	15.9	5.9
December	22.0	23.4	62	72	0.0	0.0
January	22.1	23.9	67	70	24.4	0.0
February	23.2	27.1	70	66	33.8	0.0
March	28.7	29.2	69	66	5.1	0.0

TABLE 2: Effect of tillage, irrigation, and nutrient levels on growth of sweet potato in rice fallow.

Treatment	Vine length (cm)		LAI				
	2007-2008	2008-2009	2007-2008		2008-2009		
			90 DAP	Harvest	90 DAP	Harvest	
<i>Tillage</i>							
Minimum tillage	102.3	100.6	2.51	2.38	2.42	2.33	
Conventional tillage	110.1	115.6	2.74	2.50	2.64	2.51	
LSD ($P = 0.05$)	8.1	7.7	NS	NS	0.19	0.15	
<i>No. of irrigation</i>							
3	97.8	96.7	2.31	2.11	2.26	2.12	
5	107.1	111.3	2.68	2.50	2.61	2.53	
7	114.8	117.3	2.88	2.72	2.72	2.61	
LSD ($P = 0.05$)	4.6	3.5	0.08	0.05	0.05	0.04	
<i>Nutrient levels (N-P₂O₅-K₂O kg ha⁻¹)</i>							
0-0-0	91.9	96.4	2.50	2.31	2.36	2.26	
37.5-25-37.5	110.3	112.3	2.63	2.46	2.58	2.42	
75-50-75	116.5	116.6	2.74	2.57	2.65	2.58	
LSD ($P = 0.05$)	3.8	3.4	0.07	0.07	0.07	0.06	

Significantly longest vine was observed with N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ and shortest vine was with control (no fertilizer). Application of N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ recorded significantly longer vines compared to control (no fertilizer). LAI indicator of leaf area development was found nonsignificant with respect to tillage practices at 90 DAP and harvest during both the years 2007-2008 and 2008-2009. However, conventional tillage practices recorded higher LAI than minimum tillage. Increasing LAI with increase of irrigation numbers was observed both at 90 DAP and harvest. LAI with 7 irrigations was significantly higher than 5 and 3 irrigations in both the years at 90 DAP and harvest. Application of 5 irrigations produced significantly higher LAI compared to 3 irrigations, both at 90 DAP and harvest. Lower level of LAI was observed at minimum number of irrigation (3 irrigations). Marked variation in LAI was noticed with the levels of fertilizer application (Table 2). Significantly higher LAI was registered with the application of higher level of fertilizer N-P₂O₅-K₂O at

75-50-75 kg/ha as compared to N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ and control (no fertilizer). LAI with N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ was statistically superior to control (no fertilizer). LAI at 90 DAP and harvest was found lowest during both the years of study.

3.3. *Yield Attributes.* Method of tillage had appreciable impact on yield attributes like number of roots per plant, root length, root diameter, and root yield per plant (Table 3). Maximum number of roots per plant and root length were found in conventional tillage, and it was significantly higher than minimum tillage during 2008-2009 but at par during 2007-2008. Sweet potato roots are usually cylindrical in shape. But due to puddling in the preceding rice crop that resulted in compactness of soil which led to compressed (flattened) roots in sweet potato under minimum tillage. Hence root diameter was measured in two directions North-South (N-S) and East-West (E-W). Root diameter in N-S direction was found more than E-W direction under

TABLE 3: Effect of tillage, irrigation, and nutrient levels on yield attributes of sweet potato in rice fallow.

Treatment	No. of roots per plant		Root length (cm)		Root diameter (cm)				Root yield per plant (g)	
					N-S		E-W			
	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009	2007-2008	2008-2009
<i>Tillage</i>										
Minimum tillage	2.9	2.4	13.6	12.5	6.5	6.2	5.7	5.6	154.0	147.5
Conventional tillage	3.0	2.9	13.9	13.4	7.6	7.2	7.5	7.2	162.8	163.4
LSD ($P = 0.05$)	NS	0.2	NS	0.6	0.7	0.4	0.2	0.4	7.7	11.1
<i>No. of irrigation</i>										
3	2.3	2.1	12.0	11.5	6.2	5.7	5.2	4.9	125.3	121.3
5	3.0	2.7	13.9	13.1	7.3	7.2	7.1	7.1	166.4	164.7
7	3.5	3.2	15.3	14.4	7.7	7.2	7.6	7.2	183.7	180.5
LSD ($P = 0.05$)	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.1	5.2	8.1
<i>Nutrient levels</i> ($N-P_2O_5-K_2O$ kg ha ⁻¹)										
0-0-0	2.6	2.3	13.2	12.2	6.4	6.1	6.0	5.8	129.3	127.4
37.5-25-37.5	3.0	2.8	13.9	13.0	7.2	6.9	6.8	6.6	165.2	161.1
75-50-75	3.2	2.9	14.2	13.7	7.5	7.2	7.0	6.9	180.9	177.9
LSD ($P = 0.05$)	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	4.0	6.3

minimum tillage whereas under conventional tillage such difference was not noticed. Significant difference in root diameter in N-S and E-W direction was observed between minimum and conventional tillage practices. Significantly higher diameter was noticed with conventional tillage compared to minimum tillage in both the directions during 2007-2008 and 2008-2009. Marked variation in root yield per plant was observed in tillage methods. Significantly higher root yield per plant was noticed in conventional tillage compared to minimum tillage in both the years of study.

Appreciable variation in yield attributes was observed due to number of irrigations. Increasing frequency of irrigation increased the yield attributes in both the years of study (Table 3). Significantly higher number of roots per plant, root length, root diameter (N-S and E-W), and root yield per plant were found with 7 number of irrigations as compared to 3 and 5 number of irrigation levels. However, it was on par with 5 irrigations with respect to root diameter (N-S and E-W). Application of 5 irrigations recorded significantly higher number of roots per plant, root length, root diameter (N-S and E-W), and root weight per plant than 3 irrigations. Marked difference in yield attributes was noticed with the levels of fertilizer application (Table 3). Maximum yield attributes (number of roots per plant, root length, root diameter (N-S and E-W), and root weight per plant) were found with $N-P_2O_5-K_2O$ at 75-50-75 kg ha⁻¹, which was significantly higher than other treatments. Application of $N-P_2O_5-K_2O$ at 37.5-25-37.5 kg ha⁻¹ produced significantly higher number of roots per plant, root length, root diameter (N-S and E-W), and root weight per plant compared to control (no fertilizer).

