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Studies on Matter Production of Edible Canna (*Canna edulis* Ker.)

II. Changes of dry matter production with growth*

Katsu IMAI, Takeo KAWANA**, Kiyoshi SHIMABE***, Keo INTABON**** and Kenichi TANAKA*****

*(Institute of Agriculture and Forestry ; ****Department of Research Development, University of Tsukuba, Tsukuba, Ibaraki 305, Japan)*

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Abstract : Edible canna was grown for three successive seasons from late April to early to mid-November under field conditions to clarify the basis of its productivity in the temperate climate of Japan. The growth of the aerial part of the plant was substantially accelerated by the hot weather from mid-July to late August, and the plant grew up to 2.7～2.8 m in height. It grew 20～22 leaves on its main stem, and 9～19 shoots with 29～35 newly formed rhizomes. Edible canna maintained a high leaf area index (LAI, ca. >9) for about 2 months from late August to early November with a maximum of 11.5～12.7. Accumulation of dry matter to newly formed rhizomes began in mid-August and continued until the final harvest in November, when frost damage occurred. The final dry weight of the whole plant was 2578～3968 gm^{-2} and that of rhizome was 954～1644 gm^{-2} so that the harvest index range was as low as 0.37～0.43. The mean crop growth rate (CGR) was 12.7～19.3 $gm^{-2} d^{-1}$ and interestingly, the maximum CGR (35.3～43.6 $gm^{-2} d^{-1}$) occurred from mid-September to early October in 2 of the 3 years. A tall stand of edible canna population has a high potential productivity based on its high LAI during the latter half of ontogenesis.

Key words : *Canna edulis* Ker., Crop growth rate, Dry matter production, Edible canna, Growth, Harvest index, Leaf area index, Net assimilation rate.

食用カンナの物質生産に関する研究　第2報　生育に伴う乾物生産の推移：今井勝・川名健雄**・島辺清志***・院多本華夫****・田中健一*****（筑波大学農林学系・****筑波大学研究協力部）

要　旨：日本の温帯気候下における食用カンナの生産力の基礎を明らかにしようとして3年間にわたって4月下旬から11月上•中旬に栽培を行った．植物体地上部の生長は7月中旬から8月下旬にかけての高温天候下で急激に促進され，最終的には草高2.7～2.8 m，主茎葉数20～22，茎数9～19，新根茎数29～35に達した．食用カンナは8月下旬から11月上旬にかけて2カ月余りも高い葉面積指数（約9以上，最大値は11.5～12.7）を維持し，これが乾物生産に大きく寄与しているものと考えられた．新たに形成された根茎への乾物の蓄積は8月中旬から始まり，降霜のあった11月の最終サンプリングまで継続した．収穫時の全乾物重は2578～3968 gm^{-2} あったが根茎乾物重は954～1644 gm^{-2} であったので，収穫指数は0.37～0.43と低かった．個体群生長速度の平均は12.7～19.3 $gm^{-2} d^{-1}$ であったが，9月中旬から10月上旬に最大値35.3～43.6 $gm^{-2} d^{-1}$ が得られた(3年の内2年で)．以上の結果に基づき，本作物の潜在生産力に関する論議を行った．

キーワード：*Canna edulis* Ker.，乾物生産，個体群生長速度，収穫指数，純同化率，食用カンナ，葉面積指数．

Edible canna (*Canna edulis* Ker., Cannaceae), which has been domesticated in the Peruvian Andes[2,16] probably from *Canna indica*, is a minor crop cultivated in widely scattered locations from temperate to tropical areas in the world without intensive selection or breeding[8,13,15]. Its rhizome contains about 20% starch and is utilized as a stock food and commercial source of starch[1,8,13,14]. Occasionally, its large aerial part, attaining up to 3 m hight with efficient production structure[5,14], is used for animal feeding such as cattle and pigs

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** Present address : Policy Planning Division, Ministry of Agriculture, Forestry and Fisheries, Chiyoda-ku, Tokyo 100.

