

Growth, Yield and Quality of Turmeric (*Curcuma longa* L.) Cultivated on Dark-red Soil, Gray Soil and Red Soil in Okinawa, Japan

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Abstract : We evaluated growth, yield and quality of turmeric (*Curcuma longa* L.) cultivated in pots with dark-red soil (pH 5.2), gray soil (pH 7.4) and red soil (pH 4.4) in Okinawa, Japan. The soils were collected from the 50-cm deep layer of the fields. We did not use any chemicals or organic fertilizers. Turmeric cultivated on dark-red soil had the highest plant height, root biomass and shoot biomass as compared with that cultivated on other soil types. Turmeric on dark-red soil had the highest yield with favorable color of the deep yellow and high curcumin content (0.20%). Protein content of turmeric in dark-red soil was 5.2%, which was around 40% higher than that in other soil types. Turmeric cultivated on dark-red and gray soils had a fat content 71% higher than that in red soil. The content of Ca, K and Mg was the highest when turmeric was cultivated on gray soil, and Fe was the highest when cultivated on dark-red soil. To gain a high yield and high contents of curcumin, fat, protein and Fe, we should cultivate turmeric in dark-red soil in Okinawa. We could not recognize the specific soil factor(s) required for high yielding and high quality of turmeric; however, it seems that a proper combination of soil factors, nutrients and/or pH level may be necessary to gain a high yield and high quality.

Key words : Curcumin content, Fat content, Mineral content, Protein, Turmeric color.

Turmeric (*Curcuma longa* L.) is a popular spice in many countries of Asia (Hermann and Martine, 1991; Ishimine et al., 2003). It is now important in medical science because curcumin and volatile oils of turmeric rhizomes have anti-inflammatory, antimutagen, anticancer, antibacterial, anti-oxidant, antifungal, antiparasitic and detox properties (Hermann and Martine, 1991; Osawa et al., 1995; Sugiyama, 1996; Nakamura et al., 1998). These components also promote liver and kidney functions, and alleviate biliary disorders, diabetic and hepatic disorders (Hermann and Martin, 1991). Calcium, Mg, Fe, protein and fat are also considered to be important quality parameters of turmeric. Various supplements and drinks derived from the turmeric are widely being used for keeping good health (Hossain et al., 2005a, 2005b).

It is general that growth, yield and quality of a crop species vary with the soil type, and the kind and balance of available nutrients (Oya, 1972; Oya et al., 1977). A particular crop species grows well in a particular soil type with a balance of nutrients (Oya, 1972). *Curcuma longa* L. is the most valuable medicinal plant among the turmeric species. Consumers and manufacturing companies buy turmeric not consider where and in which soil it was cultivated, and what the content of medicinal components in it was. Research

on crop cultivation under the local climatic and edaphic factors is important to achieve a high yield with a high quality (Aoi et al., 1988; Akamine et al., 1995; Ishimine et al., 2003). Turmeric is commercially cultivated in Okinawa, Japan, which is mainly occupied by dark-red soil, gray soil and red soil (Akamine et al., 1994; Ishimine et al., 2003). In our previous studies, the effects of planting depth, time and pattern, and seed size of turmeric on yield and quality of turmeric were examined (Ishimine et al., 2003, 2004; Hossain et al., 2005a, 2005b). We conducted the present study to determine the effects of different soil types on growth, yield and quality of turmeric.

Materials and Methods

1. Analysis of physical and chemical properties of soil

Dark-red soil and gray soil were collected from the 50-cm deep layer of the fields of the Subtropical Field Science Center, University of the Ryukyus, Japan, and red soil was collected at the same depth in the field of Nago Agricultural Experiment Station, Okinawa. Soil physical properties were determined with a Köhn Type Soil Sedimentation Apparatus, soil pH in H₂O with a TOA pH meter HM-20S (Toa Electronic Ltd. Japan), and mineral contents of soils using Inductively Coupled Plasma Spectrometer (ICPS-2000, Shimadzu Co. Ltd.). Total carbon content was measured by

Table 1. Chemical and physical properties of dark-red soil, gray soil and red soil in Okinawa, Japan.

