Effects of tillage in combination with spacing on yield and proximate composition of sweet potato (*Ipomoea batatas*) grown in an abandoned paddy field

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Sweet potato (*Ipomoea batatas*) is a highly nutritious root crop suitable for human food. Therefore, the development of technology for increasing sweet potato yield is necessary. The purpose of this research was to find out which cultural practices (soil preparation and plant spacing) increased the yield and quality of sweet potatoes grown in unused / abandoned paddy field condition. The experimental design was a split plot, in randomised blocks, with four replications. The main plots were two tillage types: (1) rough ploughing followed by one **regular ploughing, and (2) rough ploughing followed by two regular ploughings. The sub plots were four spacings: 50 x 30, 50 x 50, 100 x 30 and 100 x 50 cm. The results showed that different tillage methods did not significantly affect vine length, chlorophyll content, leaf area, yield and chemical composition of sweet potato tubers. However, the treatment of rough ploughing followed by one regular ploughing significantly resulted in higher dry weight accumulation. Different spacings, had significant effects on chlorophyll content, leaf area, tuber weight and numbers of sweet potato tubers; the spacing of 50 x 30 cm gave the best results. Interactions between tillage method and spacing were significant for tuber width and length, tuber weight, protein and crude fibre. The rough ploughing followed by two regular ploughings combined with a spacing of 100 x 30 cm gave the maximum width and length of tubers; while rough ploughing followed by one regular ploughing with a spacing of 50 x 50 cm gave the maximum tuber weight, protein content and crude fibre. The results indicated that rough ploughing followed by one regular ploughing with a spacing of either 50 x 30 or 50 x 50 cm (50 cm between rows and 30 or 50 cm between plants) is a suitable technology for sweet potato grown in abandoned paddy fields.**

Keywords: Sweet potato, cultural practice, tillage, spacing

The global climate is changing rapidly, unseasonable rainfall and higher average temperatures, have caused droughts in many areas, creating shortages of water for agriculture. This has led to food insecurity in Thailand where rice is the main staple food, and because of droughts, the acreage in rice production has now dropped. The main reason for the decrease in rice production is a lack of enough water to grow lowland rice. Farmers need to find alternative crops that can grow with less water. The crops must be easy to grow in unused (abandoned) rice paddy fields, do not need much water and have a high marketable value. Sweet potato (*Ipomoea batatas*) has been identified as a suitable alternative crop. It is easy to grow and grows well in almost any soil type (Dharmanitivedya and Mondet 2020). The water requirement is rather low, especially when compared to rice and other field crops (Charoenphun 2017). Sweet potato can be grown in every region of Thailand and at any time of year. It is nutritious and both the tubers and the leaves are edible (Ishida et. al. 2000). Sweet potato can be processed to make starch that is of comparable quality to potato starch, a product that Thailand imports in quite large volumes. More knowledge of the appropriate cultural practices for growing sweet potato in abandoned paddy fields, such as soil preparation and spacing, would be very useful. A fair amount of research has been done comparing tillage systems. For example, Carter et al. (2005) reported that tillage methods influenced soil water content but potato yield and quality were not adversely impacted by tillage practices. Alam et al. (2014) reported that tillage

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practices showed positive effects on soil properties and crop yields; bulk and particle densities decreased whereas porosity and field capacity increased in zero tillage. Chagonda et al. (2014) experimented with sweet potato and found that the ridge tillage system produced tubers with longer storage root lengths than the mound tillage system. Nedunchezhiyan et al. (2012) reported that conventional tillage gave maximum fresh root yield but lower water use efficiency, whereas minimum tillage advanced planting of sweet potato by 15 – 17 days and produced 80 – 90% root and fodder yield of conventional tillage. Agbede and Adekiya (2009) found that the highest sweet potato yield was achieved with conventional tillage with the lowest soil bulk density and highest porosity.

Buah et al. (2017) found that conventional tillage compared to no-tillage had no effect on soybean plant height. However, Sindelar et al. (2015) reported that the stover biomass yield of corn grown under a no-tillage regime was 9% less than under conventional tillage and 8% less than under strip tillage. In contrast, Munyao et al. (2019) reported that both corn (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.) grown under no-tillage had higher chlorophyll content in their leaves than those grown under conventional tillage. Khan et al. (2017) found that the leaf area index of corn grown under normal tillage followed by deep tillage was 10% higher compared to the leaf area index of corn grown under minimum tillage. Plant spacing is another important factor that affects plant growth and yield. The optimum plant spacing to obtain the highest yield is different for different crop varieties.