*** Present address : Agricultural Management and Technology Division, Toyama Prefectural Office, Toyama 930.

***** Present address : Liaison and Coordination Division, Ministry of Agriculture, Forestry and Fisheries, Chiyoda-ku, Tokyo 100.

(D. Beech, personal communication).

Throughout the natural range of this species, wild plants grow on the edges of moist thickets and, as expected, cultivated plants also like moist soils[8,16]. Our previous study demonstrated that edible canna was a photosynthetically medium efficient, sun species tolerant to shading[4], which would permit cultivation under a broad range of light environments[1]. Normal growth occurs at temperatures above 9°C, although the plant tolerates brief periods of temperatures down to 0°C[13]. Light frost shrivels the leaves and concentrates starch in the rhizomes[13].

Irrespective of its high potential production (22~50 gm^{-2} of fresh rhizomes after 8~10 months' growth)[8,13], the physiological and/or environmental determinants on the growth and production processes of this species have not often been examined. In this study, we observed the ontogenetic changes of growth and dry matter production of edible canna during the three successive seasons under the field conditions of a temperate climate in Japan and analyzed the basis of productivity.

Materials and Methods

On latter halves of April in 1985, 1986 and 1987 the seed-rhizomes (ca. 200 g, which was practically, most appropriate fresh weight)[7] of edible canna (cv. Aokuki-kei; a triploid cultivar, 2n=27) were planted singly in 1.0 m rows (north-west to south-east) with the plants spaced 0.5 m in the row in a single plot of 20 m×20 m experimental field at the University of Tsukuba (140° 6' E, 36° 7' N). Chemical fertilizer was applied at a rate of 6 gm^{-2} each of N, P_2O_5 and K_2O three days before planting. Planting depth was 5 cm and the soil surface was covered with a clear polyethylene film until early July. This raised soil temperature at 5 cm depth by 0~7°C. Plants were grown under rain-fed conditions. We controlled weeds and insects by hand during the growth season and there was no fungal nor bacterial disease.

By 20 days after planting, half of plants emerged and by 30 days, more than 90% had emerged. After the plants developed several leaves in early June, sampling was started. It was performed 7 to 8 times until the frost damage of plants occurred in early to mid-November (Table 1).

In each sampling, five whole plants were harvested randomly, excluding two rows of border plants. Each plant was measured for its height, stem number, leaf number on main stem and number of rhizomes. After the measurement of the leaf area, plants were sorted into leaf blade, stem+leaf sheath, rhizome, root and dead leaf fractions and oven dried at 80°C for four days. Dried samples were cooled to room temperature in desiccators and weighed. The initial dry weight was obtained by sub-sampling of seed-rhizome at planting (28.8, 33.8, 30.4 g in 1985, 1986 and 1987).

From the data of leaf area and dry weight of plant, the mean values of plant growth parameters [crop growth rate (CGR), $gm^{-2} d^{-1}$; net assimilation rate (NAR), $gm^{-2} d^{-1}$; leaf area index (LAI), $m^2 m^{-2}$;] were calculated after Watson[17]:

Table 1. Planting and sampling dates*.

Year	Planting	Sampling							
		I	II	III	IV	V	VI	VII	VIII
1985	4/27	6/8 (42)	7/8 (72)	8/2 (97)	8/27 (122)	9/17 (143)	10/14 (170)	11/12 (199)	—
1986	4/20	6/7 (48)	7/2 (73)	7/22 (93)	8/6 (108)	8/25 (127)	9/14 (147)	10/12 (175)	11/9 (203)
1987	4/18	6/8 (51)	6/28 (71)	7/18 (91)	8/3 (107)	8/22 (126)	9/12 (147)	10/10 (175)	11/7 (203)

* Numerals in parentheses indicate days from planting.

$$\underset{[\text{CGR}]}{\frac{W_2-W_1}{t_2-t_1}}=\underset{[\text{NAR}]}{\frac{(W_2-W_1)\ (\ln L_2-\ln L_1)}{(t_2-t_1)\ (L_2-L_1)}}\times\underset{[\text{LAI}]}{\frac{L_2-L_1}{\ln L_2-\ln L_1}}$$

where W_1 and W_2 are the initial and final total dry weight, L_1 and L_2 the initial and final leaf area, and t_2-t_1 the length of the interval in days. As the planting density was 1 m×0.5 m, a single plant occupied a 0.5 m^{-2} ground area and so the basic values per m^2 were obtained by multiplying the leaf area or weight of a single plant by a factor of 2.