| Soil type | Na | K | Ca | Mg | Al | Fe | P | S | NO ₃ -N | NH ₄ -N | C | pH (H ₂ O) | Coarse sand | Fine sand | Silt | Clay | Apparent density |
|---------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|--------------------|--------------------|-------|-----------------------|-------------|-----------|--------|--------|--------------------|
| | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | µg g ⁻¹ soil | % | % | % | | % | % | % | % | g cm ⁻³ |
| Dark-red soil | 30.520 | 6.387 | 24.976 | 5.366 | 0.535 | 0.253 | 0.518 | 36.682 | 0.068 | 0.059 | 0.290 | 5.263 | 2.927 | 7.394 | 23.942 | 57.243 | 0.867 |
| Gray soil | 102.356 | 42.887 | 2604.153 | 279.301 | 5.422 | 0.158 | 4.597 | 2765.067 | 0.070 | 0.080 | 0.958 | 7.426 | 3.605 | 30.941 | 24.316 | 32.841 | 0.903 |
| Red soil | 55.903 | 10.316 | 15.840 | 4.149 | 0.414 | 0.257 | 0.756 | 15.002 | 0.048 | 0.051 | 0.211 | 4.433 | 16.919 | 20.437 | 26.622 | 30.918 | 0.924 |

Note: Data are means of 3 replications. Data were recorded on the dry weight basis.

using Shimadzu gas chromatograph (Soil GS-8A) and Sumigraph (NC-90A, Shimadzu). Nitrate nitrogen (NO₃-N) and ammonium nitrogen (NH₄-N) were calculated from nitrogen content, which measured according to Kjeldahl method. Apparent density of the dark-red soil, gray soil and red soil was measured on the dry weight basis. Table 1 shows the physical and chemical properties of soils.

2. Turmeric cultivation and data collection

The glasshouse experiment was conducted from April 20, 1999 to January 28, 2000. Wagner pots (0.05 m²) were filled with 10 kg of air-dried soil for each pot. One seed-rhizome (30 g) per pot was planted at the depth of 6 cm. Ten pots were used for each soil, and the pots were placed randomly. We did not apply any chemical or organic fertilizers to determine the actual effects of physical and chemical properties of soil on growth, yield and quality parameters of turmeric. Water was applied adequately everyday to maintain optimum soil moisture level for proper seedling emergence and plant growth.

Plant height and the number of tillers were recorded at 205 days after planting when main shoot completed leaf formation. Plants were harvested when shoots completely withered. Leaves, shoots, roots and rhizomes were collected, and the plant parts were oven-dried at 80 °C for 48 hr and weighed.

3. Analysis of turmeric compositions

Rhizomes were sliced and dried at 40 °C for 48 hours, and ground finely. Powders of 10 plants were mixed together for each soil treatment, and all the quality parameters were determined for three samples of each soil. Mineral contents of turmeric powder were detected with a Shimadzu AA-660, protein was calculated from nitrogen contents, which were measured according to the Kjeldahl method and total fat was extracted with a Soxhlet apparatus using diethylether. Protein factor 6.25 was used. Curcumin content was measured by HPLC (Shimadzu Co. Ltd.).

4. Data management and statistical analysis

Mean values were calculated for physical and chemical properties of soils and turmeric as shown in the Tables 1 and 3. Mean and standard deviation (SD) of 10 replications were determined using analysis of variance (ANOVA) for growth and yield parameters of turmeric, and Fisher's protected least significance difference (LSD) test at the 5% level of significance for comparison of the means.

Results

1. Growth and yield of turmeric

Turmeric plant height did not vary significantly with the soil type, but it was slightly higher in dark-red soil. The number of tillers and leaf biomass were

not statistically different with the soil type, but red soil produced the lowest tiller number and leaf biomass (Table 2). Root biomass of turmeric significantly varied with the soil type. Dark-red soil produced significantly highest root biomass of turmeric followed by gray soil (Table 2). Shoot biomass and yield were significantly higher when turmeric was cultivated on dark-red soil than in gray and red soils.

2. Quality parameters

Daughter rhizomes were bigger when turmeric was cultivated on dark-red soil than in the red or gray soil, although the rhizomes were same in size (data not presented). Color of turmeric powder was a favorable yellow when cultivated on dark-red soil followed by gray soil (Fig. 1). The curcumin content was the

highest (0.20%) in the turmeric cultivated on dark-red soil followed by gray soil (0.10%). Protein content of turmeric in dark-red was the highest (5.2%), which was 40% higher than that in other soil types (Table 3). Total fat content was 3.6% in the turmeric cultivated on dark-red and gray soil, and was 2.1% in red soil (Table 3).

Sodium content of turmeric was the highest when cultivated on red soil followed by gray soil, whereas K content was the highest when cultivated on gray soil followed by red soil (Table 3). The calcium content of turmeric in gray soil was the highest, which was 2 to 3 times greater than that in other soil types. Turmeric contained $6.3 \mu\text{g g}^{-1}$ Mg when planted in gray soil followed by red soil, whereas Fe content was the highest when cultivated on dark-red soil.

