

Optimal Planting Depth for Turmeric (*Curcuma longa* L.) Cultivation in Dark Red Soil in Okinawa Island, Southern Japan

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Abstract : Effects of planting depth on emergence, growth, development and yield of turmeric (*Curcuma longa* L.) in dark red soil (Shimajiri Mahji) were evaluated in Okinawa, Japan. Turmeric planted at the depths of 8, 12 and 16 cm emerged earlier and more evenly than that planted at a shallower depth in both glasshouse and field experiments. Weed growth was unaffected by the planting depth of turmeric until 50–60 days after planting (DAP), but affected thereafter due to mutual shading with the canopy. Weed biomass at 90–140 DAP was significantly smaller in the fields where turmeric was planted at the depths of 8, 12 and 16 cm than in the field where it was planted at a shallower depth. The turmeric rhizome (yield) developed earlier when planted at 8, 12 and 16 cm depths than at 4 cm. In a glasshouse study, shoot biomass and yield of turmeric were significantly greater when planted at the depths of 4, 8 and 12 cm than that of 2 cm. In field experiments, they were also significantly greater when planting depth was 8 or 12 cm than 4 cm. Even in turmeric planted at a 16 cm depth shoot dry weight and yield were greater than that planted at a 4 cm depth, but it was comparatively difficult to harvest rhizomes in this field. About 30% of turmeric in the field planted at a 4 cm depth was uprooted by a typhoon, but not at the depths of 8, 12 and 16 cm. The over all results suggested that rhizomes of turmeric should be planted at a depth of 8 to 12 cm in dark red soil for a higher yield and lower weed competition.

Key words : Emergence, Planting depth, Rhizome, Turmeric yield, Weed control.

Turmeric is a root crop of Zingiberaceae propagated by rhizomes. It is one of the most important medicinal plants due to its antioxidant properties and protective powers for our health (Majeed et al., 1995). Curcumin and volatile oils in the rhizome of turmeric are known to prevent cancer diseases, tumors and the production of free radicals, and to improve liver and kidney functions (Hermann and Martin, 1991; Majeed et al., 1995). Uechi et al. (2000) found antibacterial activities of essential oils in *Curcuma* sp. It has been used for a long time in Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand as a spice, cosmetic and medicine. Recently, it is used worldwide as a spice and natural medicine (Hermann and Martin, 1991; Majeed et al., 1995).

Studies on emergence pattern, growth and development of a plant species influenced by edaphic factors are important for better production (Hossain, 1999; Ghorbani et al., 1999). It is essential to plant a root crop at the proper planting depth to obtain a higher yield, because soil type, bulk density and soil ecological factors affect the growth and development of rhizomes and tubers (Aoi et al., 1988; Hossain, 1999; Peng, 1984).

Okinawa is the best place in Japan to grow turmeric commercially due to its subtropical climate. However, the yield per unit area is very poor because the appropriate technique of turmeric cultivation is not spread to the

farmers in such environmental conditions. Typhoon disasters occur several times in a season and soil erosion caused by heavy rainfall affect the growth and yield of turmeric in Okinawa. Turmeric is widely cultivated in dark red soil (Shimajiri Mahji, Chromic Luvisols) in Okinawa. The soil consists of 3.9% coarse sand, 13.8% fine sand, 32.9% silt and 49.4% clay, containing 1.6% C and 0.21% N. The contents of exchangeable K, Ca, Mg and Na are 0.6, 18.2, 2.7 and 0.6 me (milligram equivalent) per 100 g soil, respectively, at pH 6.1 (KCl) (Tokashiki, 1993). Very few studies have been done on turmeric in this soil (Akamine et al., 1994, 1995). Even though some studies have been conducted on turmeric cultivation in Tanegashima, the information is not applicable in Okinawa because climatic conditions and soil characteristics are different (Aoi, 1988, 1992; Aoi et al., 1986, 1988; Hossain, 1999). Therefore, the present study was undertaken to evaluate the effects of planting depth on emergence, growth and yield of turmeric in dark red soil in Okinawa.