In 1989, a supplemental experiment was conducted to clarify the leaf growth of each nodal position on the main stem and the growth of the main stem. These attributes of five selected plants, which had average growth characteristics in the experimental field plot, were continuously recorded at the same time of day from May 15 to November 11 (planting : Apr. 18).

Meteorological data were obtained from the Environmental Research Center of the University of Tsukuba adjacent to our experimental field (Fig. 1).

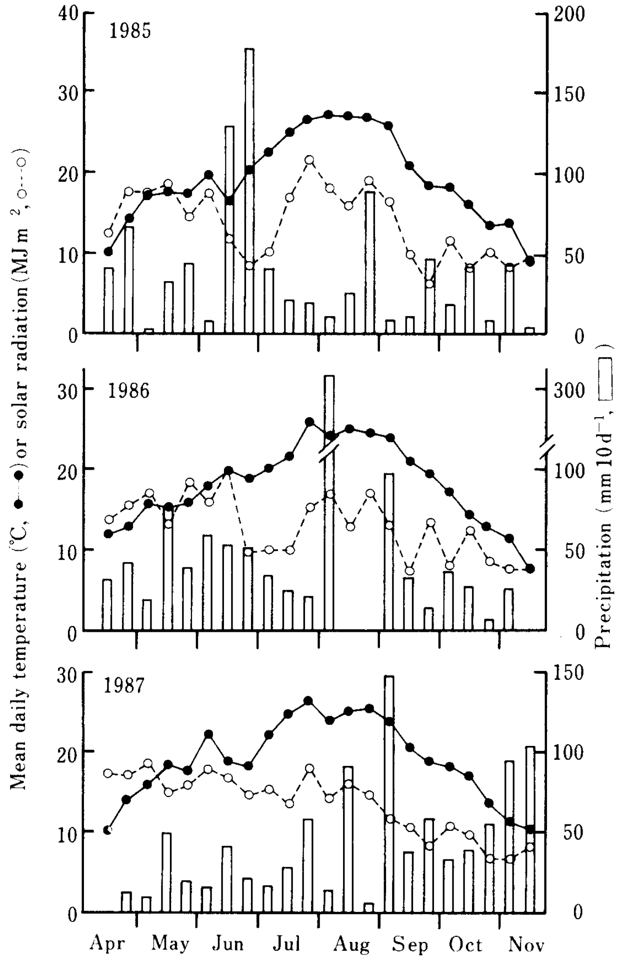

Fig. 1. Meteorological data during the growth of edible canna (1985～1987).

Results

1. Weather conditions

The 10-d averages of temperature, solar radiation and precipitation are shown in Fig. 1.

Daily mean, maximum and minimum temperatures (hourly mean) were 20.4, 27.3 (early Aug.) and 13.5 (late Oct.) °C in 1985, 19.0, 26.2 (late Jul.) and 11.6 (early Nov.) °C in 1986, and 19.9, 26.6 (late Jul.) and 11.2 (early Nov.) °C in 1987, respectively. The seasonal change of temperature similarly occurred during three years but the mean temperatures during July to August in 1986 and those of August to early September in 1987 were, respectively, 2～3°C lower than those in 1985.

