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Effects of Planting Date on Emergence, Growth and Yield of Turmeric (*Curcuma longa* L.) in Okinawa Prefecture, Southern Japan

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Abstract The present study was conducted to evaluate the effects of the temperature and planting date (month) on the emergence, growth and yield of turmeric (*Curcuma longa* L.) plats in Okinawa Prefecture, Southern Japan. Turmeric rhizomes were planted on February 15, March 15, April 15, May 15 and June 15 as treatments for the planting date. Temperature range of 25-35 ℃ was optimum for the sprouting of turmeric rhizome-buds, and sprouting did not occur below 10 ℃ or above 40 ℃. Seedlings elongated well in the temperature range between 25 and 30 ℃, but could not survive at above 40 ℃. The emergence of the turmeric seedlings in the February, March and April plantings started at nearly the same time, and was completed within June. Shoots of turmeric plants differing in the planting month started to wither at the same time in November, and completely withered in January. Shoot dry weight and yield of turmeric plants were significantly higher in the February planting followed by the March and April plantings than in late planting in the glasshouse experiment, whereas in the field experiment the values of these two parameters were significantly higher in the April planting followed by the March and February plantings than in the late planting. The fields of the turmeric plants in the February and March plantings required additional weeding before emergence because winter and spring weeds emerged earlier and grew vigorously. The order of total weed dry weight was as follows: February planting> March planting >April planting >May planting >June planting. The emergence pattern, growth and yield of turmeric plants, and weed growth in the field experiment suggested that turmeric should be planted in April followed by March in Okinawa, Japan.
Key Words: Emergence pattern, Growth response to seasonal variation, Harvest time, Vegetative and reproductive period, Weed growth

沖縄県におけるウコンの植付時期が，出芽，生育および収量に及ぼす影響　石嶺行男・Md. Amzad HOSSAIN・本村恵二・赤嶺　光・平山琢二　琉球大学農学部　〒903-0213 沖縄県西原町字千原1番地

要　約　沖縄県におけるウコン（*Curcuma longa* L.）の植付時期（月）が，出芽，生育および収量に及ぼす影響を調査した．
その結果，10℃以下と40℃以上では発芽が見られず，最適な発芽温度は，25℃から35℃であった．幼植物の生育は，25℃から30℃が良く，40℃以上では枯死した．2月，3月および4月に植付けたウコン根茎はほぼ同じ時期に出芽し始め，6月末までには全て出芽した．沖縄地域では2月～6月と植付け時期を変えてもウコンの地上部は11月頃から黄化が始まり，1月には完全に枯死した．ウコンの地上乾物重と根茎重（収量）は，ガラス室内での実験においては，2月植付区が最も高く，3月，4月植付区の間に差はなかった．5月，6月植付区の収量は極めて低かった．一方，圃場試験区においては，4月植付区が有意に高く，次いで3月，2月植付区の順であった．しかしながら，2月と3月に植付けた区では，ウコンの出芽前に冬雑草および春雑草が繁茂し，除草作業が必要となった．更に雑草の乾物重は，2月植付区が最も高く，次いで3，4，5，6月の植付区の順であった．
以上の結果から，沖縄県におけるウコンの植付時期は，4月が最も適しており，次いで3月が良いことが示唆された．
キーワード　栄養生長および生殖生長時期，雑草の繁茂，収穫時期，出芽パターン，生長の季節的変動

Introduction

Research on the effect of climatic and edaphic factors on the emergence and growth patterns of a plant species over a year is very important to understand its seasonal distribution, cultivation technologies and management practices, which help substantially to control weeds and obtain a higher profit from the plant species (ANDERSON, 1998; AOI *et al.* 1988; AOI, 1992; BECKER *et al.* 1998; DEEN *et al.* 1998; Hossain, 1999; KATOVICH *et al.* 1998; RUSHING *et al.* 1998).