Table 2. Comparison of growth parameters and yield of turmeric cultivated on dark-red soil, gray soil and red soil.

| Soil type | Plant height (cm) | Number of tillers plant ⁻¹ | Leaf biomass (g plant ⁻¹) | Root biomass (g plant ⁻¹) | *Shoot biomass (g plant ⁻¹) | #Yield (g plant ⁻¹) |
|---------------|-------------------|---------------------------------------|---------------------------------------|---------------------------------------|---|---------------------------------|
| Dark-red soil | 127.8±6.6a | 2.2±0.4a | 11.2±1.2a | 12.1±1.2a | 33.8±4.3a | 39.5±3.2a |
| Gray soil | 121.4±6.0a | 2.2±0.4a | 11.2±1.5a | 7.0±0.5b | 28.6±2.0b | 27.5±2.5b |
| Red soil | 119.4±7.4a | 1.6±0.5a | 9.2±1.5a | 4.4±0.8c | 28.5±3.7b | 30.2±2.6b |

Note: Data are means ±SD of 10 replications. Data with the same letter within each column are not significantly different at the 5% level, as determined by Fisher's protected least significant difference (LSD) test. *, Total aboveground parts (pseudostem or stem plus leaf); # rhizome dry weight.

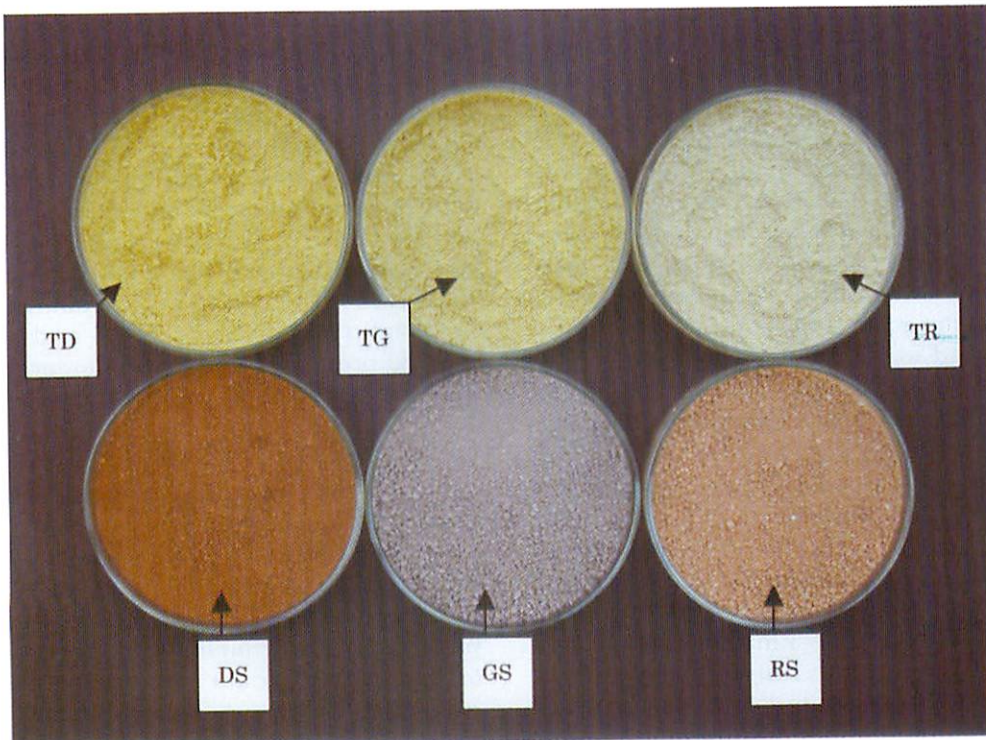


Fig. 1. Color of powder of turmeric cultivated on dark-red soil (DS), gray soil (GS) and red soil (RS) in Okinawa, Japan. TD, powder of turmeric cultivated on dark-red soil; TG, powder of turmeric cultivated on gray soil; TR, powder of turmeric cultivated on red soil.

Table 3. Quality parameters of powder of turmeric cultivated on dark-red soil, gray soil and red soil in Okinawa, Japan.

| Soil type | Na $\mu\text{g g}^{-1}$ powder | K $\mu\text{g g}^{-1}$ powder | Ca $\mu\text{g g}^{-1}$ powder | Mg $\mu\text{g g}^{-1}$ powder | Fe $\mu\text{g g}^{-1}$ powder | Protein % | Fat % | Ash % | Crude fiber % | Curcumin % |
|---------------|--------------------------------------|-------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------|----------|----------|------------------|---------------|
| Dark-red soil | 0.414 | 6.228 | 0.858 | 2.801 | 0.376 | 5.206 | 3.625 | 5.303 | 4.190 | 0.20 |
| Gray soil | 0.784 | 16.824 | 1.862 | 6.304 | 0.239 | 3.402 | 3.643 | 5.136 | 3.514 | 0.10 |
| Red soil | 1.289 | 10.096 | 0.512 | 4.209 | 0.156 | 3.363 | 2.149 | 4.020 | 3.505 | 0.06 |

Note: Data are means of 3 replications. Data were recorded on the dry weight basis.