Daily mean, maximum and minimum solar radiations (total shortwave radiation) were 14.03, 21.80 (late Jul.) and 8.25 (early Nov.) MJ m^{-2} in 1985, 13.24, 19.80 (middle Jun.) and 7.8 (early Nov.) MJ m^{-2} in 1986, and 13.65, 18.64 (early May), and 6.63 (early Nov.) MJ m^{-2} in 1987, respectively. Solar radiation from mid-July to mid-September in 1985 was higher, and that from late June to late July in 1986 went fairly lower than the other two years.

The precipitations during plant growth were 846, 965 and 847 mm, in 1985, 1986 and 1987, respectively. In 1985, there was 314 mm of rainfall in June and on August 30, a typhoon with rain fairly damaged the canopy structure. In 1986, it rained a lot (309 mm) during the first 10 days of August but in turn, there was no rain during the successive three weeks. In 1987, the main rainfall occurred during the latter half of plant growth. As a whole, weather conditions in 1987 were the best for plant growth.

2. Plant growth

Figure 2 shows the changes of plant height, stem and rhizome numbers with growth season.

From May to mid-July, plant growth was slow, probably because of low air-tempera-

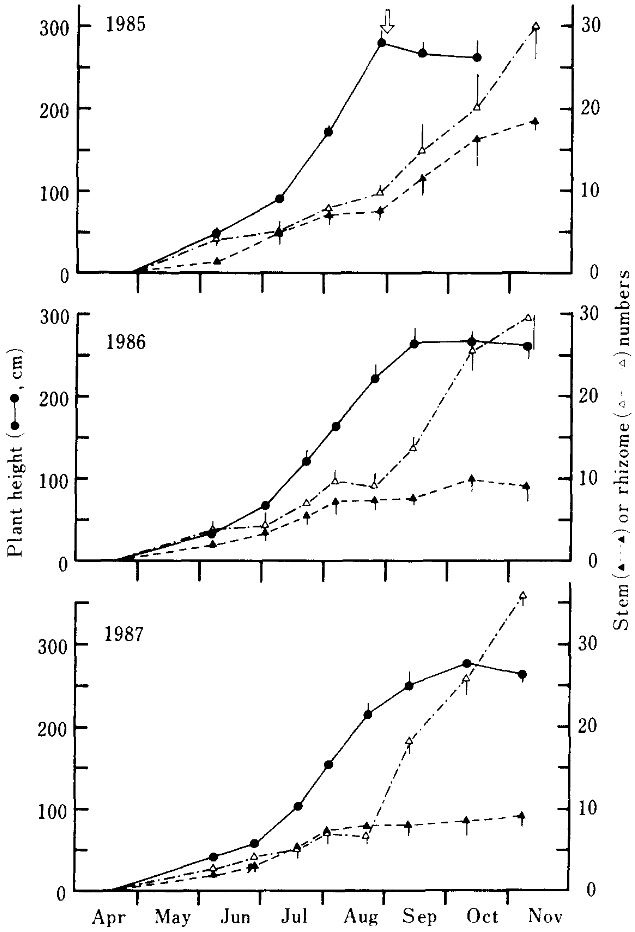

Fig. 2. Changes of plant height, stem and rhizome numbers with growth (1985 ~1987).
Arrow indicates the passage of a typhoon and vertical bars, 2×s.e.