The value of turmeric (*Curcuma longa* L.), a rhizomatous perennial plant of the Zingiberaceae family, is ascribed to its aromatic, stimulant and carminative properties (HERMANN and MARTIN, 1991). It is mainly used as spice, cosmetic and medicine in Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand (HERMANN and MARTIN, 1991; HOSSAIN, 1999). Curcuminoids in turmeric have been found to display anti-inflammatory, antimutagen, anti-carcinogenic, antibacterial, antioxidant, antifungal, antiparasitic and detox properties (HERMANN and MARTIN, 1991; UECHI *et al.*

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2000). Curcumin, volatile oil and essential oil of turmeric prevent tumor formation, improve liver and kidney functions, and they could be used to alleviate biliary disorders, diabetic and hepatic disorders (HERMANN and MARTIN, 1991).

Turmeric is commercially cultivated on a large scale in the south western islands of Japan due to the prevailing subtropical climate (AKAMINE *et al.* 1994; HOSSAIN, 1999). Demand for turmeric is increasing year by year in Japan, while its production technology has not been fully developed. Farmers in Okinawa face many difficulties in weed management, fertilizer application and irrigation in turmeric fields, because of insufficient information about the emergence, growth patterns and yield of turmeric plants, and weed growth in relation to the planting date. Therefore, the present study was undertaken to evaluate the effects of the temperature and planting date (month) on the emergence, growth and yield of turmeric plants in relation to competition with weed growth in Okinawa.

Materials and Methods

Incubator experiment

Incubator experiment was conducted from April 5 to May 20, 1999. Turmeric (*C. longa*) seed-rhizomes used for all the experiments were collected when above-ground shoots had completely withered naturally (January), from the fields of the Subtropical Field Science Center, University of the Ryukyus, Japan. The sprouting of turmeric rhizome-buds was tested at the constant temperatures of 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50℃. Light (10 hr) and dark (14 hr) cycle was maintained in the incubators (Sanyo MIR-152) during the experiment. For each temperature treatment, 5 petri dishes (9-cm-diameter) were used. Each petri dish was lined with filter paper and 10 rhizome-cuttings (each 5 g) were placed on it. The petri dishes were covered with a transparent polyethylene bag and kept in the incubator by adjusting the respective temperature levels for 15 days. Distilled water was supplied every day to maintain an adequate moisture level for proper sprouting and seedling elongation.

Glasshouse experiment

A glasshouse experiment was conducted from February 10, 2001 to January 3, 2002 at the same Center of the University of the Ryukyus on a dark red soil (Shimajiri Maji, Chromic Luvisols). The soil contained 0.8% organic matter, 0.89% C, 0.11% N, 134 mg P per 100 g soil, and the pH was 6.08. Percentage (w/w) of clay, silt and sand was 66.3, 29.3 and 4.4, respectively, and the bulk density (g/cm^3) was 0.85. The concentration of exchangeable K, Ca, Mg and Na was 0.17, 10.8, 1.35 and 0.31 meq (milligram equivalent) per 100 g soil, respectively. Turmeric is widely cultivated on dark red soil in Okinawa (AKAMINE *et al.* 19994, 1995; HOSSAIN, 1999; ISHIMINE *et al.* 1999).

Turmeric rhizomes were planted in six pots (replications) on February 15, March 15, April 15, May 15 and June 15 as treatments for the planting date. One turmeric rhizome (30 g) was planted at 8 cm depth in each Wagner pot (size 0.05 m^2, 30 cm depth) containing 13 kg of air-dried soil. Water was applied once a day to maintain an adequate soil moisture. Chemical fertilizer (N: P_2O_5: K_2O = 16: 9: 9) at the rate of 4 g/pot was applied 3 times at 60-day intervals from the 2- to 3-leaf stage. Air temperature in the glasshouse ranged from 20 to 32 ℃.

Field experiment

Field experiment was conducted from February 8, 2001 to February 20, 2002 at the same Center of the University of the Ryukyus. The field left fallow in the previous year was plowed properly, and 4 m-long ridges, 150 cm apart, were prepared by making furrows for all the treatments at the same time. The soil type and treatment design in the field were the same as those described in the previous glasshouse experiment. Each treatment consisted of 4 replications (4 ridges) in the field experiment.