Several studies have been done on plant spacing; for example Arega et al. (2018) research in potato revealed that the highest total and marketable tuber yields were observed with medium plant spacing, whereas the lowest total and marketable tuber yields were observed at wider plant spacing. Dagne et al. (2018) found that total tuber yield and marketable tuber yield were significantly affected by plant spacing. The use of medium plant spacing 60 × 30 cm was recommended for potato production. Nasir and Akassa (2018) found that total tuber number and unmarketable yield increased by using closer spacing and medium sized tubers as plant materials. Pushparajah and Sinniah (2018) researched millet and found that the narrowest spacing of 15 x 30 cm resulted in the greatest dry weight compared to the wider spacings of 15 x 45cm and 15 x 60 cm. A study of mung bean (*Vigna radiata* L.) showed that the interaction between row spacing and plant spacing affected the dry weight (Birhanu et al. 2018). Paul et al. (2019) studied chlorophyll content in corn leaves and reported that the highest chlorophyll content of 37.14 mg/g fresh weight was observed in the leaves of corn spaced at 35 × 30 cm, whereas the chlorophyll content of corn leaves spaced at 35 × 10 cm was only 34.16 mg/g fresh weight; in that study the interaction of tillage system and plant spacing was not statistically significant. A study on cassava, showed that leaf area and phyllochron were higher with narrower plant spacing (Streck et al. 2014). Detpiratmongkol et al. (2011) revealed that the vine weight, leaf weight, root weight and whole plant dry weight of sweet potato were higher with wider plant spacing; however, fresh and dry tuber weights were highest with plant spacing of 30 x 50 cm and the lowest with spacing of 50 x 100 cm. No interaction was observed between variety of sweet potato and plant spacing.

At present, most Thai farmers who are growing sweet potatoes are relying solely on their experience; thus the quality and volume of their harvests are unpredictable and varied. It is therefore important to study the optimum cultural practices for growing sweet potatoes on land formerly used for growing rice, so that farmers will be provided with guidelines for growing sweet potatoes as a reliable source of food and an alternative means of income. This can help to increase food and financial security. The objective of this research was to develop soil preparation and spacing recommendations for growing high quality sweet potato in paddy fields.

Materials and methods

Experimental design

The experiment was a split plot in four randomised blocks each with two main plots and four sub plots. The main plots were two soil preparation methods:

1. A rough ploughing followed by one regular ploughing
2. A rough ploughing followed by two regular ploughings

   The sub plots were four plant spacings:
   1. 30 x 50 cm
   2. 50 x 50 cm
   3. 30 x 100 cm
   4. 50 x 100 cm

Experimental methodology

Sweet potato stem cuttings 30 – 40 cm long, were planted at spacings of 30 x 50, 50 x 50, 30 x 100 and 50 x 100 cm in 3 x 5 m plots. Land preparation was either rough ploughing followed by one regular ploughing, or rough ploughing followed by two regular ploughings. The sweet potato plants were cultivated following standard recommendations, i.e. 15-15-15 formula fertiliser was applied at the rate of 312.5 kg/hectare 30 days after planting; then 13-13-21 formula fertiliser at the rate of 312.5 kg/hectare was divided into two applications at 2 months and 3 months after planting, by placing on the row ridge before watering. When the sweet potato plants were 2 months old, vines that strayed outside their respective plots were pulled up and placed back inside the selected plots. Hand weeding was regularly done during 2 months after planting depending on weed densities. Water was applied through a sprinkler system two to three times monthly until near harvest.