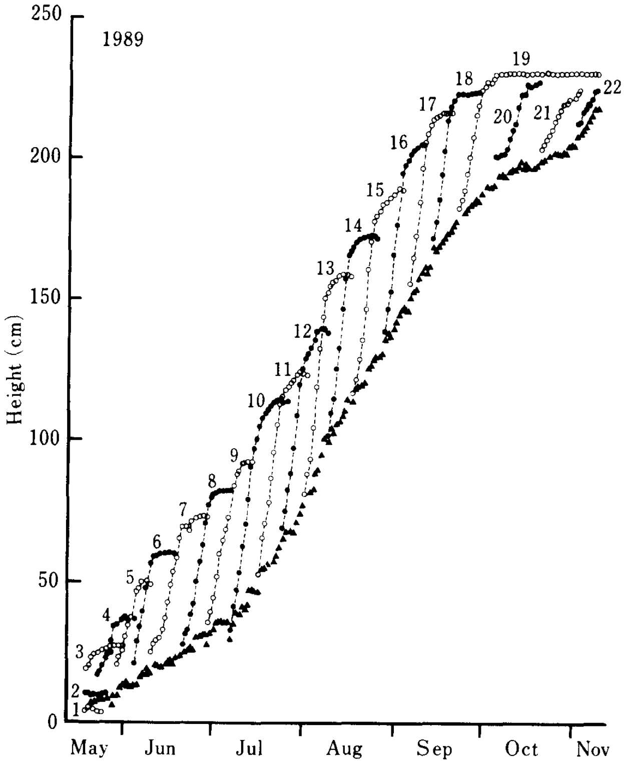

Fig. 3. Ontogenetic changes of plant leaf (●, ○) and stem (▲) lengths (1989).
Leaf positions on main stem are numbered from the bottom.
Leaf lengths are shown from the height of leaf appearance so that the tops of expanded leaves indicate plant length.

ture, irrespective of mulching. From the latter half of July, rapid growth occurred until early September. During that period, the aerial part developed extensively. In 1985, the stem number increased substantially from September through early November, the trigger being the passage of a typhoon on August 30. The final stem numbers were 18.6, 9.0 and 10.2 in 1985, 1986 and 1987, respectively. In general, the plant height increment stopped by early October when most plants had small, terminal leaves (20th~22nd leaves from the bottom, data partly shown in Fig. 3) on their main stems and some plants had flowers (racemes). The plant height attained up to 277, 268 and 278 cm in 1985, 1986 and 1987, respectively. The numbers of rhizome increased rapidly after entering to September and this continued until the last sampling. In 1986 and 1987, the increment of rhizome number seemed to be suspended during August when aerial parts developed very rapidly. The numbers of new rhizome at final sampling were 29.2, 28.6 and 35.3 in 1985, 1986 and 1987, respectively.

Figure 3 shows the changes of leaf growth, main stem growth and plant length of a representative plant in 1989. This year plant growth was worse than in previous years, probably due to decreased nutrient supply from the soil, and plant length (generally larger than plant height) was about 230 cm at the maximum. The measurement of leaf growth indicated that the curving changes in plant length consisted of the leaf growth from each nodal position on the main stem. Leaf growth progressed rapidly during the middle stage of ontogenesis, which was accompanied by rapid stem growth, and in October, a small terminal leaf was formed.