The weeds detected at planting time were removed manually from all the treatments. Twenty-eight turmeric rhizomes (each 30 g) were planted manually at 10 cm depth with 30 cm distance in two rows of each ridge. Chemical fertilizer (N: P_2O_5: K_2O = 16: 9: 9) at the rate of 370 kg/ ha was applied 3 times at 60-day intervals from the 2 - to 3-leaf stage. Overhead irrigation was provided as required. Hand-hoeing was performed on April 15, June 15, August 15 and October 15.

Procedures for data collection and statistical analysis

Number of sprouted rhizomes was counted every day when at least a newly emerged sprout protruded over 0.5 mm through the epidermis from a rhizome, and the counts were continued over a period of 15 days after incubation. Average length of available seedlings for each replication was measured 15 days after incubation. Physiological and morphological characteristics (color and survival rate) of the test rhizomes and seedlings were evaluated visually.

Soil temperature from the upper 15 cm layer in the field was recorded 3 times at 10-day intervals every month. Data on emergence were recorded when the seedlings (radicle) appeared above the soil surface at 10-day intervals from 20 DAP in the glasshouse, and at 15-day intervals from 30 DAP in the field experiment. The percentage (%) of emergence was calculated from 6 and 112 rhizomes in the glasshouse and the field experiment, respectively for each planting date. The emergence of the turmeric seedlings in the February, March, April and May plantings started in May-June, and more than 80% emergence occurred before June 30. Therefore, the data on the plant length, shoot number and leaf number were recorded at 15-day intervals from July 2, 2001 in the glasshouse, and at 30-day intervals from June 30, 2001 in the field (Fig. 5). These data were not recorded after the occurrence of a typhoon in September, 2001 for the field experiment due to the damage sustained by the plants. Weed dry weight was recorded at weeding time. Turmeric plants were harvested in January and February, 2002 in the glasshouse and the field experiment, respectively. Plant parts were oven-dried at 80 ℃ for 48 hr and weighed. Dry weight of weeds and turmeric plants (shoot and yield) per unit area (m^2) was calculated for the field experiment. Means and standard deviations (SD) of the samplings were determined through analysis of variance (ANOVA). Fisher's Protected LSD test at the 5% level of significance was used to compare the treatment means.

Results and Discussion

Sprouting and emergence of turmeric

Rhizome-buds of turmeric did not sprout below 10℃ or at above 40℃. Sprouting increased from 76 to 100% with the increase of the temperature from 15 to 25 ℃ and the rate was constantly high between 25 and 35 ℃, while thereafter, the sprouting rate rapidly decreased to almost 0% at 40 ℃ (Fig. 1). A second order polynomial equation adequately described the

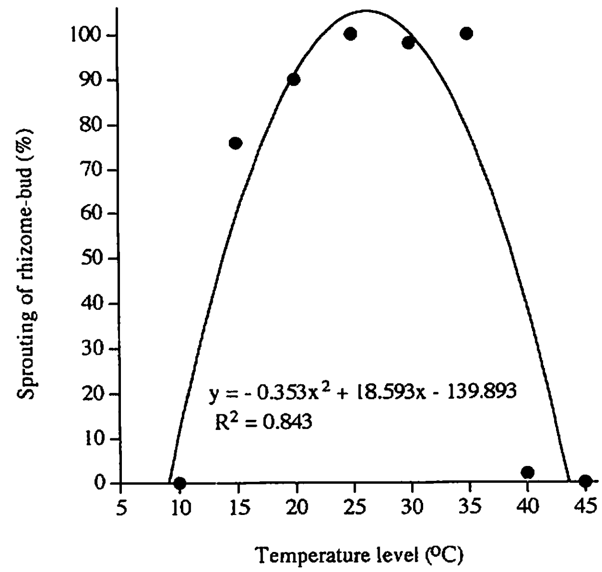

Fig. 1. Effect of temperature on sprouting of turmeric rhizome-buds. Data are means of 50 turmeric rhizomes for each temperature level.

