Effects of Harvest Time on Shoot Biomass and Yield of Turmeric (Curcuma longa L.) in Okinawa, Japan

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Abstract: This study was conducted in 2003-2004, 2005-2006 and 2006-2007 in Okinawa, Japan (24-28° N and 126-130° E) to evaluate the effects of harvest time on biomass accumulation pattern in shoots and rhizomes (yield) of turmeric (Curcuma longa) for determining critical harvest time. Four lines/cultivars, Aki Ukon, Ryudai Gold, Ryudai-11 and Ryudai-44 were tested. Turmeric was planted in April every season, and biomass was monitored at different dates. Shoots of all turmeric lines/cultivars remained green until November, thereafter turned yellow and completed drying in January every season. Turmeric shoot biomass increased until November and decreased thereafter. Fresh yield of turmeric harvested in November, December and January was almost the same, but dry yield increased significantly with the delay in harvest until January. Percentage (%) of dry yield to fresh yield was 7-10 in September and October, 10-16 in November, 14-22 in December and 15-24 in January; and yield-shoot ratio in dry weight was 0.2-0.5, 0.5-1.2, 0.9-2.2 and 1.3-3.0, respectively. All the lines/cultivars maintained a similar biomass accumulation pattern during the harvest time in each season. These results suggest that maximum dry yield is obtained when turmeric shoots wither completely, and turmeric should be harvested in January for higher dry yield in Okinawa.

Key words: Dry matter accumulation pattern, Dry matter translocation, Harvest time, Rhizomatous plant, Root crop, Yield-shoot ratio.

It is important to harvest a plant species in an appropriate time for increasing yield, quality and storability, and reducing disease incidence (Elias and Copeland, 2001; Darby and Lauer, 2002; Lewandowski et al., 2003; Boyhan et al., 2004; Drake et al., 2004; Mendonca et al., 2004; Ullah et al., 2004; Gesch et al., 2005; Adler et al., 2006; Farrer et al., 2006).

Turmeric (Curcuma longa L.) is a rhizomatous plant used as a natural spice, cosmetic and medicine in the world (Hermann and Martin, 1991; Osawa et al., 1995; Nakamura et al., 1998; Hossain et al., 2005a). Turmeric is usually planted in April, and its shoot develops until October, turns yellow from early December and withers in January (Fig. 1) in several countries in tropical and subtropical regions, such as Bangladesh, India, Myanmar and Japan (Okinawa), where 95% of the world turmeric is grown (Ishimine et al., 2004). In these areas, turmeric rhizome (yield) usually develops from August to November and matures in December-January. Turmeric is harvested from September to January for commercial and household needs without considering yield per unit area and dry yield to fresh yield (dry yield percentage) (personal survey, unpublished). Some farmers remove shoots before complete withering for early harvest of turmeric rhizomes. It is assumed that removing green shoots affects turmeric yield, and there is a correlation between harvest time and fresh yield and dry yield of turmeric. Several studies reported that yield of turmeric differs with the planting depths, planting times, planting patterns, seed sizes, soil types and fertilizer managements (Reddy and Rao, 1978; Yamgar et al., 2001; Ishimine et al., 2003, 2004; Hossain and Ishimine, 2005; Hossain et al., 2005a, 2005b, Akamine et al., 2007; Hossain and Ishimine, 2007) but no comprehensive study has yet been conducted on harvest time in relation to yield in the world. Present study has been conducted to evaluate the effects of harvest time on shoot biomass and yield of turmeric for determining critical harvest time in Okinawa, Japan.

Materials and Methods

1. Field experiment in 2003-2004

The experiment was conducted from 15 April, 2003 to 4 January, 2004 on dark red soil (Shimajiri mahji, pH 5-6) at the Subtropical Field Science Center of University of the Ryukyus, Okinawa, Japan (24-28° N and 126-130° E). The field plowed to a depth of 35 cm was divided into six plots.
Three 6 m long ridges spaced 1.2 m apart (furrow to furrow distance) were made by furrowing in each plot. One hundred and twenty six (126) seed rhizomes (each 30 g) of cultivar Aki Ukon (AU) were planted in a 30 cm triangular pattern (two rows on a ridge) at the depth of 10 cm in a plot (6.0 m × 3.6 m = 21.6 m²). Chemical fertilizers of N (H₂NCONH₂) at 75 kg ha⁻¹, P (CaH₄(PO₄)₂H₂O) at 75 kg ha⁻¹ and K (KCl) at 150 kg ha⁻¹ were applied 3 times at a 45-d interval from the 2 to 3 leaf stage (60 d after planting (DAP)). Overhead irrigation was given immediately after turmeric planting and fertilizer application. Hand weeding was performed at 60, 105 and 150 DAP. Six turmeric plants (one plant from each plot) were harvested on 19 November (first harvest, 218 DAP, when shoot growth terminated), 4 December (second harvest, 233 DAP, when shoots turned yellow), 19 December (third harvest, 248 DAP, when shoots began to break over), 2003, and 4 January (fourth harvest, 263 DAP, when shoots withered completely and separated from rhizome-stub naturally), 2004.