Data collection

1. Leaf area: five plants were randomly sampled and all the leaves were measured using a leaf area meter (WinDias3 by Delta-T Device) and averaged to get the mean leaf area per plant.
2. Plant dry weight: five plants were randomly sampled and all the above-ground parts were dried in a hot air oven at 70 °C for 48 hours, then weighed, and averaged to get the mean dry weight per plant.
3. Vine length: ten plants were randomly sampled and the vines were measured from base to tip, then the measurements were averaged to get the mean vine length per plant.
4. Chlorophyll analysis: five plants were randomly sampled and three leaves were randomly sampled from each plant. The three leaves from each sample were combined and chlorophyll was extracted with N, N-Dimethyl formamide (Moran and Porath 1980).
5. Sweet potato tuber numbers: all the tubers produced by the plants within each 15 m^2 plot were counted.
6. Tuber yield (weight): all the tubers produced by the plants within each 15 m^2 plot were weighed.
7. Tuber width/length: ten tubers from each plot were randomly sampled; the width of each tuber was measured using vernier calipers and the length was measured with a ruler.
8. Proximate components of tubers were analysed (Association of Official Analytical Collaboration 2000):
   - 8.1 Moisture following AOAC Official Method: 934.06
   - 8.2 Fat following AOAC Official Method: 991.36
   - 8.3 Ash following AOAC Official Method: 900.02
   - 8.4 Crude fibre following AOAC Official Method: 962.29
   - 8.5 Protein following AOAC Official Method: 979.09
   - 8.6 Carbohydrate following the difference method

Data analysis

All data were subjected to analysis of variance (ANOVA) according to the experimental design used and compared treatment means by Least Significant Difference (LSD) by STAR software (International Rice Research Institute 2014).

Results and discussion

Growth and chlorophyll content / vine and leaf characteristics

There was no significant difference in vine length, leaf area and leaf chlorophyll content for sweet potato plants grown under the two different soil preparation methods (Tables 1 and 2). This may be due to similar physical properties (soil texture, soil porosity and water holding capacity) of the soil, irrespective of the different soil preparation methods. This is consistent with the results of Buah et al. (2017), who found that there was no significant difference in soybean height when comparing conventional tillage with no tillage. In our study, we found that dry weight of sweet potato plants (above ground portion) showed a significant difference; rough ploughing followed by one regular ploughing resulted in higher dry weight, when compared with the rough ploughing followed by two regular ploughings (Table 1). Sindelar et al. (2015) found that corn grown under no tillage had less biomass accumulation than corn grown under conventional tillage and strip tillage. No significant difference was found between the different plant spacings for vine length and dry weight. Similarly, plant spacing did not affect the growth of mangrove (*Avicennia officinalis*) in a study by Miah et al. (2014). Tilahun et al. (2017) also reported that plant spacing had no significant effect on biomass accumulation of desho grass (*Pennisetum pedicellatum* Trin). Contrary to this result, De Almeida et al. (2016) reported that potato plant height and stem number increased with reduced plant spacing.

Plant spacings significantly affected leaf area and chlorophyll content, the spacing of 50 x 30 cm resulted in the highest chlorophyll content and leaf area whereas the spacing of 100 x 30 cm gave the lowest chlorophyll content and leaf area (Table 2). Streck et al. 2014, in a study on cassava, it was reported that leaf area and phyllochron were greater with narrower plant spacing. In this study, there was no statistically significant interaction between tillage pattern and plant spacing on growth (vine length, dry weight, leaf area) and chlorophyll content of sweet potato.

Table 1: Effects of tillages and spacings on vine length and dry weight of sweet potato

Spacing (cm) (S)	Vine length (cm)		Average	Dry weight (g/plant)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	106.3	98.1	102.2	90.3	82.4	86.3
50 x 50	116.0	89.2	102.6	112.0	75.0	93.5
100 x 30	100.4	101.2	100.8	74.3	89.2	81.8
100 x 50	118.9	118.9	118.9	66.0	71.1	68.6
Average	110.4	101.9		85.7	79.4	
LSD (M)	ns			5.1		
LSD (S)	ns			ns		
LSD (M*S)	ns			ns		
(%) CV (M)	28.5			3.5		
(%) CV (S)	16.2			22.9		

LSDs are for P = 0.05

Table 2: Effects of tillages and spacings on chlorophyll content and leaf area of sweet potato

Spacing (cm) (S)	Chlorophyll content (mg/g fresh wt)		Average	Leaf area (cm^2)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	2.33	2.22	2.28	952	1585	1269
50 x 50	1.95	1.46	1.71	739	1000	869
100 x 30	1.22	1.19	1.21	553	732	642
100 x 50	1.50	1.38	1.44	731	634	682
Average	1.75	1.56		744	988	
LSD (M)	ns			ns		
LSD (S)	0.49			361		
LSD (M*S)	ns			ns		
(%) CV (M)	13.1			25.0		
(%) CV (S)	23.5			33.2		