relationship between rhizome-bud sprouting and temperature levels. Similar germination pattern was also observed in *Sorghum halepense, Cyperus rotundus, Gossypium hirsutum* and *Panicum repens* (HOLT and ORCUTT, 1996; HOSSAIN, 1999). About 50% of the rhizome-buds had sprouted within two days in the temperature range of 25-35 ℃, and the sprouting was delayed by lower temperatures (data not presented). The temperature range of 25-35℃ was presumably favorable for the physiological activity, protein synthesis, metabolism of storage reserves and enzyme synthesis in the turmeric rhizome-buds. This is consistent with the results obtained by AKANDA *et al.* (1996), who reported that the optimum range of temperature regulates seeds and propagules of plants for proper germination.

Seedling emergence from turmeric rhizomes was initiated at 100-105, 75-80, 40-50, 30-40 and 20-30 days after planting (DAP) in the February, March, April, May and June plantings, respectively in both the glasshouse and field experiments (Table 1). Turmeric seedlings in the February and March plantings required a longer time to complete emergence because the temperature was too low during this period, compared to those in the April, May and June plantings (Table 1, Fig. 2). In addition, dormancy of turmeric rhizomes harvested in January-February, was broken naturally in April-June, which probably resulted in faster emergence in the April, May

Table 1. Effect of planting date (month) on changes in the percentage (%) of seedling emergence from turmeric rhizomes grown in glasshouse and field experiments.

	Glasshouse experiment [a)]										Field experiment [b)]							
	Days after planting										Days after planting							
Planting date	20	30	40	50	60	70	80	90	100	110	30	45	60	75	90	105	120	135
February-15	n	n	n	n	n	n	n	n	33	100	n	n	n	n	n	68	91	100
March-15	n	n	n	n	n	n	80	100	100	100	n	n	n	84	96	100	100	100
April-15	n	n	n	33	83	100	100	100	100	100	n	91	97	100	100	100	100	100
May-15	n	n	17	83	100	100	100	100	100	100	84	100	100	100	100	100	100	100
June-15	50	100	100	100	100	100	100	100	100	100	50	100	100	100	100	100	100	100

a): % emergence was datermined from 6 rhizomes in each treatment (each planting date) in the glasshouse experiment.
b): % emergence was datermined from 112 rhizomes in each treatment in the field experiment.
n: emergence did ot occur.

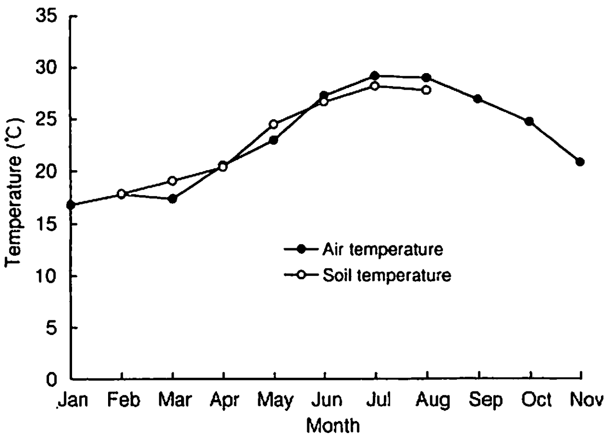

Fig. 2. Mean monthly air and soil temperatures in 2001. Air temperature recorded at the Subtropical Field Science Center, University of the Ryukyus. Soil temperature recorded from the upper 15 cm soil layer in the experimental field.

and June plantings than in the early planting (data not published). As turmeric rhizomes sprout well in the temperature range of 24-26 ℃, it is not necessary to plant these before April in Okinawa. A similar tendency in sugarcane bud sprouting was reported by Miah *et al.* (1988) in a tropical area.