3.4. Fresh Root and Fodder Yield. The perusal of data indicated that method of crop establishment had influenced the fresh root yield appreciably (Table 4). Conventional tillage system recorded significantly higher root yield than minimum tillage planting. But the yield difference between minimum tillage and conventional tillage crop establishment was 4.6% during 2007-2008 whereas it was 30.3% during 2008-2009. Increasing irrigation frequency increased sweet potato root yield (Table 4). However, the rate of increase between 3 and 5 irrigations was higher than between 5 and 7 irrigations. Between 3–5 irrigation the root yield increase was 24.9% and 28.1% whereas the increase of root yield between 5 and 7 irrigations was 24.5% and 19.0% during the year 2007-2008 and 2008-2009, respectively. Appreciable response for irrigation was noticed in both methods of crop establishment (Table 5). Under minimum tillage the yield increase rate was higher and continued up to 7 irrigations. In conventional system of planting uniform response for irrigation frequency was observed. The highest yield was obtained at 7 irrigations.

Marked variation on fresh root yield was noticed with the variation of nutrient levels (Table 4). Significantly higher root yield was obtained with the application of $N-P_2O_5-K_2O$ at 75-50-75 kg ha⁻¹. It was 25.5% and 8.8% higher than control (no fertilizer) and $N-P_2O_5-K_2O$ at 37.5-25-37.5 kg ha⁻¹, respectively, during the year 2007-2008 whereas 34.7% and 14.8% higher yield over control (no fertilizer) and $N-P_2O_5-K_2O$ at 37.5-25-37.5 kg ha⁻¹, respectively, were observed during the year 2008-2009. Under minimum tillage conditions sweet potato recorded higher root yield when no fertilizer was applied as compared to conventional system of

TABLE 4: Effect of tillage, irrigation, and nutrient levels on root and fodder yield of sweet potato in rice fallow.

Treatment	Root yield (kg ha ⁻¹)		Fodder yield (kg ha ⁻¹)	
	2007-2008	2008-2009	2007-2008	2008-2009
<i>Tillage</i>				
Minimum tillage	11100	9210	10370	10530
Conventional tillage	11600	12000	10810	12820
LSD (<i>P</i> = 0.05)	470	410	NS	380
<i>No. of irrigation</i>				
3	9320	8360	8390	9770
5	11640	10710	10860	11640
7	13100	12750	12510	13630
LSD (<i>P</i> = 0.05)	500	330	250	330
<i>Nutrient levels (N-P₂O₅-K₂O kg ha⁻¹)</i>				
0-0-0	9990	9040	9670	10190
37.5-25-37.5	11530	10610	10770	11700
75-50-75	12540	12180	11330	13140
LSD (<i>P</i> = 0.05)	340	240	390	260

TABLE 5: Interaction effect of tillage and number of irrigation on sweet potato root yield (kg ha⁻¹) in rice fallow.

Method of tillage	Number of irrigation			LSD (<i>P</i> = 0.05)
	3	5	7	
2007-2008				
Minimum	8990	11530	12770	610
Conventional	9650	11750	13430	
2008-2009				
Minimum	7140	9240	11250	430
Conventional	9590	12180	14240	

TABLE 6: Interaction effect of tillage and nutrient levels on sweet potato root yield (kg ha⁻¹) in rice fallow.

Method of tillage	Nutrient levels (N-P ₂ O ₅ -K ₂ O kg ha ⁻¹)			LSD (<i>P</i> = 0.05)
	0-0-0	37.5-25-37.5	75-50-75	
2007-2008				
Minimum	10290	11170	11830	460
Conventional	9690	11880	13250	
2008-2009				
Minimum	8190	8980	10460	360
Conventional	9880	12230	13890	

planting during the year 2007-2008, but it was reverse in the year 2008-2009 (Table 6). However, conventional system of planting responded up to N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ compared to minimum tillage.

Sweet potato response to nutrient application, increased with increase in irrigation levels in both the years of study (Table 7). At lower level of irrigation frequency (3 irrigations), increasing fertilizer doses increased the fresh root yield at lower rate as compared to higher level of irrigation

TABLE 7: Interaction effect of irrigation and nutrient levels on sweet potato root yield (kg ha⁻¹) in rice fallow.

Number of irrigation	Nutrient levels (N-P ₂ O ₅ -K ₂ O kg ha ⁻¹)			LSD (<i>P</i> = 0.05)
	0-0-0	37.5-25-37.5	75-50-75	
2007-2008				
3	7270	8200	9490	590
5	8950	10730	11230	
7	10750	11650	14400	
2008-2009				
3	7010	8180	9900	450
5	8940	11370	11830	
7	11160	12280	14810	

frequencies. The highest root yield was noticed with higher amount of nutrient application (N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹) and irrigation (7 irrigations). Lowest amount of yield was observed in control (no fertilizer applied) and minimum number of irrigations (3 irrigations).

Sweet potato vine is used as a green fodder for livestock. No significant difference in green fodder yield was noticed among methods of tillage (Table 4). A negligible difference of fodder yield (5.6%) was observed between minimum tillage and conventional tillage during 2007-2008 whereas significant difference of 21.7% was observed during 2008-2009. Increasing the frequency of irrigation increased the green fodder yield. Significantly higher green fodder yield was registered with 7 irrigations. It was 49.2 and 15.2% higher than 3 and 5 irrigations, respectively, during 2007-2008 whereas 39.5 and 17.1% higher than 3 and 5 irrigations, respectively, during 2008-2009. Similarly, application of higher levels of nutrients N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ recorded significantly higher green fodder yield of 17.3% and 29.0% than control, 5.2% and 12.3% than N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ during the years 2007-2008 and 2008-2009, respectively. Application of N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ increased green fodder yield of 11.5% and 14.9% than control during 2007-2008 and 2008-2009, respectively.

3.5. Profile Moisture Contribution and Consumptive Use.

Sweet potato produces adventitious roots on the nodes which are below the soil surface. Some of the roots bulge due to accumulation of starch in the parenchyma tissues and developed into tuberous roots. The effective root depth of sweet potato appears to be in the range of 0.4 to 0.6 m, although roots can extend to at least one meter [21]. Hence, soil moisture profile studies were carried out up to 0.6 m soil depth. Profile moisture contribution from 0–15, 15–30, 30–45, and 45–60 cm indicated that 78% moisture was extracted from top 0.45 m of the soil profile (Tables 8 and 9). In minimum tillage 78.4% soil moisture was contributed from 0–0.45 m soil depth and 21.6% soil moisture was from 0.45–0.60 m soil depth in the year 2007-2008 (Table 8) whereas 78.6% soil moisture was contributed from 0–0.45 m soil depth and 21.4% soil moisture was from 0.45–0.60 m soil depth in the year 2008-2009 (Table 9). In conventional

TABLE 8: Effect of different treatments on consumptive use of water by sweet potato in rice fallow during 2007-2008.