LSDs are for P = 0.05

Yield and yield components

There was no statistically significant difference in tuber numbers, tuber weight, tuber length and width of sweet potato plants grown under the two different soil preparation methods (Tables 3 and 4). This might be because tillage was performed before planting, so it only impacted the soil physical properties in the early stages of growth. Tillage method might not have any lasting effect that would impact the plants up to harvest stage, because the duration of the sweet potato growing season is rather long at more than 4 months. This is consistent with the findings of Seree, et al. (2017), who reported that ploughing to different depths had no significant effect on cassava yield. Similarly, Jongruaysup, et al. (2004) studied different tillages for planting sugar cane and found that the treatments of no tillage, minimal tillage (ploughing once with number 3 discs before planting) and normal ploughing (once with number 3 discs and again with number 7 discs before planting) did not significantly affect sugar cane yield.

However, plant spacing had a significant effect on tuber numbers and tuber weight. The plant spacing of 50 x 30 cm gave the highest number of tubers, although it was not significantly different from the number of tubers at the spacing of 50 x 50 cm. Closer spacings resulted in a significantly higher number of tubers compared to the plots with wider spacings of 100 x 30 and 100 x 50 cm (Table 4). This confirms the findings of Gvertal and Kemble (1997), who compared plant spacings of 15, 20, 25 and 30 cm when growing sweet potatoes and found that 15 cm spacing resulted in the highest yield. Streck et al. 2014 found that tuber root yield per area was higher at higher densities, while yield per plant and per root was higher at lower densities. Szarvas et al. (2019) found that higher plant density increased the total yield per hectare but decreased the yield per plant in sweet potato. Total and marketable tuber yield significantly affected by plant spacing. The spacing of 50 x 30 cm also resulted in the highest average tuber weight, which was significantly different from the lowest tuber weight observed under the 100x50 cm spacing treatment. Plant spacings had no significant effect on tuber length and width (Table 3). In the present study, we observed a statistically significant interaction between tillage pattern and plant spacing on tuber yield and yield components. The results indicated that rough ploughing followed by one regular ploughing, in combination with spacing of 50 x 30 cm, gave the highest number of tubers and tuber weight. Amare and Gebremedhin (2020) also found a significant interaction between plants and row spacing on fruit length of tomatoes.

Table 3: Effects of tillages and spacings on tuber length and tuber width of sweet potato

Spacing (cm) (S)	Tuber length (cm)		Average	Tuber width (mm)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	16.2	13.1	14.7	55.2	46.1	50.6
50 x 50	15.9	13.0	14.5	57.51	42.1	49.8
100 x 30	14.7	16.1	15.4	55.11	57.9	56.5
100 x 50	153	15.8	15.6	51.7	55.3	53.5
Average	15.5	14.51		54.87	50.33	
LSD (M)	ns			ns		
LSD (S)	ns			ns		
LSD (M*S)	2.0			9.8		
(%) CV (M)	4.6			8.1		
(%) CV (S)	8.3			11.3		

LSDs are for P = 0.05

Table 4: Effects of tillages and spacings on tuber numbers and tuber weight of sweet potato

Spacing (cm) (S)	Tubers/plot 15m^2		Average	Tuber weight/plot 15m^2 (kg)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	62.3	59.3	60.8	9.9	9.6	9.8
50 x 50	53.3	54.7	54.0	10.3	7.9	9.1
100 x 30	40.7	37.0	38.8	7.1	8.0	7.6
100 x 50	43.3	30.3	36.8	4.7	5.5	5.1
Average	49.9	45.3		8.0	7.8	
LSD (M)	ns			ns		
LSD (S)	13.6			4.2		
LSD (M*S)	13.6			4.2		
(%) CV (M)	14.6			16.0		
(%) CV (S)	16.8			14.0		

LSDs are for P = 0.05

Proximate composition in tubers

There was no statistically significant difference on proximate composition, such as moisture, ash, protein crude fibre and carbohydrate in tubers of sweet potatoes grown under the two different soil preparation methods (Tables 5, 6 and 7). This might be because the tillage methods we compared affected the physical properties of the soil but had little or no impact on the chemical properties of the soil. So, if the nutrients in the soil were the same in all treatments, then it is not surprising that the chemical compositions of the sweet potatoes were the same.