Optimum environmental conditions such as light and moisture level in incubators led to the rapid sprouting of rhizome-buds compared to the conditions in glasshouse or field experiment. Soil covering was probably another factor for the delay and reduction in the sprouting rate of rhizome-buds in the glasshouse and field experiments, compared to the conditions in the incubator experiment (Holt and Orcutt, 1996; Hossain, 1999). In addition, after spouting, turmeric plants need about 5 to 20 days to develop culms, which was another reason for the delay in emergence in the pot and field experiments from 8-10 cm depth (data not published). It was assumed that the turmeric rhizome-buds planted in February, March and April maybe have sprouted at that time but the seedlings could not emerge, because the temperature was too low (17 to 20.5℃) for culm elongation which required a longer period of time.

Effect of planting month of turmeric on weed growth

First weeding in the fields with the February and March plantings was required before turmeric seedling emergence, because winter and spring weed species including *Amaranthus spinosus, Amaranthus viridis, Chenopodium album, Cyperus rotundus, Digitaria ciliaris, Digitaria timorensis, Oxalis corymbosa, Rottboellia exaltata, Solanum nigrum, Sonchus asper* and *Sonchus oleraceus* emerged earlier and grew vigorously. Weed dry weight in the field with the February planting was larger because of the presence of weeds over a longer period of time than in the March planting (Fig. 3). *Acalypha australis, Amaranthus spinosus, Amaranthus viridis, Bidens pilosa, Chenopodium album, Cyperus rotundus, Eleusine indica, Paspalum distichum, Rottboellia exaltata* and *Solanum nigrum* were detected at the weeding time on June 15. Weed dry weight at this time was similar to that in the fields with the February, March and April plantings because previous weeding was performed at the same time and turmeric growth was similar. However, these values were significantly larger because weeds had been present in the field over a

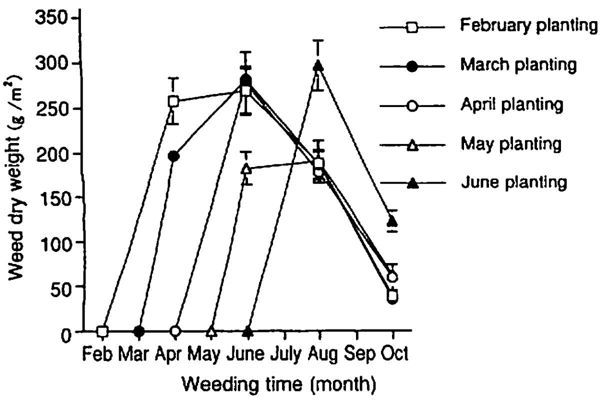

Fig. 3. Effect of planting month of turmeric rhizomes on weed growth at different weeding times. Data are means ± SD.

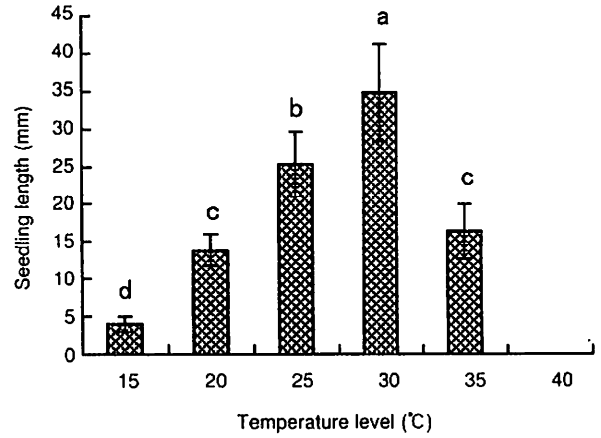

Fig. 4. Effect of temperature on the length of turmeric seedlings in an incubator. Data are means ± SD. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test.