Discussion

1. Growth and yield

It is difficult to explain the effects of individual or combined soil nutrient(s) on growth of turmeric plant in this study. Similarly, Oya (1972) reported that no general tendencies in the relationship between the plant growth and the concentrations of K, Ca and Mg were found in different soils. It is assumed that the lowest P and K contents, and the high $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ content of dark-red soil are comparatively good combinations, which resulted in higher vegetative growth (Table 2). Gray soil had higher/highest $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ contents, but did not produce a large shoot biomass like dark-red soil, indicating that there was an interaction among the nutrient contents, which influenced plant growth. Similarly, other studies (Mazid, 1993; McCrea et al., 2004; Hao and Papadopoulos, 2004) reported that unbalanced nutrient resulted in lower growth and yield of plants. Dark-red soil was comparatively loose (apparent density was the lowest (Table 1)) and it contained optimum moisture, which resulted in greater root and vegetative growth (Table 2). Similarly, Houlbrooke et al. (1997) reported that root biomass and shoot biomass of ryegrass (*Lolium perenne*) were increased by the lower soil bulk (apparent) density. The water-logging condition continued for some time in red and gray soils after water application, but it was not found in dark-red soil. In addition, red soil became compact when it dried, and gray soil remained wet for a longer time. Therefore, it is assumed that aeration and microbial activities were poor in red and gray soil, which probably caused in lower vegetative and reproductive growth of turmeric.

A large shoot biomass of turmeric on dark-red soil resulted in a higher yield, which is in agreement with the results of our previous studies (Ishimine et al., 2003; Hossain et al., 2005a). Rhizomes grew bigger in dark-red soil because this soil was comparatively loose. Turmeric shoots on dark-red soil remained green for a longer period, resulting in a longer period of photosynthesis and increased the yield (Table 2). Similarly, Zaman et al. (2001) reported that a longer period of photosynthesis was the key factor of higher rice-yield.

2. Quality parameters

The color of turmeric powder was the deepest yellow when cultivated on dark-red soil followed by gray soil (Fig. 1). We could not determine the specific elements required for preferable coloring of turmeric. However, a proper combination of minerals, nutrients and soil pH is required. The curcumin, protein and total fat contents of turmeric were highest when cultivated on dark-red soil, perhaps due to optimum mineral and soil pH levels.

Sodium content of turmeric was the highest when cultivated on red soil though this soil did not contain the largest amount of Na. Turmeric in gray soil had the highest K, Ca and Mg contents, because this soil contained the largest amount of K, Ca and Mg (Table 1 and 3). Iron (Fe) content of turmeric was the highest in dark-red soil followed by gray soil. We did not find any clear relationship between the mineral content in soil and that of turmeric powder. However, it is assumed that balanced fertilization (naturally existed in soil), soil pH and soil physiological properties were necessary for higher mineral content of turmeric. Other studies reported that yield and quality of crops are positively and/or negatively correlated with physical, chemical and nutrient properties of soil (Oya, 1972; Miyazawa et al., 2004). From the results/information of this study and other studies, it is assumed that a certain ratio of minerals, a balanced fertilization, a limited soil pH and a certain soil physical properties are required to increase yield and quality of a specific plant species.

Conclusions

The highest yield with favorable color and high curcumin content were achieved when turmeric was cultivated on dark-red soil. Protein and fat content of turmeric were about two times higher when cultivated on dark-red soil than other soil types. To achieve a high yield, and high curcumin, fat, protein and Fe contents of turmeric we should cultivate the plants on dark-red soil in Okinawa, Japan. It is assumed that a wide range of soil pH is probably favorable for turmeric cultivation. In addition, a certain combination of soil factors, nutrients and/or pH level may be necessary to increase the quality of turmeric, which should be examined in future experiments.

Acknowledgement

The authors would like to thank Associate Professor Yoshinobu Kawamitsu, Associate Professor Makoto Kitou, Professor Yasuhiro Kawamoto, Professor Fujiya Hongo, Mr. Kazutoshi Kinjo, Mr. Susumu Mizumachi and Ms. Kuniyoshi Megumi, Faculty of Agriculture, University of the Ryukyus, and Ryukyu Bio-resource Co. Ltd. for using their laboratories to determine soil chemical and physical properties, and quality parameters of turmeric.

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* In Japanese

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