Treatment	Moisture contribution from profile storage (mm)					Evaporation (mm)	Effective rainfall (mm)	Consumptive use (mm)	Water use efficiency (kg mm ⁻¹)
	0–15 cm	15–30 cm	30–45 cm	45–60 cm	Total				
<i>Method of tillage</i>									
Minimum tillage	34.4 (28.3)*	31.9 (26.2)	29.1 (23.9)	26.3 (21.6)	121.6 (100.0)	24.8	58.2	204.6	54.6
Conventional	28.9 (25.9)	28.8 (25.8)	28.2 (25.3)	25.6 (23.0)	111.5 (100.0)	22.7	58.2	192.4	60.6
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	13.5	NS
<i>No. of irrigation</i>									
3	21.7 (25.8)	21.5 (25.6)	21.4 (25.4)	19.5 (23.2)	84.1 (100.0)	14.4	58.2	156.7	59.5
5	29.0 (25.6)	31.1 (27.4)	29.0 (25.6)	24.3 (21.4)	113.4 (100.0)	23.5	58.2	195.1	59.5
7	40.1 (26.3)	40.8 (26.8)	39.1 (25.7)	32.3 (21.2)	152.3 (100.0)	33.4	58.2	243.9	53.8
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	5.0	3.6
<i>Nutrient levels (kg h⁻¹)</i>									
0-0-0	27.3 (25.1)	29.2 (26.9)	27.6 (25.4)	24.5 (22.6)	108.6 (100.0)	23.8	58.2	190.6	52.8
37.5-25-37.5	31.1 (26.5)	30.8 (26.3)	30.2 (25.8)	25.1 (21.4)	117.2 (100.0)	23.8	58.2	199.2	58.4
75-50-75	33.8 (27.3)	32.7 (26.4)	31.2 (25.2)	26.1 (21.1)	123.9 (100.0)	23.8	58.2	205.9	61.7
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	3.4	2.4

* Percentage values are given within parentheses.

NS: Not significant.

tillage, 77.0% soil moisture was contributed from 0–0.45 m soil depth and 23.0% soil moisture was from 0.45–0.60 m soil depth in the year 2007-2008 whereas 77.3% soil moisture was contributed from 0–0.45 m soil depth and 22.7% soil moisture was from 0.45–0.60 m soil depth in the year 2008-2009. Increasing the irrigation frequency resulted in the decrease of the percentage of moisture contribution between 0.45 and 0.60 m soil depth. At 3 irrigations, the maximum contribution of 23.2% and 23.0% soil moisture at 0.45–0.60 m soil depth was noticed during 2007-2008 and 2008-2009, respectively. Similarly increasing fertilizer level had decreased the percentage of soil moisture contribution from 0.45 to 0.60 m soil depth. Lower percentage of contribution was observed at higher fertilizer dose of N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹.

The perusal of data on consumptive use of water indicated that method of tillage had influenced the consumptive use of water in sweet potato (Tables 8 and 9). Higher consumptive use of water was observed in zero-tillage crop establishments than conventional system of planting in both years of study. Consumptive use of water under minimum tillage was 6.3% and 7.0% higher than conventional system of planting during 2007-2008 and 2008-2009, respectively.

Consumptive use of water was markedly higher with more number of irrigations. Significantly higher consumptive use of water was observed with 7 irrigations than other irrigation levels in both the years of study. The lowest consumptive use of water was noticed at 3 irrigations, which was 24.5% and 55.6% lower than 5 and 7 irrigations, respectively, in 2007-2008 and 35.3% and 79.6% lower than 5 and 7 irrigations, respectively, in 2008-2009. Increasing the level of nutrient application increased the consumptive use of water. Maximum consumptive use of water was observed with the application of N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹, which was significantly superior to other treatments. Consumptive use of water with the application of N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ was higher than control. The lowest consumptive use of water was noticed in control (no fertilizer) in both years.

3.6. Water Use Efficiency (WUE). Water use efficiency is a function of economic produce to the consumptive use of water. Water use decreased with increased water supply thereby resulting in decline in WUE. Minimum tillage recorded lower WUE than conventional tillage in both the year of study (Tables 8 and 9). Reduction in WUE was found

TABLE 9: Effect of different treatments on consumptive use of water by sweet potato in rice fallow during 2008-2009.

Treatment	Moisture contribution from profile storage (mm)					Evaporation (mm)	Effective rainfall (mm)	Consumptive use (mm)	Water use efficiency (kg mm ⁻¹)
	0–15 cm	15–30 cm	30–45 cm	45–60 cm	Total				
<i>Method of tillage</i>									
Minimum tillage	39.1 (28.9)*	33.9 (25.1)	33.3 (24.6)	28.9 (21.4)	135.2 (100.0)	26.7	5.9	167.8	55.7
Conventional	34.9 (27.8)	31.7 (25.2)	30.5 (24.3)	28.5 (22.7)	125.7 (100.0)	25.2	5.9	156.8	77.5
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	11.0	3.7
<i>No. of irrigation</i>									
3	25.1 (26.0)	24.9 (25.7)	24.5 (25.3)	22.2 (23.0)	96.7 (100.0)	14.8	5.9	117.4	71.2
5	34.5 (26.9)	33.1 (25.8)	32.2 (25.1)	28.5 (22.2)	128.3 (100.0)	24.6	5.9	158.8	67.6
7	45.2 (27.2)	43.6 (26.2)	40.9 (24.6)	36.6 (22.0)	166.3 (100.0)	38.6	5.9	210.8	60.8
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	4.7	2.8
<i>Nutrient levels (kg ha⁻¹)</i>									
0-0-0	32.2 (26.3)	31.4 (25.7)	30.9 (25.3)	27.8 (22.7)	122.3 (100.0)	26.0	5.9	154.2	60.0
37.5-25-37.5	34.7 (26.5)	33.8 (25.8)	32.9 (25.1)	29.6 (22.6)	131.1 (100.0)	26.0	5.9	163.0	66.7
75-50-75	37.5 (27.2)	36.3 (26.3)	35.0 (25.4)	29.1 (21.1)	137.9 (100.0)	26.0	5.9	169.8	73.0
LSD (<i>P</i> = 0.05)	—	—	—	—	—	—	—	2.8	1.7

* Percentage values are given within parentheses.

with increasing number of irrigations. Maximum WUE was found with 3 irrigations. However, increasing fertilizer levels increased water use efficiency. The highest WUE was found with the application of N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹, which was significantly superior to other treatments. The lowest WUE was noticed in control (no fertilizer) in both years.