2. Field experiment in 2005−2006

The experiment was conducted from 21 April, 2005 to 21 January, 2006 on the same dark red soil at the Subtropical Field Science Center of the University of the Ryukyus. The field was plowed to a depth of 35 cm, and 8 m long ridges spaced 1.1 m apart were made. Four C. longa lines/cultivars Aki Ukon (AU: tall shoot, yellow rhizome, around 0.2% curcumin), Ryudai gold (RDG: short shoot, big and reddish rhizome, around 2.58% curcumin),
Ryudai-11 (RD-11: medium shoot, narrow, long and orange rhizome, around 1.92% curcumin) and Ryudai-44 (RD-44: medium shoot, narrow and reddish rhizome, around 2.26% curcumin) were chosen from my previous study (data unpublished; Hossain et al., 2004). AU has been cultivating in Okinawa for several decades and RDG has been developed by University of the Ryukyus (under registration). RD-11 and RD-44 have been selected by University of the Ryukyus, but not yet registered. This experiment was arranged as a randomized complete block design and each cultivar/line was planted in three plots. Each plot size was 8.8 m² (8 m ×1.1 m), and 54 best seed rhizomes (AU, each 28−30 g; RDG, 28−30 g; RD-11, 23−25 g; RD-44, 23−25 g) of each cultivar/line were planted randomly in each plot according to the previous experiment. The fertilizer, weed management and irrigation were provided according to the previous experiment.

Three turmeric plants (one plant from each plot) were harvested on 30 September (first harvest, 162 DAP, rhizome development stage), 22 November (second harvest, 215 DAP, when shoots turned yellow), 2005, and 21 January (third harvest, 275 DAP, when shoots withered completely and separated from rhizome-stub naturally), 2006 for each cultivar/line.

3. Field experiment in 2006−2007
The previous experiment (2005−2006) was repeated from 25 April, 2006 to 20 March, 2007 on another field with the same soil of University of the Ryukyus. Each turmeric line/cultivar was cultivated in 5 plots (each plot, 8 m ×1.1 m) and all the agronomic practices were applied according to the experiment 2005−2006.

Five turmeric plants (one plant from each plot) were harvested on 17 August (115 DAP), 17 September (146 DAP), 17 October (176 DAP), 17 November (207 DAP), 17 December (237 DAP), 2006, and 20 January (271 DAP, when shoots withered completely and separated from rhizome-stub naturally), 2007 for each cultivar/line.

4. Data collection and statistical analysis
Shoots and rhizomes (yield) were separately collected from each plant, and fresh rhizomes were weighed. Shoots and sliced rhizomes were oven-dried at 80ºC for 48 hr and weighed for biomass. Dry yield percentage ((dry rhizome weight/fresh rhizome weight)×100) and yield-shoot ratio (in dry weight) were calculated each harvest time. Rhizomes taken in paper bags were stored at room temperature (16−30ºC, Fig. 2A) for 60 d after each harvest in the experiment in 2006−2007, and the changes in rhizome morphology (shape) were visually evaluated. Mean and standard deviation (SD) of the replications were calculated, and a one-way ANOVA was used to determine whether harvesting time affects shoot biomass and yield of turmeric. Means were separated by Fisher’s Protected LSD (least significance difference) test at P <0.05. Quadratic regression analysis was used to determine relationship of harvest time to shoot biomass and yield of turmeric in the experiment in 2006−2007.

