Jpn. J. Crop Sci. 63(2): 345—351 (1994)

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

III. Changes of production structure with growth*

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Received October 31, 1993)

Abstract: Edible canna is a highly productive crop in temperate to tropical regions. To clarify ontogenetic changes of structure which contribute to its high yield capacity, edible canna was grown from late April to mid-November in 1-m rows with spacing of 0.5 m between plants in the row at the experimental field of the University of Tsukuba. During the growth period, light transmittance into the canopy was measured and the aerial allocatons of dry weight and leaf area were determined by stratified clipping. The plants reached maximum height by mid-September, at which time the leaf area index (LAI) exceeded 10 and reached a maximun of 11.2 before declining as the plant matured. The light extinction coefficient (K) changed from 1.34 (typical of broad-leaf plants) in early growth to 0.4-0.5 (typical of grasses) in the latter growth stages. This indicated that in the early growth, this crop developed planophyll leaves which maximized light interception under low LAI but with growth, the upper leaves became more upright, which enabled light to penetrate deep into the tall canopy. The initiation of shoots and the azimuth angles of leaves as the plants grew appeared to be such that light interception by the crop canopy was maximized.
Key words: *Canna edulis* Ker., Dry matter production, Edible canna, Growth, Leaf area, Leaf inclination, Light extinction coefficient, Production structure.

食用カンナの物質生産に関する研究 第3報 生育に伴う生産構造の推移：今井 勝・島辺清志・田中健一・川名健雄（筑波大学農林学系）

要 旨：食用カンナは温・熱帯地域における生産力の高い作物の一つである．その高生産力の基礎として，生産構造の個体発生に伴う変化を明らかにするために畦間1m，株間0.5mとして4月下旬から11月中旬まで筑波大学の実験圃場で食用カンナを栽培した．その間，個体群各層における光の分布を測定すると共に，層別刈り取りを行って，葉面積および植物体地上部の乾物の分布を調べた．食用カンナの草高は9月中旬に最大値を示した後，生育後期までほぼ同じ高さを保った．葉面積指数は同時期までに10を越え，11.2の最大値を示した後，植物体の成熟に伴って漸減した．群落の吸光係数は，生育の初期に広葉型の1.34であったが，生育の後期には0.4—0.5とイネ科型の値へと変化した．それは，食用カンナが生育初期の葉面積指数が小さい時には太陽光を有効に利用するため，水平葉を展開し，個体発生に伴って草高と葉面積指数が大きくなると，次第に直立的な葉を形成するためであった．また，植物の生育に伴って発生する茎の位置および葉の方位角分布は，葉群が光を最大限に受容するためのものと考えられた．
キーワード：*Canna edulis* Ker.，乾物生産，吸光係数，食用カンナ，生産構造，生長，葉身角度，葉面積．

Edible canna has been reported to have a high yield potential (2,200—5,000 gm^{-2} of fresh rhizomes after 8—10 months' growth)[9,11] but there are few reports related to analysis of its productivity[3,4,5,12].

In a previous paper[4], we reported that each edible canna seed-rhizome of ca. 200 g FW produced 9—19 shoots $plant^{-1}$ (2.7—2.8 m plant height) and 29—35 rhizomes $plant^{-1}$, with an average whole plant biomass of 2,600—4,000 g DW m^{-2}. However, it had a low harvest index (0.37—0.43) when cultivated in the temperate climate of Tsukuba City, Japan,

*Supported by a Grant-in-Aid for Scientific Research (No. 62480035) from the Ministry of Education, Science and Culture, Japan to K.I. Part of this work was presented at the 186th meeting of the Crop Science Society of Japan held on October 4, 1988.

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because of incomplete ontogenesis due to the frost damage in late autumn. Such high dry matter production was brought about by a high crop growth rate (mean : 12.7—19.2 g $m^{-2}d^{-1}$, maximum : 35.3—43.5 g $m^{-2}d^{-1}$) which was mainly attributed to high leaf area index (>9 for about 2 months) during the latter growth stages.

To clarify the productivity of edible canna further, we examined its production structure by a stratified clipping method, and by the observations of leaf development and orientation. We also examined the azimuth angle of leaves during canopy development.

Materials and Methods

On the latter halves of April in 1985 and 1986, the seed-rhizomes of edible canna (cv. Aokuki-kei) weighing about 200 g FW were planted singly in 1.0 m, north-west to south east rows, with the plants spaced 0.5 m in the row in a single plot of 20×20 m experimental fields of the University to Tsukuba. Chemical fertilizer was applied at a rate of 6 g m^{-2} each of N, P_2O_5 and K_2O three days before planting. The cultivation procedure and growth conditions of plants were described in our previous paper[4].