Materials and Methods

1. Glasshouse experiment

The glasshouse experiment was conducted from 10 April, 1999, to 16 February, 2000, at the Subtropical Field Science Center of the University of the Ryukyus, Okinawa, Japan. Dark red soil (Shimajiri Mahji) with

pH 6.08, 0.8% organic matter, 0.89% C, 0.11% N, 134 mg P per 100 g soil was used. Percent (w/w) clay, silt and sand were 66.3, 29.3 and 4.4, respectively and bulk density (g cm^{-3}) was 0.85. Exchangeable K, Ca, Mg and Na were 0.17, 10.8, 1.35 and 0.31 me (milligram equivalent) per 100 g soil, respectively.

The experiment consisted of planting depths of 2, 4, 8 and 12 cm with 12 replications each. Air-dried soil was placed in the Wagner pot (size 0.05 m^2 , 30 cm depth) to each planting depth on which one turmeric rhizome (*C. longa* L., 30 g) was placed, and then the pot was filled with soil (13 kg soil in each pot). Water was applied once a day to maintain adequate soil moisture. Chemical fertilizer (N : P_2O_5 : K_2O = 16 : 9 : 9) at 370 kg ha^{-1} was applied 3 times at 60-day intervals from 70 days after planting (DAP). Air temperature in the glasshouse ranged from 18 to 32°C .

2. Field experiment in 1999-2000

The field experiment was conducted from 5 May, 1999, to 14 February, 2000, at the Subtropical Field Science Center of the University of the Ryukyus. The ambient temperature during field experiments is presented in Fig. 2. The field left uncultivated in the previous year was plowed properly, and 8 m-long ridges with a 1.5 m distance were prepared mechanically. The soil type and turmeric rhizome used in this experiment were the same as those used in the glasshouse experiment.

The experiment consisted of 3 planting depths (4, 8 and 12 cm) with 4 replications (4 ridges). Fifty-six turmeric rhizomes (each 30 g) were planted manually in two rows in each ridge maintaining a 30 cm distance. Chemical fertilizer (N : P_2O_5 : K_2O = 16 : 9 : 9) at 370 kg ha^{-1} was applied 3 times at 60-day intervals from 70 DAP. Overhead irrigation was done immediately after turmeric planting and fertilizer application. The major weed species in the field were *Panicum repens*, *Bidens pilosa*, *Cyperus rotundus*, *Paspalum urvillei* and *Amaranthus viridis*. Hand hoeing was done 3 times for weed management at 45-day intervals from 50 DAP.

3. Field experiment in 2001

This experiment was conducted from 1 April to 2 December, 2001 on the same field used for previous experiment. The field left uncultivated in previous season (April, 2000 to January, 2001) was plowed properly, and 4 m-long ridges were prepared according to a previous field experiment.

Turmeric was planted at the depths of 4, 8, 12 and 16 cm with 3 replications (3 ridges). A total of 28 turmeric rhizomes (each 30 g) were planted manually in two rows in each ridge maintaining a 30 cm distance. Fertilizer and agronomic practices, and major weed flora were similar to those in the field experiments in the previous years. Hand hoeing was done 3 times for weed management at 30-day intervals from 60 DAP.

4. Procedures of data collection and statistical analysis

Data on emergence of turmeric was recorded at 5-, 10- and 7-day intervals from 30 DAP in the glasshouse, 20 DAP in the field in 1999 and 53 DAP in the field in 2001, respectively. Data on emergence and biomass of weeds was recorded at weeding time. Plant length, and the number of shoots and leaves of turmeric were recorded at 30-day intervals from 75 DAP in glasshouse study, and turmeric was harvested in February, 2000. In the 1999-2000 field study, 4 and 30 plants were harvested from each replication at 105 and 285 DAP, respectively; and in 2001, 6 plants were harvested in December. Plant length, the number of shoots and leaves, leaf area, and the dry weight of shoots and rhizomes were recorded. Plant materials were oven-dried at 80°C for 48 hours. Data on emergence and biomass of weeds, and shoot dry weight and yield of turmeric per unit area (m^{-2}) were calculated for field experiments. Means and standard deviations (SD) of samplings were determined using analysis of variance (ANOVA). Fisher's Protected LSD test at the 5% level of significance was used to compare the means.