Results and Discussion

1. Climatic condition during experiments
The monthly mean temperature, rainfall and humidity during the study period in Okinawa, Japan are presented in Fig. 2. The average temperature range in January and February was 16−18ºC, thereafter the temperature increased gradually with time, reached at plateau in July-August (29−30ºC), and then decreased gradually (Fig. 2A). The temperature was slightly different (0.5–1.5ºC) with the year. The monthly mean rainfall differed remarkably with the years and months (Fig. 2B). A little
rainfall occurred in July (13.5 mm) and December (60.0 mm), and it was 106.0−245.0 mm in other months in 2003−2004 cropping season. In 2005−2006, a little rainfall occurred in July (6.5 mm), September (64.0 mm), October (60.0 mm) and November (48.0 mm), and the rainfall was 101.5−860.5 mm in other months. The rainfall was few in October (39.0 mm) and February (67.5 mm), and it was 114.0−333.5 mm in other months in 2006−2007 cropping season. Humidity was 71−85% during April to September, and 58−74% during October to March (Fig. 2C).

2. Shoot biomass at different harvest times

Turmeric shoots remained green until November and turned yellow in December followed by drying in January every cropping season (Fig. 1). Turmeric shoots separated from rhizome stubs and decayed naturally after January, and then weeds started to grow in the field (visual observation). It was found that turmeric shoots turned yellow when temperature fell to below 20°C (Figs. 1, 2). Similarly, Ishimine et al. (2004) reported that turmeric planted in February, March, April, May and June dried at the same time in January because temperature dropped to below 20°C. In the first experiment (2003−2004), turmeric on 19 November and 4 December, 2003 resulted in a similar shoot biomass, and the shoot biomass thereafter reduced significantly with the delay in harvest (Table 1). The similar shoot biomass obtained on 19 November and 4 December indicates that vegetative growth of turmeric reached to plateau in November and remained constant until 4 December. In addition, it is assumed that the photosynthetic product accumulated in rhizomes, not in shoots after 19 November. The decreased shoot biomass (19% on 19 December and 33% on 4 January) indicates that some shoot biomass probably moved to rhizomes. Howeler and Cadavid (1983) reported that cassava dry-matter accumulation increased rapidly in shoots during the first 6 mo and slowly during the final 6 mo, and that dry-matter accumulated mainly in roots at harvest (12 mo after planing).

In the second experiment (2005−2006), shoot biomass (dry weight) of the cultivar Aki Ukon (AU) was the largest in November (second harvest) followed by September (first harvest) and January (third harvest) (Fig. 3A). On the other hand, shoot biomass of the Ryudai gold (RDG) was the largest in September, and thereafter decreased with the delay in harvest. The shoot biomass of the RD-11 and RD-44 was the same and significantly higher in September and November than the shoot biomass in January (Fig. 3A). In the third experiment (2006−2007), shoot biomass increased until November thereafter decreased in all lines/cultivars tested (Fig. 4A). The shoot biomass decreased 23−32% after November (calculated from the value of Fig. 4A), which probably turned into rhizome yield when leaf senescence occurred. These results also indicate that vegetative growth pattern differed more or less with the years probably due to the differences in environmental condition and soil nutrient status.

3. Yield (rhizome) at different harvest times

In the first experiment (2003−2004), turmeric harvested on 19 November, 4 and 19 December, and 4 January had a similar fresh yield, while dry yield and dry yield percentage increased significantly with the delay in harvest (Table 1). These results indicate that biomass increased and water content decreased in rhizome with the delay in harvest. The dry yield increased significantly after December when shoots became yellow and leaf senescence occurred, which indicates that the lost shoot biomass of turmeric turned into rhizome. The 19−33% decrease in shoot biomass probably contributed to the 12−35% increase in rhizome biomass from December to January (calculated from Table 1).

In the second (2005−2006) and third (2006−2007) experiments, fresh yield of turmeric increased rapidly until November and thereafter increased only slightly in all the lines/cultivars (Figs. 3B, 4B), whereas the dry yield and dry yield percentage increased significantly with the delay in harvest (Figs. 3C, D, 4C). Fresh yield of the AU, RDG, RD-11 and RD-44 harvested in January increased by 18−20, 12−21, 7−9 and 7−15%, respectively compared to those

| Harvest time  | Shoot biomass (g plant⁻¹) | Fresh yield (g plant⁻¹) | Dry yield (g plant⁻¹) | Dry yield (%) | Yield-shoot ratio |
|---------------|---------------------------|-------------------------|----------------------|---------------|------------------|
| 19 November   | 96±7 a                    | 799±71 a                | 116±13 d             | 16±0 d        | 1.2±0.1 d        |
| 4 December    | 94±13 a                   | 75±48 a                 | 143±12 c             | 19±0 c        | 1.5±0.1 c        |
| 19 December   | 79±9 b                    | 789±50 a                | 173±6 b              | 22±1 b        | 2.2±0.2 b        |
| 4 January     | 64±7 c                    | 701±30 a                | 193±9 a              | 24±9 a        | 3.0±0.2 a        |

Data are means ± SD of 6 replications. Means with the same letter within each column are not significantly different at the 5% level, as determined by Fisher’s Protected LSD test.