4. Discussion

Sweet potato tends to grow continuously at varying rate depending upon the growing conditions. Reduction in leaf area at harvesting was noticed due to maturity of the crop. Tillage practices had influenced the vine growth and LAI (indicator of leaf area development) but not at marked level. Conventional tillage had just only 7.6% and 9.6% longer vine length than the minimum tillage during 2007-2008 and 2008-2009, respectively. Similarly conventional tillage practices had little higher LAI than the minimum tillage. Ndaeyo and Aiyelari [22] indicated that with optimum soil moisture, crop establishment was similar in both tilled and nontilled plots. Initial slow growth due to planting of vines under zero-tillage (anaerobic) conditions might reduce the growth. But, the crop might have been recovered

later after aerobic conditions (earthing up at 15–20 and 60 DAP), hence the difference with conventional tillage was less. Water, the basic of life processes increased the growth parameters with the increasing level of its availability in the soil. Moisture stressed conditions (3 irrigations) reduces photosynthesis rate which in turn might have decreased the growth parameters. Application of nutrients enhanced the growth processes in our study, which lead to development of more leaf area and vine growth. In poor nutrient soil, application of higher dose of fertilizer N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ was essential for higher growth and development.

Tillage practices had significant influence on yield forming processes. Number of tubers per plant and tuber length was maximum in conventional planting. However, the difference of these parameters between conventional and minimum tillage planting was nominal. This was due to earthing up carried out in minimum tillage at 15–20 DAP and 60 DAP which has loosen the soil moderately. Number of tuberous roots per plant in sweet potato is decided between 20 and 30 DAP depending on cultivar [23] and season [24]. In minimum tillage first earthing up was carried out at 15–20 DAP, which has loosen the soil sufficiently, hence number of roots per plant was affected. Second earthing up at 60 DAP further loosened the soil, hence it has not much affected

the tuber length. But it could not completely reduce the soil compactness. Hence, compressed (flattened) roots were found in minimum tillage. Root yield per plant is a function of number of roots per plant, root length, and root diameter [25]. Hence, tillage methods could significantly influence the root yield per plant. Increasing level of irrigation increased the yield attributes size. Soil moisture stressed conditions restrict the yield forming processes. Under stress-free conditions, soil rhizosphere favour yield attributes development. Hence in the present investigation higher yield attributes were obtained at higher level of irrigation (7 irrigations). This might be due to availability of more nutrients to plants at higher level of fertilizer application. Nutrient stress in control (no fertilizer) treatment restricted the yield attributes size.

Tillage practices had significant impact on root yield. Planting sweet potato under conventional tillage produced higher root yield than minimum tillage. This was due to higher growth and yield attributes. But the yield difference between minimum tillage and conventional tillage crop establishment was 4.6% during 2007-2008 whereas it was 30.3% during 2008-2009. Soil penetration resistance measured at harvest indicates the soil compactness, which directly influenced the root yield of sweet potato. Increase in penetration resistance of the soil proportionately decreased root yield of sweet potato (Figure 1). Soil penetration resistance was negatively correlated ($r, P = 0.01$) with root yield during 2007-2008 (-0.5638) and 2008-2009 (-0.7914). During 2007-2008, the root yield was higher and the difference between minimum and conventional tillage planting was minimal. This might be due to more rainfall received during October month (Table 1), which leads to more moisture in the soil profile after harvest of rice and favoured early establishment and growth of sweet potato. High soil compactness during the year 2008 drastically reduced the root yield under minimum tillage (Figure 3). The compact soils contain low concentration of oxygen which reduced the root bulking [26]. Reasonable yield under minimum tillage methods could be due to various favourable factors like availability of higher moisture and early establishment of sweet potato which might have helped the crop to compete with the crop planted under conventional tillage system [27-29]. The growth, development, and consequently yield of crops are highly influenced by available soil moisture [30]. Increasing the irrigation frequency increased the root yield. The highest root yield was noticed at maximum level of irrigation (7 irrigations). This was mainly due to increase of yield attributes. The number of tubers, tuber length, and diameter were found increasing with levels of irrigation. Soil penetration resistance decreased with increased levels of irrigation (Figure 4). Singh [31], Thakuria et al. [32], and Yadav et al. [33] reported that improvement in yield under more frequent irrigation was due to higher availability of soil moisture, which might have helped in better nutrient uptake by the crop which is in turn resulted in assimilation of photosynthates towards sink. Due to smaller size of yield attributes, lower root yield was recorded at 3 irrigations.

Minimum tillage crop responded very well to irrigation. Under zero-tillage crop stand establishment the yield

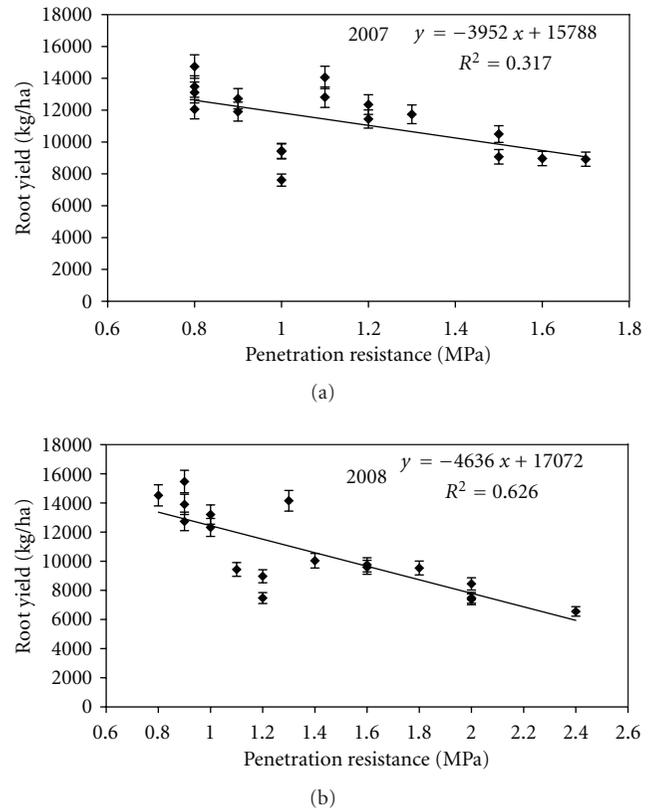


FIGURE 1: Relationship between penetration resistance and root yield. Bars indicate standard error of mean.