Results and Discussion

1. Effect of planting depth on emergence

Turmeric planted at depths of 8, 12 and 16 cm completed emergence earlier by 5 days in the glasshouse and by 10-14 days in field experiments as compared with that planted at a 4 cm depth (Fig. 1). Emergence of plant seeds and propagules is usually delayed with increasing planting depth (Hossain, 1999). Similarly, Watanabe et al. (2002) reported that, in apple, seed size limits the planting depth which allows seedling emergence in soil. However, this did not apply to turmeric, probably due to the bigger propagule size. Turmeric emerged evenly and earlier when planted at 8, 12 and 16 cm depths, because the soil layer from 6 to 15 cm usually contains a higher soil moisture than the surface 5 cm soil layer in Shimajiri Mahji (data not published, Laboratory of Irrigation and Water Management, University of the Ryukyus), which might influence rhizomes to emerge properly (Fig. 1). The soil moisture in the upper 5 cm layer may be insufficient for emergence seedling from a bigger propagule (30 g). Accordingly, Ghorbani et al. (1999) reported that the germination rate of *Amaranthus retroflexus* increased with increasing water potential. Other investigators reported that the seed-soil conditions in seeding depth, soil-seed contact and soil moisture affected the emergence of rice (Haque et al., 1991; Jaggi and Bisen, 1986). The present study indicated that planting depth of a 4 cm was insufficient for good soil-seed (rhizome) contact for better seedling emergence from a big propagule (30 g) of turmeric. Earlier emergence of crops might suppress weed growth and increase yield.

Turmeric planted on 1 April, 2001 required a longer

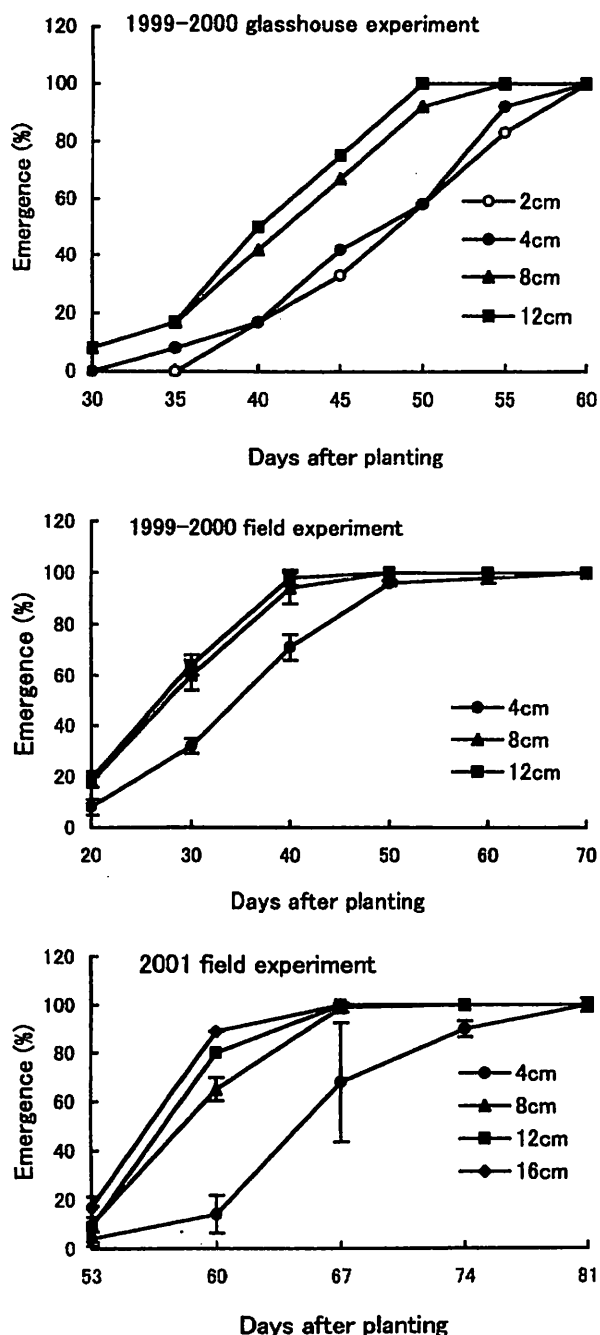


Fig. 1. Effect of planting depth on emergence of turmeric.