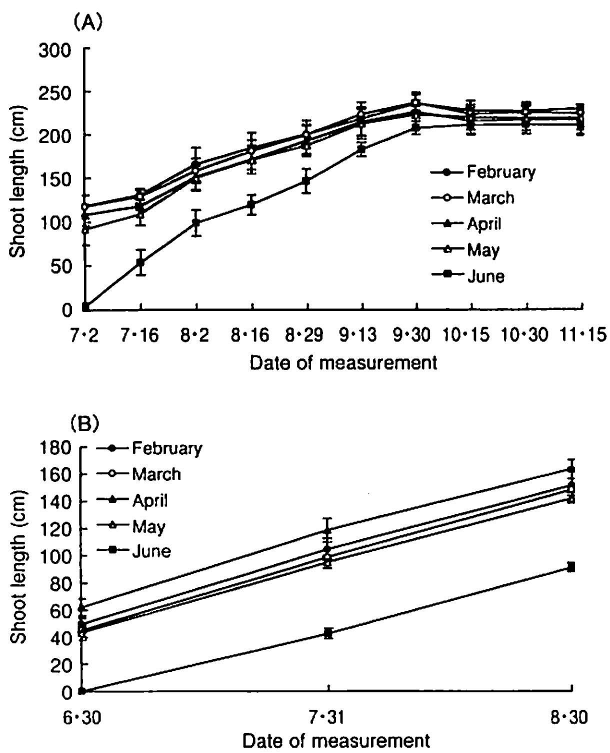

Fig. 5. Effect of planting month on shoot elongation of turmeric plants in the glasshouse (A) and field (B) experiments. Data are means ± SD.

longer period of time than in the field with the May planting. *Bidens pilosa, Eleusine indica, Mimosa indica* and *Panicum repens* were detected on August 15 and October 15. Weed dry weight at these times was significantly lower in the fields with February, March, April and May plantings because the full canopy structure of the turmeric plants suppressed weed growth, compared to the field with the June planting. These results indicated that the weed flora and weed dry weight somehow varied with the planting time and/or weeding time, which is consistent with the findings reported in several studies (Hossain, 1999; Ishimine *et al.* 2002). The order of total weed dry weight was February > March > April > May > June (Computed from Fig. 3)

Growth and yield of turmeric

The length of turmeric seedlings was significantly highest at 30 ℃, followed by 25 ℃, and the seedlings from the rhizome-buds that sprouted at 40 ℃ could not survive (Fig. 4). Turmeric seedlings in the February, March, April and May plantings showed a similar trend in shoot elongation in both glasshouse and field experiments because they emerged at almost the same time, and they developed significantly longer shoots than those in the June planting (Table 1, Fig. 5). The shoot length and shoot number (data not presented) of the turmeric plants increased rapidly in all the treatments until September because of the higher temperature (Fig. 2, 5) and thereafter, shoot growth remained constant until October. All the shoots started to wither at the same time in November, and they withered completely at the same time (January) because of the low temperature (16-19 ℃) from November to February. Similarly in other studies it was reported that the phenological development of the plant species is regulated by the specific temperature level and day length (Becker and Fawcett, 1998; Hardy *et al.* 1998; Rushing and Oliver, 1998). In the turmeric plants from the

June planting, shoot length and shoot number could not reach maximum values because the growth period was too short. Higher plant length, and higher number of shoots and leaves of turmeric plants resulted in an improved canopy structure in the field, which suppressed weed growth and received higher solar energy for photosynthetic processes that ultimately led to the increase of crop yield (BUAH *et al.* 2000; HOSSAIN, 1999).

Shoot dry weight of turmeric plants was significantly larger in the February planting, followed by the March, April and May plantings, compared to that in the June planting in the glasshouse experiment, whereas it was significantly larger in the April planting, followed by the March, February and May plantings in the field experiment (Fig. 6). Shoot dry weight in the field with the February planting was significantly lower due to weed infestation before turmeric seedling emergence, resulting in nutrient deficiency, compared to that in the April planting. Turmeric plants in the May and June plantings exhibited a lower shoot biomass because shoots were thinner and the shoot number was lower than that in the earlier plantings. Higher shoot dry weight usually contributes to a higher turmeric yield (AKAMINE *et al.* 1995; HOSSAIN *et al.* 2000).

Yield (rhizome) of turmeric was significantly higher in the February, March and April plantings because seedling emergence occurred earlier, shoots were larger and the rhizomes developed earlier than those in the late plantings in both the glasshouse and field experiments (Fig. 7). Turmeric plants in the February, March and April plantings showed a statistically similar yield because emergence was completed at nearly the same time, vegetative growth was nearly the same and the rhizomes started to develop at the same time. However, the order of the planting month based on yield was February > March > April > May > June in the glasshouse experiment, and April > March > February > May > June in the field experiment.