3. Dry matter accumulation

Figure 4 shows the ontogenetic changes of

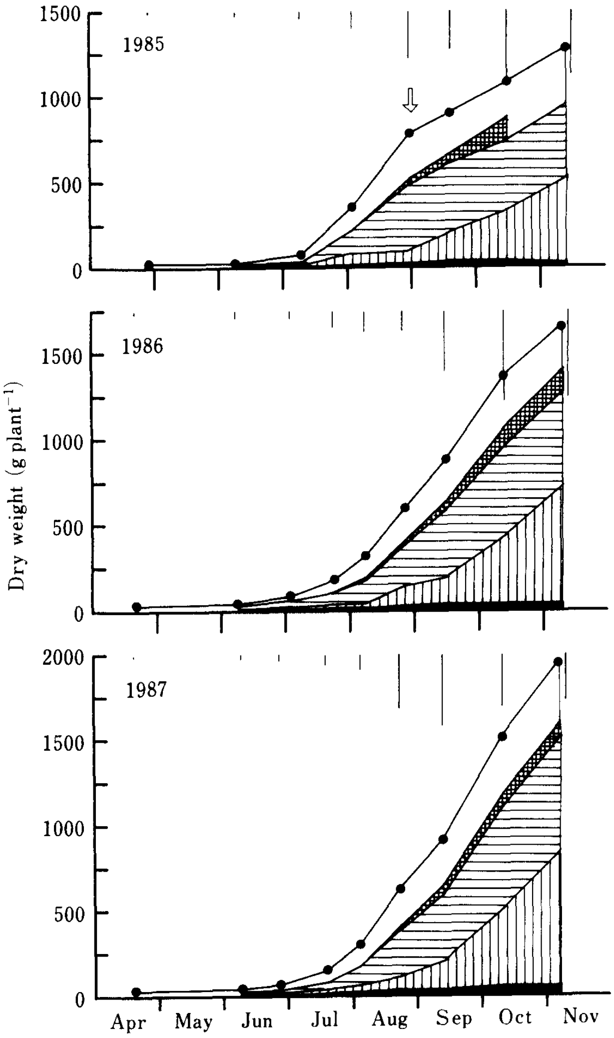

Fig. 4. Dry matter accumulation with growth (1985～1987).
●—● : Whole plant, ▭ : leaf blade, ▦ : dead leaf blade, ▤ : stem+leaf sheath, ▥ : rhizome, ■ : root.

Arrow indicates the passage of a typhoon and vertical bars, 2×s.e. for whole plant weight.

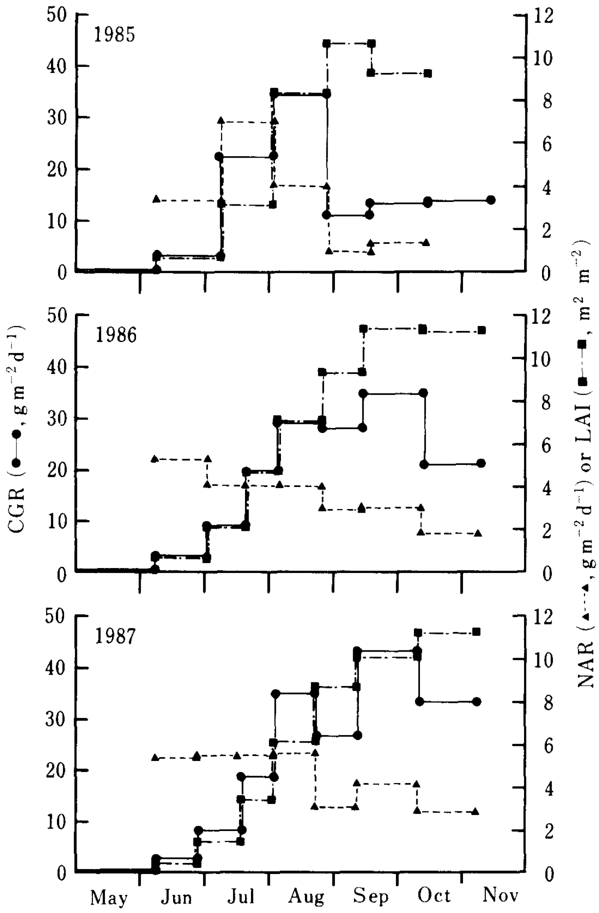

Fig. 5. Changes of mean crop growth rate (CGR), net assimilation rate (NAR) and leaf area index (LAI) with growth (1985～1987).

dry matter accumulation to plant organs. In 1985, the typhoon attack on August 30 clearly inhibited the dry weight increment after that time. Although this species was said to be warm climate-adapted[8,16], active accumulation of the whole plant dry matter continued until early November in all three years when the mean temperature declined to 11.2～14.2°C. The whole plant dry weights at final sampling were 1289, 1663 and 1984 g in 1985, 1986 and 1987, respectively. The leaf weight tended to increase until mid-September except in 1985, when dead leaf fraction increased rapidly. At the last sampling in 1985, we did not separate the leaf blade from the dead leaf blade fraction because it seemed to take too much time to identify whether the leaves were still alive or not. The stem fraction fundamentally attained its maximum weight by October. The mass of rhizome fraction increased rapidly from September and continued to increase until the last sampling in November, when plants suffered frost. The weight of rhizomes at final samplings were 477, 707 and 822 g in 1985, 1986 and 1987, respectively. The weight of root fraction increased until September and was sustained until the last sampling (33～54 g).