1999, because lower temperature prevailed in soil (20°C) and air (20.6°C) in April than in May (23°C, 23.8°C) (Fig. 2). Our previous study indicated that turmeric emerged rapidly at a temperature of 25–30°C in an incubator (data not published).

Effect of planting depth on growth, yield and weed control

Emergence and biomass of weeds were unaffected by planting depth of turmeric until 50–60 DAP, but affected later (Fig. 3, Table 1). Weed biomass recorded 90–95

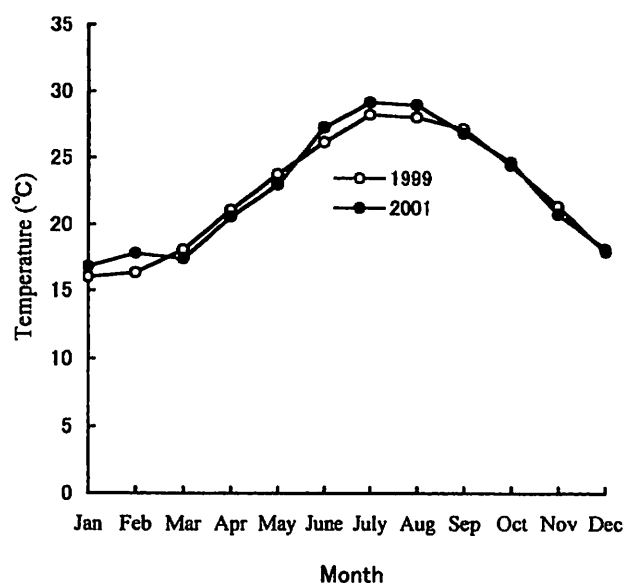


Fig. 2. Mean monthly air temperature in 1999 and 2001. Data from the Agricultural Experiment Farm, University of the Ryukyus.

and 120–140 DAP was significantly lower in the plots where turmeric was planted at 8, 12 and 16 cm depths than where planted at a 4 cm depth (Table 1). Because earlier and evenly emerged turmeric had a higher leaf area (canopy structure), it covered the field earlier and reduced weeds (Fig. 1, 3, 4, Table 1, 2). This study indicated that crop planting patterns could not reduce emergence and biomass of weeds before the canopy structure established. Similarly, Tharp and Kells (2001) reported that a higher corn population did not initially affect emergence and biomass of common lambsquarters, but did later because it developed a canopy structure earlier than a lower corn population in the field. A delay in turmeric emergence may permit weed to become well established in the field with turmeric planted at a depth of 4 cm. Early weed establishment probably reduced nutrient and soil moisture, which would ultimately decrease yield of turmeric in the field where it was planted at a 4 cm depth. Similar results have been reported in different crop fields by others (Ivany, 1997; Tanji et al., 1997). Weed infestation was similar in the fields of turmeric planted at 8, 12 and 16 cm depths due to the similar turmeric growth.

Plant length, and number of shoots and leaves were not significantly influenced by the planting depths in the glasshouse experiment (data not presented), but in field experiments, these parameters were significantly higher when the planting depth was 8, 12 or 16 cm than 4 cm (Table 2). Turmeric plants could not establish properly in the fields with turmeric planted at 4 cm depth because some roots grew on soil surface, which might result in lower plant length, shoots and leaves. Shoot diameter and leaf area per leaf (individual leaf area) were smaller when planted at 2–4 cm depths than at a deeper depth