No statistically significant difference for plant spacing was detected for moisture, ash, protein, crude fibre and carbohydrate. This may be that different plant spacings did not affect dry weight accumulation of sweet potatoes. Therefore, the translocation of assimilate from the vegetative part to the reproductive part was not different. Chayanont et al. (2021) did not find a statistically significant difference in ash content when the corn was grown at different spacings. Similarly, Ogundare et al. (2015) found that spacing had no significant effect on fibre content of tomato. We observed a statistically significant interaction between tillage pattern and plant spacing that affected tuber protein content and crude fibre. The treatment of one rough ploughing followed by one regular ploughing combined with 50 x 50 cm spacing gave the highest tuber protein content and crude fibre.

Table 5: Effects of tillages and spacings on moisture content and ash of sweet potato

Spacing (cm) (S)	Moisture (%)		Average	Ash (%)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	73.8	72.7	73.2	1.63	1.60	1.62
50 x 50	73.1	77.6	75.4	1.50	1.92	1.71
100 x 30	73.06	71.0	72.1	1.77	1.34	1.56
100 x 50	73.5	70.3	71.9	1.56	1.56	1.56
Average	73.3	72.9		1.62	1.61	
LSD (M)	ns			ns		
LSD (S)	ns			ns		
LSD (M*S)	ns			ns		
(%) CV (M)	3.5			18.3		
(%) CV (S)	3.5			17.8		

LSDs are for P = 0.05

Table 6: Effects of tillages and spacings on protein and crude fibre of sweet potato

Spacing (cm) (S)	Protein (%)		Average	Crude fibre (%)		Average
	Number of tillages (M)			Number of tillages (M)		
	Two	Three		Two	Three	
50 x 30	1.47	1.07	1.27	1.00	1.02	1.01
50 x 50	1.57	1.25	1.41	1.04	0.96	1.00
100 x 30	1.51	1.43	1.47	0.99	0.97	0.98
100 x 50	1.29	1.49	1.39	0.96	1.00	0.98
Average	1.46	1.31		1.00	0.99	
LSD (M)	ns			ns		
LSD (S)	ns			ns		
LSD (M*S)	0.23			0.09		
(%) CV (M)	5.2			4.5		
(%) CV (S)	6.8			2.6		

LSDs are for P = 0.05

Table 7: Effects of tillages and spacings on carbohydrate of sweet potato

Spacing (cm) (S)	Carbohydrate (%)		Average
	Number of tillages (M)		
	Two	Three	
50 x 30	22.6	24.2	23.4
50 x 50	23.3	18.7	21.0
100 x 30	22.6	25.7	24.2
100 x 50	23.2	25.9	24.6
Average	23.0	23.6	
LSD (M)	ns		
LSD (S)	ns		
LSD (M*S)	ns		
(%) CV (M)	12.0		
(%) CV (S)	12.1		

LSDs are for P = 0.05

Conclusion

This experiment tested two different tillage patterns and four different plant spacing methods on sweet potatoes found that:

1. Tillage pattern had no statistically significant effect on vine length, chlorophyll content, leaf area, yield or chemical components of sweet potatoes, but it did have a statistically significant effect on the dry weight of the above-ground part of the plant. Less tillage (rough ploughing followed by one normal ploughing) resulted in greater dry weight accumulation than more tillage (rough ploughing followed by two normal ploughings).
2. Plant spacing had a statistically significant effect on chlorophyll content, leaf area, tuber weight and tuber number. The spacing of 50 x 30 cm gave the best results.
3. There was a statistically significant interaction between tillage pattern and plant spacing for tuber width, tuber length, tuber weight, tuber protein content and tuber crude fibre content. The combination of one rough ploughing and one normal ploughing and 50 x 50 cm spacing resulted in the greatest tuber weight, tuber protein content and tuber crude fibre content.
4. Based on these results, we can recommend that farmers growing sweet potatoes on abandoned rice paddy land should plough once roughly and once normal and plant the stem cuttings with 50 cm between rows and 30 – 50 cm between plants.

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