In early June, when plants developed several leaves, the measurement of the structure of the crop canopy was initiated, and the last samples were taken in early to mid-November. Five randomly selected plants were harvested on each sampling date. In the afternoon one day before sampling or the early morning of the sampling day, the light intensity at 10 cm or 20 cm horizontal strata was measured by an illuminometer (Toshiba, Model 5). The light extinction coefficient (K) was calculated after Monsi and Saeki[10] by regressing the light transmittance through the cummulative leaf area of the canopy. On the day of sampling, we made the stratified clipping of the selected plants at the same level of light measurements. The harvested plant parts were separated into leaf blade, stem+leaf sheath, and dead leaf blade fractions. Leaf area was measured with an automatic area meter (Hayashi-denko, Model AAM-7). After oven drying at 80°C for four days, plant materials were placed in desiccators to cool and weighed. We examined the canopy structure four times in 1985 and eight times in 1986. Because of similar figures in both years, we showed those obtained in 1986.

In 1989, a supplemental experiment was performed to clarify the leaf and shoot distribution as components of the production structure of edible canna. For this, five plants were selected under the same cultivation procedure as in 1985 and 1986. The weather conditions in 1989 were similar to those in 1986. In this experiment, leaf area was estimated *in situ* by measuring the length and width of every leaf blade and calculating leaf area as 0.704×leaf length×leaf width ($r=0.984$)[8]. The leaf inclination was measured with a clinometer by reading an angle between the stem and the central portion of a leaf. The azimuth angle of leaves (0—360°) were measured clockwise with a compass by setting the North as 0°. The leaf area distribution function[7,16] was obtained by dividing the leaf area located in each 45° azimuth section around the maternal shoot by the total leaf area of a plant. On November 11, all shoots were cut at 10 cm at the ground level and the azimuth angle and distance of the daughter shoots from the maternal shoot were measured. The underground parts were dug out and the location of rhizomes recorded.

Results

1. Dry matter and leaf area allocations in the canopy

Figure 1 shows the ontogenetic change of production structure of the edible canna population on the eight sample dates, June 7 to November 9, obtained by the stratified clip method. The nonassimilatory organs (stem+leaf sheath, flower ; g m^{-2}) are given at the right and the assimilatory organs (leaf blade ; g m^{-2}) in the central position of each graph. The dead leaf blade fraction was put in the leaf blade fraction because its role in light interception in the crop canopy appeared to be similar to that of the green leaf blade. Also the central part of figures, the relative light intensity was plotted from the top of canopy (100% light) to the ground level. The leaf area index (LAI, m^2m^{-2}) and the light extinction coefficient (K) are expressed in the right part of figures. The vertical distribution of LAI in the canopy is shown at the left in the graphs.