increase rate was higher with increasing level of irrigation and continued up to 7 irrigations. In less frequently irrigated treatment (3 irrigations) under zero-tillage crop establishments highly flattened and irregular-shaped roots were observed. This might be due to soil compactness. With the increasing frequency of irrigation the compactness has reduced and roots bulked uniformly. Irrigation brings changes in soil physical properties, basically acting as soil lubricant [16] influencing soil compaction. Soil compaction and soil moisture are known to influence tuber growth in sweet potato [26, 34]. Roy Chowdhury et al. [35] observed higher tuber volume at higher irrigation levels and it inversely related to soil penetration resistance. In conventional system of planting uniform response for irrigation frequency was observed and highest yield was noticed at 7 irrigations.

Fertilizer application enhanced the root yield. Higher root yield was found at higher levels of nutrient application. Fertilizer application provided better conducive conditions for better uptake of nutrients and in turn helped the plants to boost their growth, leading to the development of yield attributes through supply of more photosynthates towards the sink. Penetration resistance decreased with increasing levels of fertilizer (Figure 5). Probably less evapotranspiration due to more vine growth and more moisture retained by more number of roots and their volumes in more fertilized soils leads to less penetration resistance.

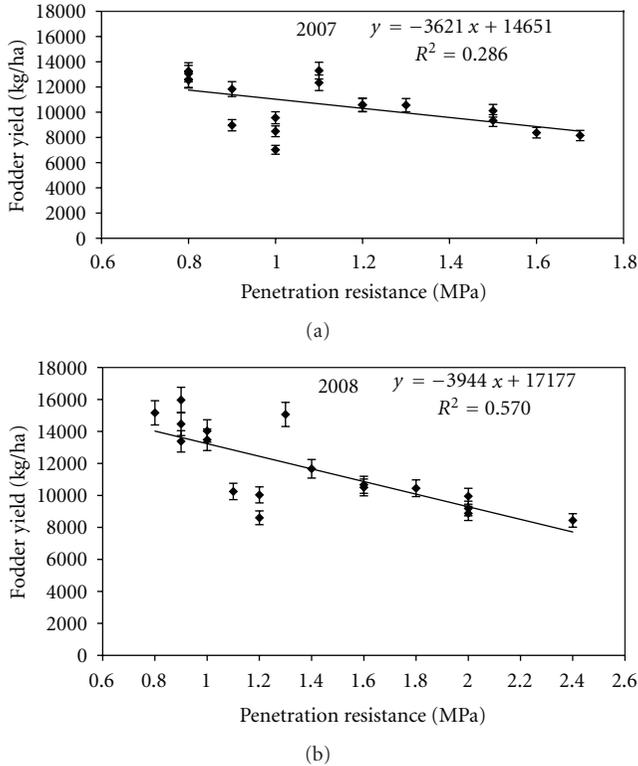


FIGURE 2: Relationship between penetration resistance and fodder yield. Bars indicate standard error of mean.

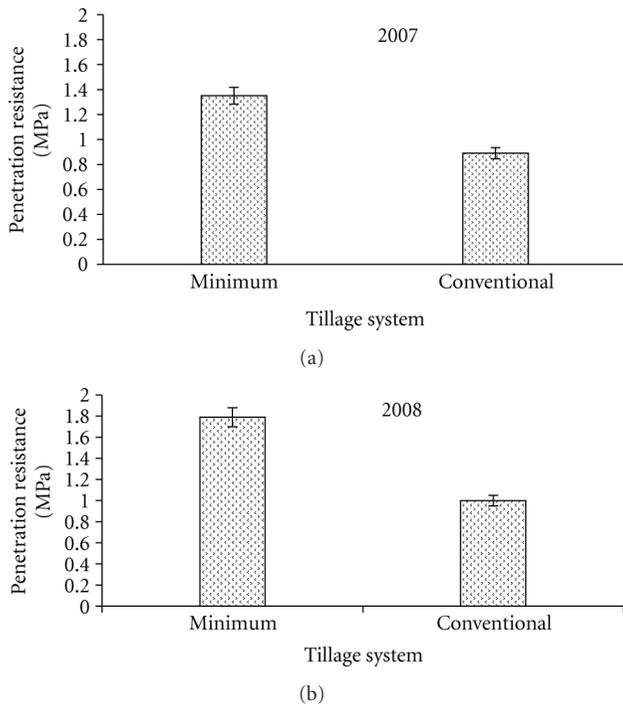


FIGURE 3: Tillage effect on soil compactness. Bars indicate standard error of mean.

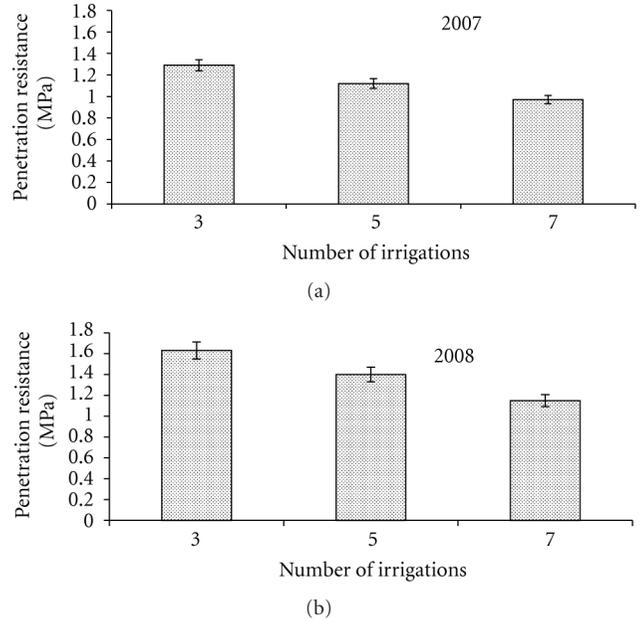


FIGURE 4: Effect of number of irrigations on soil compactness. Bars indicate standard error of mean.

Under minimum tillage conditions sweet potato recorded higher root yield when no fertilizer was applied compared to conventional system of planting. This may be due to more nutrients conservation in zero-tillage established crops whereas various kinds of nutrient losses in conventional system of planting. But conventional system of planting responded well up to N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ whereas zero-tillage established crop yield increased up to N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ and it remained on par with N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹. Under minimum tillage the crop was unable to utilize applied nutrients because of restricted root development caused by soil compactness.