Yield-shoot ratio = Dry rhizome weight/dry shoot weight.
Harvested in November, whereas the dry yield increased by 48–87, 64–88, 70–93 and 57–93%, respectively. These data indicate that 32–48% of total dry yield accumulated from November to January (calculated from Table 1; Figs. 3C, 4C), and the lost shoot biomass turned into rhizome-yield. Shoot biomass of all turmeric lines reached at plateau in November, and thereafter shoot biomass decreased 23–32% (calculated from Fig. 4A). On the other hand, rhizome biomass (yield) increased 10–48% from November to January (calculated from the value of Fig. 4B). The values of the lost shoot biomass and gained rhizome biomass were not the same, which indicate that all the lost shoot biomass did not turn into the rhizome (yield) or the gained rhizome did not come from only the lost
Shoot biomass. Some leaves remained green in December (Fig. 2E), which may have contributed to photosynthesis. Therefore, it is assumed that some portions of lost shoot biomass turned into rhizome. After January, the shoots separated from rhizome-stubs and decayed naturally, and could not contribute to the further increase in turmeric rhizome (yield). The dry yield percentage (%) of AU was 16, 19–22 and 24 in November, December and January, respectively, in the 2003–2004 cropping season (Table 1), and the dry yield percentage of four lines/cultivars was 7–10 in September and October, 10–15 in November, 14–16 in December and 15–21 in January in the 2005–2007 cropping seasons (Fig. 3D, and calculated value from Fig. 4), indicating that water content in rhizome was lower in January than before November.

Yield differed with the cultivation year in all turmeric lines/cultivars probably due to differences in rainfall (Fig. 2) and soil nutrient status. Aki Ukon (AU), RDG, RD-11 and RD-44 gave a 216, 225, 189 and 203 g rhizome biomass (yield) per plant, respectively, at final harvest in 2005-2006 (data from Fig. 3C), and 157, 167, 159 and 138 g, respectively, in 2006–2007 (data from Fig. 4C). It is assumed that the heavier rainfall in June in the 2005-2006 cropping season was effective to increase turmeric shoot at an early stage, which subsequently resulted in a higher yield. The yield slightly varied with the line/cultivar (Figs. 3C, 4C). Similarly, Irikura et al. (1979) reported that root yield of cassava differed with the variety.

### 4. Yield-shoot ratio at different harvest times

The yield-shoot ratio of turmeric was 1.2 in November, 1.5–2.2 in December and 3.0 in January in the 2003–2004 (Table 1); it was 0.24–0.36 in September, 0.65–1.14 in November and 2.15–2.92 in January in the 2005–2006 (Fig. 3E); and the value was 0.26–0.38 in September, 0.37–0.49 in October, 0.55–0.68 in November, 0.85–1.04 in December and 1.25–1.63 in January in the 2006–2007 (data not presented). These results indicate that shoot biomass of turmeric was greater than rhizome biomass until November, but rhizome biomass was greater than shoot biomass in December and January. The results also indicate that rhizomes (yield) increase on a large scale from November to January.

Shape of rhizomes harvested in the green stage of turmeric shoot in December or earlier degraded greatly during the 60 d after harvest compared with the rhizomes harvested in January (data not presented). Rhizome-skin shrank markedly due to perhaps high moisture evaporation from rhizomes. It was assumed that skin of rhizomes harvested before December was immature and could not prevent moisture evaporation properly. This visual evaluation indicated that fresh rhizome quality is degraded when rhizomes are harvested in the green stage of shoots or before shoots are completely withered.
Conclusion

This study concluded that shoots of all turmeric lines/ cultivars remained green until November and turned yellow in December followed by withering in January in Okinawa, Japan. Shoot biomass of turmeric increased until November and decreased thereafter in Okinawa, which indicated that some photosynthetic products of shoots contributed to rhizome (yield). Fresh yield of turmeric was almost the same in November, December and January, but the dry yield was significantly increased with the delay of harvesting. Dry yield percentage and yield-shoot ratio varied markedly with the cultivation year and turmeric line/cultivar, but all lines tended to show a similar change with the harvest time. Fresh rhizome quality degraded when rhizomes were harvested before shoots withered completely. The overall results of this study indicate that turmeric produces the highest dry yield when shoots are withered completely, and it should be harvested in January in Okinawa, Japan.

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