4. Growth analysis

The time course changes of mean CGR, NAR and LAI are shown in Fig. 5.

In general, the CGRs increased with time until mid-October, except in 1985, when typhoon damage occurred on August 30.

Table 2. Summary of the final dry weight, mean and maximum crop growth rate (CGR) and harvest index (H. I.).

Year	Growing days	Dry weight ($g\ m^{-2}$)	Mean CGR* ($g\ m^{-2}d^{-1}$)	Maximum CGR ($g\ m^{-2}d^{-1}$)	H. I.
1985	199	2578	12.66	34.10	0.37
1986	203	3325	16.05	35.28	0.43
1987	203	3968	19.25	43.55	0.41
Aver.	202	3290	15.99	37.64	0.40

* Initial weight of seed-rhizome is subtracted.

Average CGRs, which were obtained by dividing the total dry matter production by growing days, were 12.66, 16.05 and 19.25 $gm^{-2}\ d^{-1}$ in 1985, 1986 and 1987, respectively. The maximum CGRs, which were obtained in relatively short periods (25～28 days), were 34.10, 35.28 and 43.55 $gm^{-2}\ d^{-1}$ in 1985, 1986 and 1987, respectively (Table 2). It was reported that the NAR had a tendency to decline with plant growth under field conditions[17], mainly because of progressive mutual shading by the increased leaf area. In the case of edible canna, the NARs declined during the latter half of plant growth, but in the earlier half, in 1986 and 1987, the NARs were rather stable. The maximum NARs were 7.03, 5.37 and 5.64 $gm^{-2}\ d^{-1}$ in 1985, 1986 and 1987, respectively (Fig. 5). The LAIs increased at least up to mid-October in 1986 and 1987. In the case of this species, the maximum LAIs were calculated as 10.71, 11.52 and 11.40 in 1985, 1986 and 1987, respectively (Fig. 5). The actual, maximum values of LAIs at sampling in 1985, 1986 and 1987 were 11.50, 12.72 and 12.08, respectively (data not shown). Interestingly, the high values of LAI (ca. >9) were sustained for about two months during the latter growth stages.

Discussion

Dry matter production of edible canna successively increased throughout the season but the increase of plant height ceased before the end of season because of flower bud formation (Figs. 2～4).

By checking plants with terminal leaves, we found that the main stems of those plants had 20 to 22 leaves. But it was not the requirement for flower formation because we observed in a tropical area (Sabah, Malaysia : climate type ; tropical rain forest), edible canna had fewer leaves (ca. 12) for flowering (unpublished). At present it is not known whether day length or temperature or both induce flower formation of this species.

The maximum plant heights (2.7～2.8 m) were obtained before the final samplings in November. Toward late autumn, the heights tended to decrease because of heavy aerial weight and shallow allocation of stock in the soil. In studies in the Republic of China, a similar plant height was observed only under fertile soil conditions[11]. Our plants studied in 1989 (ca. 2.3 m of length) might reflect the poor soil conditions induced by active nutrient absorption to support a large plant body despite the application of the same dose of chemical fertilizer every year (Fig. 3). Recently, we found that edible canna vigorously absorbed nutrients from the soil[6] and was not a "low nutrient-requiring" crop as cited by Koyama[8].

At the fixed planting space (0.5 m × 1.0 m), plants had about 10 stems in 1986 and 1987 but when the aerial part was disturbed, as in 1985, the appearance of a new stem did not stop and also new, smaller rhizomes were formed. As the shoot and rhizome developed from the same origin, i.e. an underground growing point like the aerial lateral bud, these phenomena would reflect an easy breaking of apical dominance, or the rhizome formed did not rest if suitable conditions for growth continued. We observed in Sabah that the same cultivar as in the present studies had flowers on all of 12～13 primary and secondary stems and small, tertiary stems appeared but no swollen rhizomes at three months after planting (unpublished). We suspect that to get a good rhizome yield, the growth activity of edible canna should be suspended by low temperature[13] or by a dry season[14] at the final stage of ontogenesis.