Irrigation level improved the efficiency of nutrient utilization. Increasing nutrient levels at lower level of irrigation frequency increased the root yield at lower rate compared to higher level of irrigation frequencies. It indicated that plant requires sufficient moisture to fully utilize applied nutrients. Soil compaction reduced both the water and nutrient use efficiencies of wheat and sorghum (*Sorghum bicolor*) by about 38 and 22%, respectively, in fine loamy soil [36]. Maximum root yield was noticed when higher dose of fertilizer was applied along with maximum number of irrigation. Sumathi and Rao [37] and Yadav et al. [33] also reported that better availability of nutrients in the soil solution ascribed to increase in yield under more irrigation frequency.

Sweet potato vine (aerial top) serves as fodder for livestock [38, 39] as well as direct and indirect human food [40]. Sweet potato vine in terms of chemical composition and digestibility is superior to most of the grasses [41]. The crude protein content ranges from 18–30% while the crude fibre content is about 18% [42]. With a dry matter

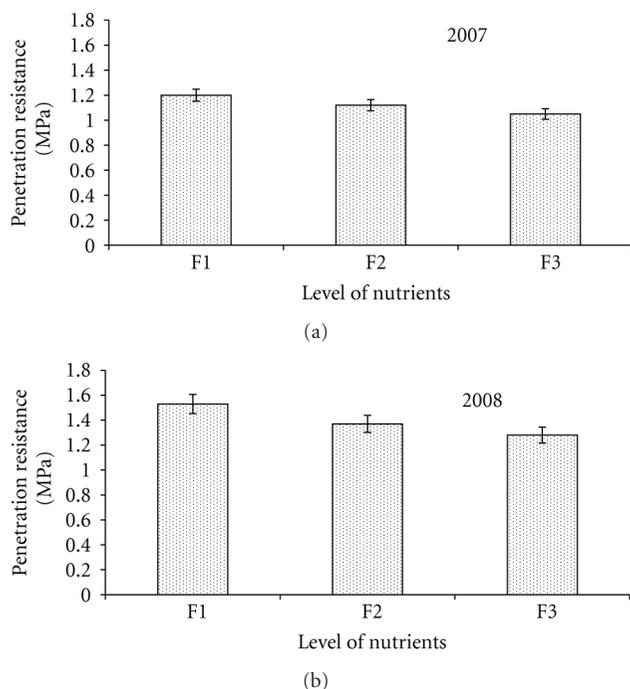


FIGURE 5: Effect of nutrient levels on soil compactness. Bars indicate standard error of mean.

digestibility of 70% and above [38, 43], sweet potato vine is an ideal fodder for livestock. Marked variation in green fodder yield was noticed among methods of tillage. Higher green fodder yield in conventional tillage was due to higher growth parameters like vine length and leaf area (Table 2). Soil compaction (penetration resistance) decreased fodder yield in minimum tillage. Fodder yield was found inversely proportionate to penetration resistance (Figure 2). Soil penetration resistance significantly negatively correlated (r) with fodder yield during 2007-2008 ($P = 0.05$, -0.5348) and 2008-2009 ($P = 0.01$, -0.7550). Increasing the frequency of irrigation increased the green fodder yield. Significantly higher green fodder yield was registered with 7 irrigations. Increased moisture availability favoured higher crop growth. Similarly, application of higher level of nutrients N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹ recorded higher green fodder yield owing to more nutrients available to the crop for growth and development.

Profile moisture contribution from 0.45–0.6 m soil layer under zero-tillage was less due to more availability of water in upper layers and soil compactness which restricted root development in lower layers. Moisture depletion in lower layer (0.45–0.6 m) was higher with reduced frequency of irrigation. When the crop suffered from scarcity of water (more intervals) more water was extracted from lower layers [32]. In frequently irrigated fields more water was taken in upper and middle layers. For example, more and more water was extracted by sunflower from upper and middle layers when irrigated more frequently [33]. This was due to better proliferation of roots in upper and middle layers because of lower resistance of soil, attributed by higher irrigation

frequency. In control plot more moisture was depleted in lower layer (0.45–0.60 m) as compared to fertilized plot. Roots in search of plant nutrients tend to grow deep and extract water along with nutrients.

Consumptive use of water under minimum tillage was found higher than conventional system in both years. This might be owing to more available water in the soil profile which caused higher evaporation. Due to higher consumptive use of water and less root yield, the minimum tillage treatment recorded less WUE than conventional tillage. Consumptive use of water was increased with increase in irrigation level. This might be due to the fact that under more irrigation, evaporation was at potential rate due to availability of more water than the crop irrigated with less irrigations [32]. In spite of higher root yields, the WUE efficiency of irrigation treatments was found decreased with increasing level of irrigations, owing to higher consumptive use of water. The rate of moisture use increased with progressive increase in fertility levels, perhaps due to improved vegetative growth and root system (more number of roots per plant, root length and diameter, and root yield per plant), which enabled the plant to utilize more moisture from soil layers. This might be attributed to increased root activity and proliferation of root system (root number, length, and diameter) due to translocation of more photosynthates to the roots thereby resulting in greater extraction of moisture with increasing levels of nutrients. Thus, consumptive use and WUE were found increased with increasing nutrients levels. However, under decreased fertilization treatment the root growth was not much extensive (less number of roots per plant, root length and diameter, and root yield per plant) and hence moisture extraction was progressively decreased [33], low consumptive use and WUE.