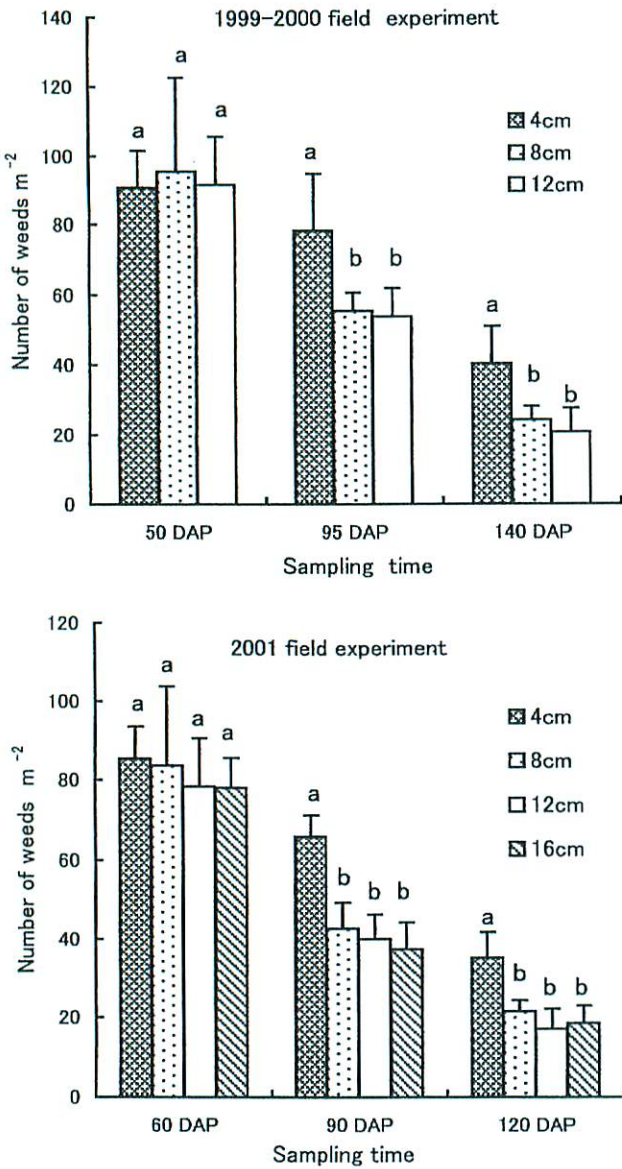


Fig. 3. Effect of turmeric planting depth on weed population (emergence). DAP : days after planting. Data are means \pm SD. Bars with the same letter within each sampling time are not different at the 5% level of significance, as determined by LSD test.

in both the glasshouse and field experiments (data not presented). A higher plant length, shoot number and leaf number of turmeric composed a better canopy structure in the field, which ultimately reduced weed biomass and provided the plants to utilize maximum nutrients and moisture (Hossain, 1999). A larger leaf area usually receives a higher solar energy for photosynthetic processes that ultimately increases crop yield (Buah et al., 2000; Kawamoto et al., 1988).

Shoot dry weight of turmeric at final harvest was significantly higher when planted at the depths of 4, 8 and 12 cm in a glasshouse, and 8, 12 and 16 cm in fields than planted at a shallower depth (Table 3). In field experiments, shoot dry weight recorded on 105 DAP increased with increasing planting depth (Table 3), because earlier seedling emergence increased plant length, and dry weight of shoots and leaves (Hossain, 1999). On the other hand, shoot dry weight at final harvest did not differ significantly among the plants planted at 8, 12 and 16 cm depths, because growth parameters increased rapidly from 105 DAP to harvest in the field planted at a depth of 8 cm. This indicated that turmeric planted at a depth of 8 cm finally reached the

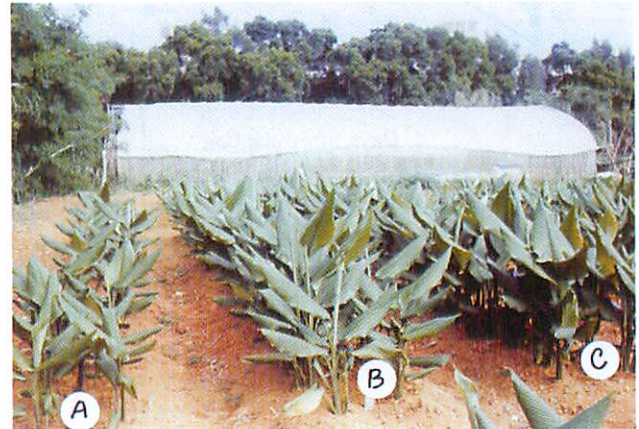


Fig. 4. Turmeric growth at 105 days after planting as influenced by planting depth. A, B and C represent 4, 8 and 12 cm planting depths, respectively.