This study indicated that turmeric plants

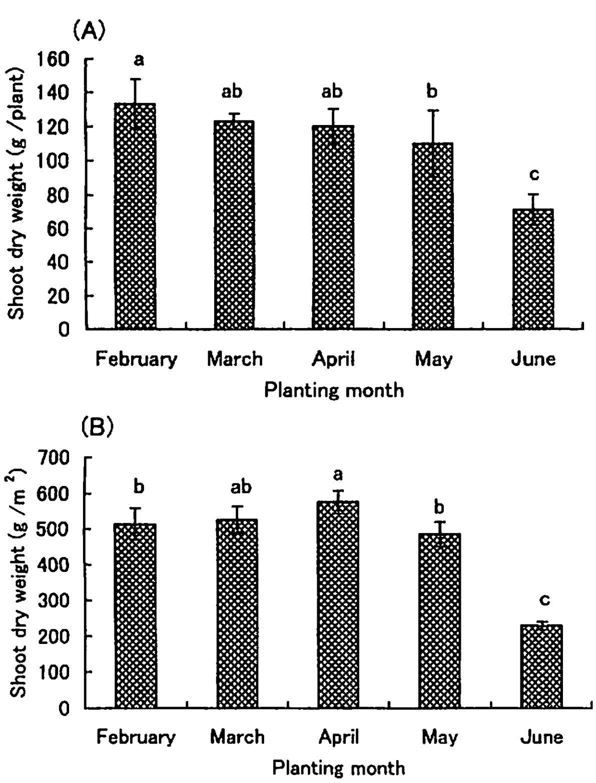

Fig. 6. Effect of planting month on shoot dry weight of turmeric plants in the glasshouse (A) and field (B) experiments. Data are means ± SD. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test.

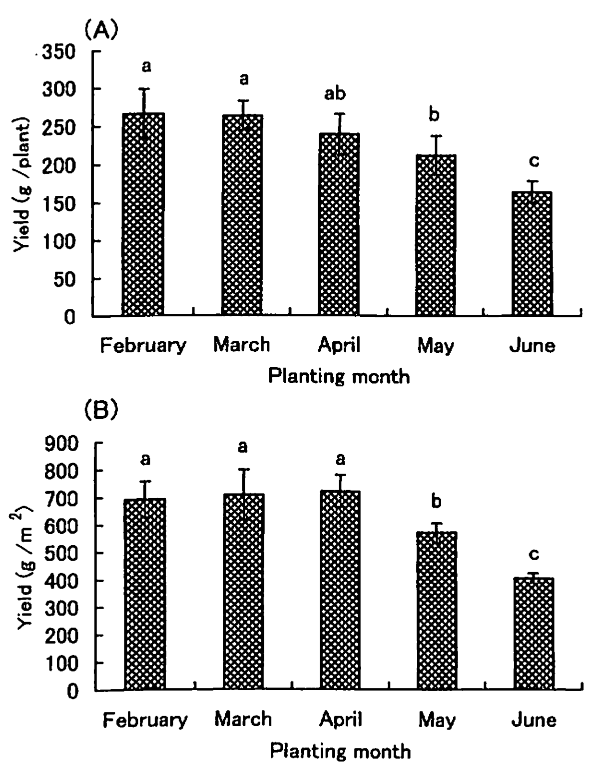

Fig. 7. Effect of planting month on yield of turmeric plants in the glasshouse (A) and field (B) experiments. Data are means ± SD. Bars with the same letter are not significantly different at the 5% level, as determined by LSD test.

require temperature range of 25-35 ℃ for proper rhizome-bud sprouting and 25-30 ℃ for seedling growth. An additional weeding was found to be necessary in the fields with the February and March plantings before the emergence of the turmeric seedlings. Emergence pattern, growth and yield of turmeric plants, as well as weed growth in the field experiment suggested that turmeric rhizomes should be planted in April, followed by March in Okinawa for higher profit.

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