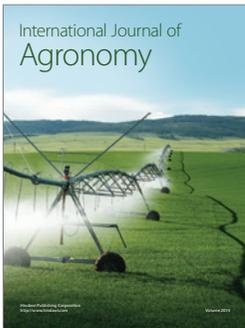
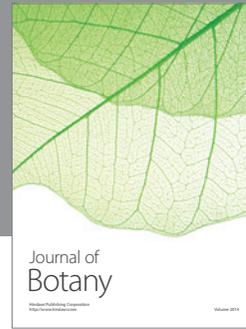
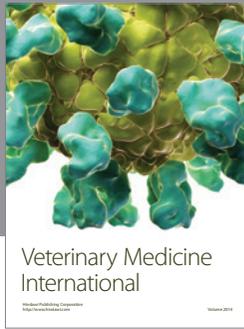
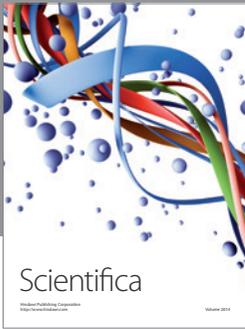
5. Conclusion

Difference in growth parameters between minimum and conventional tillage was small. However, method of tillage had appreciable impact on root attributes (number of roots per plant, root length, root diameter, and root yield per plant) and root yield. Minimum tillage with frequent irrigation improved the root yield by reducing the penetration resistance. Conventional tillage system registered higher yield because of higher growth and yield attributes, and lower penetration resistance. It also had higher WUE owing to lower consumptive use of water and higher root yield. Increasing irrigation and nutrient levels increased root and vine yields. Soil compactness was reduced with higher levels of irrigation and nutrients. Minimum tillage allowed planting of sweet potato 15–17 days in advance and produced 80–90% root and fodder yield of conventional tillage. To increase cropping intensity in rice fallows, zero-tillage practice may be adopted for sweet potato crop establishment, followed by earthing up at 15–20 and 60 DAP, and later 7 irrigations and N-P₂O₅-K₂O at 37.5-25-37.5 kg ha⁻¹ might be applied to get uniform size roots and higher yields. In case of conventional tillage system of planting after rice, maximum yield potential could be realized with 7 irrigations and N-P₂O₅-K₂O at 75-50-75 kg ha⁻¹.

References

- [1] CRRI, Annual Report, Central Rice Research Institute, Cuttack, India, 2008.
- [2] R. C. Ray and K. I. Tomlins, *Sweet Potato: Post Harvest Aspects in Food, Feed and Industry*, Nova Science, 2010.
- [3] R. Bhattacharyya, S. Kundu, S. C. Pandey, K. P. Singh, and H. S. Gupta, "Tillage and irrigation effects on crop yields and soil properties under the rice-wheat system in the Indian Himalayas," *Agricultural Water Management*, vol. 95, no. 9, pp. 993–1002, 2008.
- [4] R. P. Tripathi, P. Sharma, and S. Singh, "Influence of tillage and crop residue on soil physical properties and yields of rice and wheat under shallow water table conditions," *Soil and Tillage Research*, vol. 92, no. 1-2, pp. 221–226, 2007.
- [5] S. Jongruaysup, P. Namwong, A. Tiensiroek et al., "Minimum tillage for cassava in Thailand," in *Cassava Research and Development in Asia—Exploring New Opportunities for an Ancient Crop, Proceedings of the 7th Regional Workshop, held in Bangkok, Thailand, Oct 28- Nov 1, 2002*, pp. 251–263, CIAT, Bangkok, Thailand, 2007.
- [6] A. Tongglum, P. Suriyapan, and R. H. Howeler, "Cassava agronomy research and adoption of improved practices in Thailand—major achievements during the past 35 years," in *Cassava's Potential in the 21st Century: Present Situation and Future Research and Development Needs, Proceedings of the 6th Regional Workshop, held in Hochi Minh City Vietnam, Feb 21-25, 2000*, pp. 228–258, CIAT, Bangkok, Thailand, 2001.
- [7] Z. Weite, L. Xiong, L. Kimian et al., "Cassava agronomy research in China," in *Cassava Breeding, Agronomy and Farmers Participatory Research in Asia, Proceedings of the 5th Regional Workshop held in Danzhou, Hainan, China, Nov 3-8, 1996*, R. H. Howeler, Ed., pp. 191–210, CIAT, Bangkok, Thailand, 1998.
- [8] R. H. Howeler, "Cassava agronomy research in Asia: has it benefitted cassava farmers," in *Cassava's Potential in the 21st Century: Present Situation and Future Research and Development Needs, Proceedings of the 6th Regional Workshop, held in Hochi Minh City Vietnam, Feb 21-25, 2000*, pp. 345–376, CIAT, Bangkok, Thailand, 2001.
- [9] N. U. Ndaeyo, E. O. Ekpe, S. O. Edem, and U. G. Umoh, "Growth and yield responses of *Colocasia esculenta* and *Xanthosoma saggitifolium* to tillage practices in Uyo, south-eastern Nigeria," *Indian Journal of Agricultural Sciences*, vol. 73, no. 4, pp. 194–198, 2003.
- [10] D. L. Plucknett, H. C. Ezumah, and R. S. de la Pena, "Mechanization of taro (*Colocasia esculenta*) culture in Hawaii," in *Proceedings of the 3rd Symposium of International Society of Tropical Root Crops*, pp. 286–292, Ibadan, Nigeria, 1973.
- [11] T. M. Agbede, "Nutrient availability and cocoyam yield under different tillage practices," *Soil and Tillage Research*, vol. 99, no. 1, pp. 49–57, 2008.
- [12] Y. L. Castroverde, *Cassava production: influence of tillage, weed control systems, fertilizer sources and harvest age*, Ph.D. thesis, UPLB College, Laguna, Philippines, 1983.
- [13] J. R. Pardales Jr., "Effect of croppings and pre planting tillage systems on the yield of cassava and mung bean intercrop," *Philippine Journal of Crop Science*, vol. 11, no. 1, pp. 33–36, 1986.
- [14] M. A. Liebig, D. L. Tanaka, and B. J. Wienhold, "Tillage and cropping effects on soil quality indicators in the northern Great Plains," *Soil and Tillage Research*, vol. 78, no. 2, pp. 131–141, 2004.
- [15] P. Sharma, R. P. Tripathi, and S. Singh, "Tillage effects on soil physical properties and performance of rice-wheat-cropping system under shallow water table conditions of Tarai, Northern India," *European Journal of Agronomy*, vol. 23, no. 4, pp. 327–335, 2005.
- [16] R. W. Miller and R. L. Donahue, *Soils: An Introduction to Soils and Plant Growth*, Prentice Hall of India, New Delhi, India, 1992.
- [17] D. J. Watson, "The physiological basis of variation in yield," *Advances in Agronomy*, vol. 4, pp. 101–145, 1952.
- [18] J. Doorenbos and W. O. Pruitt, "Guidelines for predicting crop water requirements," FAO Irrigation and Drainage Paper 23, FAO, Rome, Italy, 1977.
- [19] D. Lenka, *Irrigation and Drainage*, Kalyani, Ludhiana, India, 3rd edition, 2005.
- [20] C. A. Black, *Methods of Soil Analysis. Part I. Monograph 9*, Agronomy Series, Madison, Wis, USA, 1965.
- [21] F. Gomes and M. K. V. Carr, "Effects of water availability and vine harvesting frequency on the productivity of sweet potato in southern Mozambique. II. Crop water use," *Experimental Agriculture*, vol. 39, no. 1, pp. 39–54, 2003.
- [22] N. U. Ndaeyo and E. A. Aiyelari, "Evaluation of different tillage practices for monocultural cowpea (*Vigna unguiculata* (L.) Walp.) production in Ibadan, South-western Nigeria," *Triplicultura*, vol. 15, no. 4, pp. 195–202, 1997.
- [23] M. Nedunchezhiyan, D. Srinivasulu Reddy, and J. Surya-prakasa Rao, "Characteristics of dry matter production and partitioning in sweet potato," in *Proceedings of the National Seminar on Physiological Interventions for Improved Crop Productivity and Quality: Opportunities and Constraints*, P. V. Reddy, Ed., pp. 110–115, Tirupati, India, 2004.
- [24] M. Nedunchezhiyan and G. Byju, "Effect of planting season on growth and yield of sweet potato (*Ipomoea batatas* L.) varieties," *Journal of Root Crops*, vol. 31, no. 2, pp. 111–114, 2005.
- [25] M. Nedunchezhiyan and D. S. Reddy, "Nitrogen management in sweet potato (*Ipomoea batatas*) under rainfed conditions," *Indian Journal of Agronomy*, vol. 47, no. 3, pp. 449–454, 2002.
- [26] A. Sajjapongse and Y. C. Roan, "Physical factors affecting root yield of sweet potato (*Ipomoea batatas* (L.) Lam)," in *Sweet Potato Proceedings of the 1st International Symposium*, R. L. Villareal and T. D. Griggs, Eds., pp. 203–204, AVRDC, Taiwan, 1982.
- [27] R. Kumar and D. S. Yadav, "Effect of zero and minimum tillage in conjunction with nitrogen management in wheat (*Triticum aestivum*) after rice (*Oryza sativa*)," *Indian Journal of Agronomy*, vol. 50, no. 1, pp. 54–57, 2005.
- [28] M. Gupta, A. S. Bali, B. C. Sharma, D. Kachroo, and R. Bharat, "Productivity, nutrient uptake and economics of wheat (*Triticum aestivum*) under various tillage and fertilizer management practices," *Indian Journal of Agronomy*, vol. 52, no. 2, pp. 127–130, 2007.
- [29] N. Jain, J. S. Mishra, M. L. Kewat, and V. Jain, "Effect of tillage and herbicides on grain yield and nutrient uptake by wheat (*Triticum aestivum*) and weeds," *Indian Journal of Agronomy*, vol. 52, no. 2, pp. 131–134, 2007.
- [30] G. Alem, "Evaluation of tillage practices for soil moisture conservation and maize production in dryland Ethiopia," *Agricultural Mechanization in Asia, Africa and Latin America*, vol. 24, no. 3, pp. 9–13, 1993.
- [31] O. Singh, "Response of sunflower (*Helianthus annuus*) to date of sowing and irrigation," *Agronomy Digest*, vol. 4, pp. 39–40, 2004.