Under field conditions at the University of Tsukuba, we found that as a whole, it was not sufficient to complete the ontogenetic change of edible canna. Aerial growth progressed fairly sufficiently throughout the season but the rhizome growth did sustain at the final sampling in early to mid-November, when frost damage occurred on the aerial plant part. The final rhizome weights in 1985, 1986 and 1987 were 477, 707 and 822 g, respectively. These values are equivalent to 954, 1414 and 1644 gm^{-2}, or 9.54, 14.14 and 16.44 t ha^{-1}, respectively. If there was delayed frost or no frost, further production and translocation of photoassimilate occurred, and the accumulation of dry matter to rhizome progressed substantially toward higher H.I. The H.I. obtained in 3 years was low and ranged 0.37 ~0.41 (Table 2), though Oka et al.[14] reported about 0.5 in Thailand (more than 300 days after planting). When we use this species only as the "tuber and root crops" for food or starch source, amelioration of H.I. through breeding and/or cultural practice is needed. If we use its large aerial part for animal feeding, edible canna could be a potent source judging from its mass and nutrient composition[6]. Therefore, an alternative use such as that of forage crop for green fodder and silage should be examined extensively.

Finally, whole plant dry weights in 1985, 1986 and 1987 were 1289, 1663 and 1984 g, respectively (Table 2). These values are equivalent to 2578, 3326 and 3968 gm^{-2}, or 25.78, 33.26 and 39.68 t ha^{-1}, respectively. The highest dry matter production obtained in 1987 was the reflection of the best weather conditions during the 3 seasons. The net production of edible canna (3228 gm^{-2} in 3 year's avarage) can be ranked on a higher position among C_3 species when compared with high values cited by Murata[12] (sugar-beet, cassava, oil palm, rubber, alfalfa, potato, sweet potato, rice, oats, groundnut and barley ; 4240, 4100, 4000, 3600, 2970, 2200, 2050, 2000, 1850, 1550 and 1530 gm^{-2} y^{-1}, respectively). If this species meets warmer climatic conditions than those in Tsukuba under intensive cultivation practice, we can speculate that close to or more than 5000 gm^{-2} of total dry matter production with higher H.I. will be achieved, because in the Republic of China[11] and in Thailand[14], edible canna is grown for more than 300 days (cf., ca. 200 days in Tsukuba). Examinations by combining planting density with fertilization may, also, be worthwhile to assess potential productivity of this crop.

The growth analysis data indicated that 3-year averages of the maximum (short-term) and mean (long-term) CGR were 37.64 and 15.99 gm^{-2} d^{-1} (Table 2). These occupy substantially high rankings among the high records of C_3 crops obtained so far[3,12]. The basis of high CGR is due mainly to the maintenance of high LAI for a long period (ca. <9 for two months) rather than to NAR. This is coupled with high tolerance of leaves to shading[4] and good light penetration into tall stand[5,14] having upright leaves such as corn[10]. The LAI up to 10 showed a positive correlation with CGR in our 3-year experiments when we omit data obtained after the typhoon in 1985 and the last in 1986, which showed a drastic decline of CGR relative to LAI [Y (CGR) $=4.89+3.303$X(LAI), $R^2=0.83$]. But the NAR would also contribute to dry matter production because in 1985, a drastic decline of NAR was accompanied by a drastic decline of CGR under sufficiently high LAI, for example (Fig. 5). The NAR was rather steady during the period when LAI was 2 to 6. This may indicate both NAR and LAI are important for dry matter production during this growth stage. Further analysis of the relative contribution of NAR and LAI to edible canna production should be done.

Once again, a tall stand of edible canna population has a high production potential based on its high LAI during the latter half of ontogenesis.

The analyses of the 1) production structure, 2) relationships among dry matter accumulation, temperature, solar energy and rain fall, and 3) nutrient absorption in the edible canna population will be demonstrated in successive papers.

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