Table 1. Effect of planting depth of rhizomes on weed biomass in turmeric fields in 1999-2000 and 2001.

Planting depth (cm)	Weed biomass (g m^{-2})					
	1999-2000 experiment			2001 experiment		
	50 DAP	95 DAP	140 DAP	60 DAP	90 DAP	120 DAP
4	318 \pm 20a	306 \pm 20a	193 \pm 23a	260 \pm 31a	251 \pm 22a	183 \pm 26a
8	315 \pm 26a	198 \pm 12b	37 \pm 8b	267 \pm 40a	179 \pm 11b	48 \pm 9b
12	314 \pm 30a	162 \pm 31b	29 \pm 7b	268 \pm 23a	176 \pm 20b	38 \pm 12b
16	#	#	#	259 \pm 26a	157 \pm 21b	45 \pm 10b

DAP : days after planting; # : experiment not conducted. Means within each column not followed by the same letter are different at the 5% level of significance, as determined by LSD test.

Table 2. Effect of planting depth on plant length, number of shoots, number of leaves and leaf area of turmeric at 105 days after planting in 1999–2000 and 2001 field studies.

Season	Planting depth (cm)	Plant length (cm)	Shoot (no. plant ⁻¹)	Leaf (no. plant ⁻¹)	Leaf area (cm ² plant ⁻¹)
1999-2000	4	88 ± 10c	2 ± 1b	7 ± 1c	2193 ± 317c
	8	111 ± 6ab	3 ± 0a	10 ± 1b	4457 ± 352b
	12	122 ± 9a	4 ± 1a	13 ± 2a	6206 ± 694a
2001	4	65 ± 3b	1.2 ± 0.2b	6.6 ± 0.5b	‡
	8	85 ± 12a	2.1 ± 0.2a	10.3 ± 0.5a	‡
	12	87 ± 3a	2.2 ± 0.1a	11.0 ± 0.8a	‡
	16	81 ± 1a	2.3 ± 0.1a	10.7 ± 0.5a	‡

‡ : data not recorded. Means within each column for each season not followed by the same letter are different at the 5% level of significance, as determined by LSD test.

Table 3. Effect of planting depth on shoot dry weight and yield (rhizome dry weight) of turmeric in glasshouse (G-house) and field studies in 1999–2000 and 2001.

Planting depth (cm)	Shoot dry weight (g plant ⁻¹ , g m ⁻²)				Yield (g plant ⁻¹ , g m ⁻²)			
	G-house	Field-1999-2000		Field-2001	G-house	Field-1999-2000		Field-2001
		105 DAP	285 DAP			105 DAP	285 DAP	
2	23 ± 4b	#	#	#	33 ± 4b	#	#	#
4	29 ± 4a	106 ± 27c	245 ± 39b	479 ± 22b	42 ± 5a	33 ± 5b	267 ± 36b	362 ± 16b
8	29 ± 3a	176 ± 18b	352 ± 14a	645 ± 92a	47 ± 5a	48 ± 6a	433 ± 49a	465 ± 41a
12	28 ± 3a	239 ± 26a	381 ± 23a	655 ± 48a	46 ± 6a	59 ± 8a	436 ± 42a	466 ± 53a
16	#	#	#	653 ± 63a	#	#	#	449 ± 42ab

* : unit for G-house experiment; # : experiment not conducted. Means within each column not followed by the same letter are different at the 5% level of significance, as determined by LSD test.

optimum shoot dry weight. However, shoot dry weight usually contributes to higher turmeric yield (Akamine et al., 1995, Hossain et al., 2000).

Turmeric rhizomes (yield) developed earlier in the fields where they were planted at the depths of 8, 12 and 16 cm than where they were planted at a 4 cm depth due to the earlier emergence and establishment of plants. About 30% of turmeric plants were completely uprooted in the fields where they were planted at a depth of 4 cm by a strong typhoon occurring in September, because of smaller root distribution in the soil. Turmeric shoots planted in a deeper soil layer were injured by a typhoon but not uprooted, and they recovered earlier.