- [32] R. K. Thakuria, H. Singh, and T. Singh, "Effect of irrigation and antitranspirant on biometric components, seed yield and plant water-use of spring sunflower (*Helianthus annuus*)," *Indian Journal of Agronomy*, vol. 49, no. 2, pp. 121–123, 2004.
- [33] R. P. Yadav, M. L. Tripathi, and S. K. Trivedi, "Effect of irrigation and nutrients levels on productivity and profitability of sunflower (*Helianthus annuus*)," *Indian Journal of Agronomy*, vol. 54, no. 3, pp. 332–335, 2009.
- [34] Y. Yanfu, T. Jialan, Z. Yunchu, and Q. Ruilian, "Breeding for early maturing sweet potato variety," in *Sweet Potato Research and Development for Small Farmers*, K. T. Mackay, M. K. Palomer, and R. T. Sanico, Eds., pp. 67–82, SEAMEO-SEARCA, College, Laguna, Philippines, 1989.
- [35] S. Roy Chowdhury, R. Singh, D. K. Kundu, E. Antony, A. K. Thakur, and H. N. Verma, "Growth, dry-matter partitioning and yield of sweet potato (*Ipomoea batatas* L.) as influenced by soil mechanical impedance and mineral nutrition under different irrigation regimes," *Advances in Horticultural Science*, vol. 16, no. 1, pp. 25–29, 2002.
- [36] M. Ishaq, A. Hassan, M. Saeed, M. Ibrahim, and R. Lal, "Subsoil compaction effects on crops in Punjab, Pakistan i. Soil physical properties and crop yield," *Soil and Tillage Research*, vol. 59, no. 1-2, pp. 57–65, 2001.
- [37] V. Sumathi and D. S. K. Rao, "Effect of organic and inorganic sources of nitrogen with different irrigation schedules on growth and yield of sunflower (*Helianthus annuus*)," *Indian Journal of Agronomy*, vol. 52, no. 1, pp. 77–79, 2007.
- [38] M. Nedunzhiyan, *Studies on time of planting, genotypes and integrated nitrogen management for rainfed sweet potato (*Ipomoea batatas* L.)*, Ph.D. thesis, Acharya N.G. Ranga Agricultural University, Hyderabad, India, 2001.
- [39] S. K. Naskar, J. J. Gupta, M. Nedunchezhiyan, and R. K. Bardoli, "Evaluation of sweet potato tubers in pig ration," *Journal of Root Crops*, vol. 34, no. 1, pp. 50–53, 2008.
- [40] J. A. Woolfe, *Sweet Potato: An Untapped Food Resource*, Cambridge University Press, New York, NY, USA, 1992.
- [41] O. A. Olorunnisomo, "An economic analysis of sweet potato production for sheep feeding in the southwest of Nigeria," *Journal of Root Crops*, vol. 32, no. 1, pp. 32–36, 2006.
- [42] L. V. An, B. E. Frankow-Lindberg, and J. E. Lindberg, "Effect of harvesting interval and defoliation on yield and chemical composition of leaves, stems and tubers of sweet potato (*Ipomoea batatas* L. (Lam.)) plant parts," *Field Crops Research*, vol. 82, no. 1, pp. 49–58, 2003.
- [43] D. Foulkes, D. Dcb Hovell, and F. D. Prewston, "Sweet potato forage as cattle feed: voluntary intake and digestibility of mixtures of sweet potato forage and sugarcane," *Tropical Animal Production*, vol. 3, no. 2, pp. 140–144, 1978.



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