Turmeric yield was significantly higher when the rhizomes were planted at a depth of 4, 8 and 12 cm in a glasshouse, and at a depth of 8 and 12 cm in fields, than when planted at a shallower depth (Table 3). Turmeric planted at a 16 cm depth showed a slightly lower yield than that planted at 8 and 12 cm, and it was comparatively difficult to harvest rhizomes, probably due to the higher compactness or bulk density in deeper soil (Akio and Ishihara, 1985). Early emergence and establishment, and bigger shoots of turmeric plants were responsible for the higher yield in the fields where they were

planted at 8, 12 and 16 cm depths than at a 4 cm depth. Similar results have been reported in sugarcane fields (Hossain, 1999). In a glasshouse study, the turmeric shoot base was longer the deeper the planting depth, and more rhizomes were produced. Rhizomes developed from the side of the shoot base, and expanded in a horizontal and upward direction where planted at a 12 cm depth. When planted at a 4 or 8 cm depth, rhizomes developed from the side of the shoot base and expanded only in a horizontal direction. On the other hand, when planted at a 2 cm depth rhizomes developed only from the tip of the shoot base and expanded mostly in a deeper direction, and were small (Fig. 5). When planted at an 8 cm depth in pots (glasshouse) rhizomes were longer and larger in diameter than when planted at a shallower or deeper depth. However, in the fields, rhizomes were bigger when planted at 8 and 12 cm depths than at other depths. Aoi et al. (1987) reported a higher yield of turmeric when the rhizomes were planted at a 20–30 cm depth because soil was loose at that depth. Developmental characteristics of rhizome may vary with the soil characteristics.

Glasshouse and field experiments showed a somewhat different results on the effect of planting depth on yield.

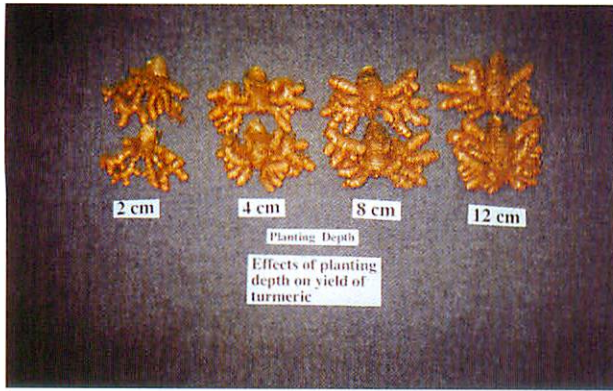


Fig. 5. Development characteristics of turmeric yield (rhizome) observed at final harvest as influenced by planting depth.

Soil was well prepared and water was applied regularly in the glasshouse experiment, but in fields soil characteristics mostly depended on natural rainfall.

We concluded that turmeric plants planted at depths of 8, 12 and 16 cm emerged more evenly and earlier than those planted at a shallower depth, which ultimately reduced weed biomass. Weed control-efficiency was nearly the same at the planting depths of 8, 12 and 16 cm. Turmeric rhizomes (yield) developed earlier when they were planted at 8, 12 and 16 cm depths than at 4 cm. Shoot dry weight was significantly higher when the rhizomes were planted at 4, 8 and 12 cm depths in the glasshouse experiment, and at 8, 12 and 16 cm depths in the field experiments. Yield was the highest when rhizomes were planted at the depth of 8 cm followed by 12 cm in the glasshouse experiment, while it was the highest at the depth of 12 cm followed by 8 cm in the field experiments. Even though shoot dry weight and yield of turmeric planted at a 16 cm depth were almost similar to those of turmeric planted at 8 and 12 cm depths, and markedly higher than those of turmeric planted at 4 cm, turmeric planted at a 16 cm depth was difficult to harvest rhizomes in this field. Recovery from injury caused by a typhoon was observed in the fields with a planting depth of 8, 12 and 16 cm. About 30% of turmeric planted at a 4 cm depth was uprooted by a typhoon. This study indicated that turmeric should be planted at the depth of 8 to 12 cm for higher yield and lower weed competition in dark red soil (Shimajiri Mahji) in Okinawa.

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