As we reported earlier[4], the plant height

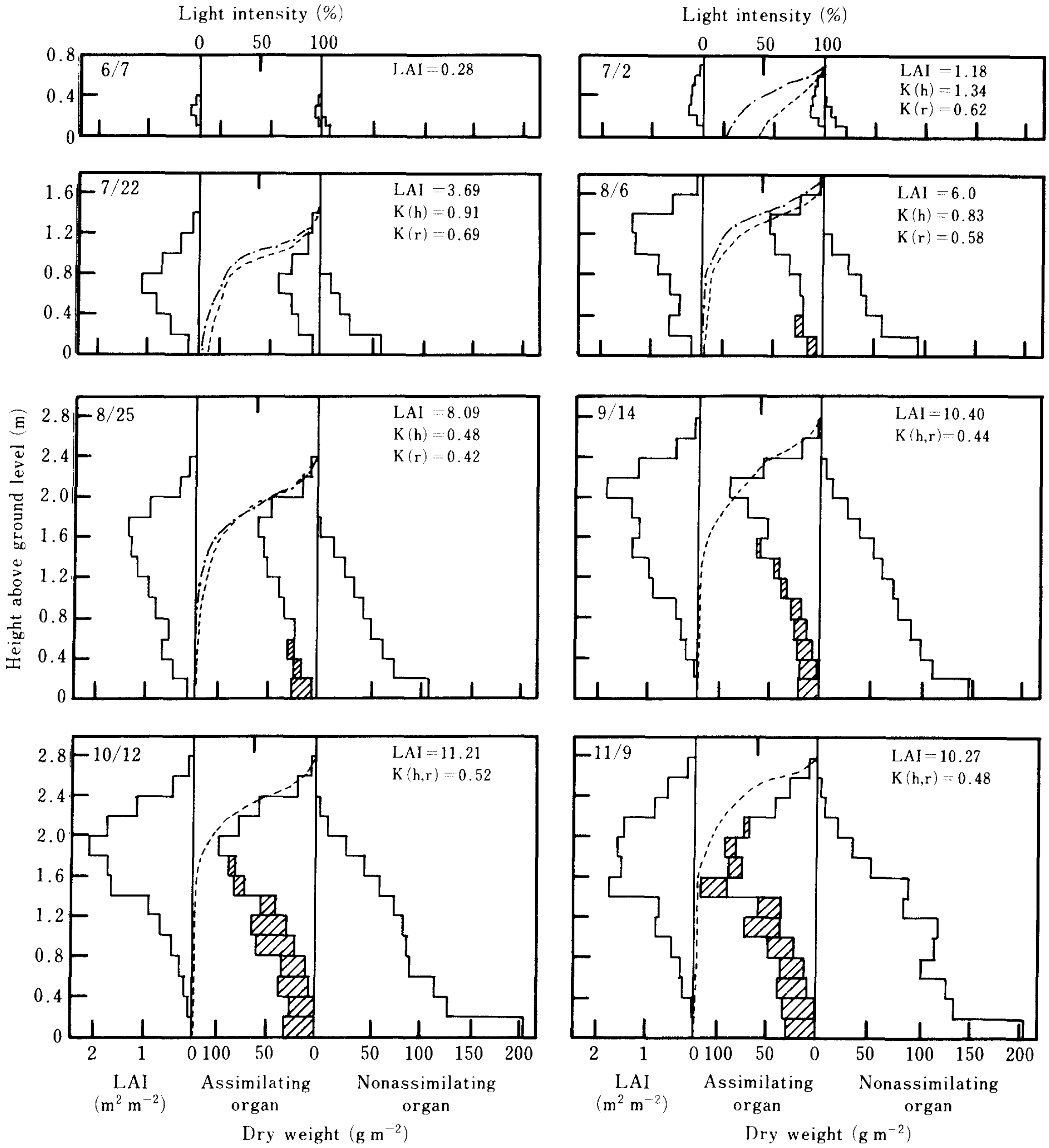

Fig. 1. Ontogenetic changes of production structure in edibele canna (1986).
K (h), K (r) : Light extinction coefficients measured between hills and rows, respectively.
— — —, — • — : Relative light intensities measured between hills and rows, respectively.
▨ : Dead leaf blade.

attained 2.65 m on September 14. The LAI increased with growth and exceeded 10 after September 14. The maximum LAI (11.21) was obtained on October 12.

The spatial distributions of assimilatory organs (leaf blades), which were expressed as LAI and leaf dry weight, changed with growth : the position of maximum distribution was located in the middle or lower layers during the early growth stages (June 7 to July 22), but as growth proceeded (August 6 to November 9), the position of maximum leaf area density shifted to the upper layers. The distribution of leaf area corresponded with green-leaf dry weight throughout the growth period.

Senescent leaves were found from August 6 onward, and leaf senescence moved gradually up the stem. It appeared that leaves senesced whenever 95% of the light was absorbed in layers above the leaf.

As the edible canna had thick and heavy

stems, the nonassimilatory organ was a large fraction of aerial plant dry weight and its proportion increased in time, especially after October 12, when substantial dying of leaves occurred as the maximum leaf area density shifted to near the top of the canopy and little light penetration to lower leaves.

2. Light transmittnace into canopy

In the early growth stages of edible canna, much solar radiation reached the ground level because the LAI was small. During the growth, both the leaf fraction and later the stem+leaf sheath fraction increased. The light which reached the soil level decreased with plant growth and after September 14, the relative light intensity at the ground level became less than 1% of the top of canopy (Fig. 1).

The K value was the greatest on July 2 (between rows : 1.34, between hills : 0.62) and thereafter decreased ; by August 25 it was 0.42 between rows and 0.48 between hills. The difference of light transmittance between rows and hills diminished with plant growth and practicallay disappeared by September 14 (Fig. 1).

3. Ontogenetic changes in length and width of leaves

Fig. 2 shows the ontogenetic changes of leaf length, width and the width/length ratio on the maternal shoot.

Leaf 8 to 15 exceeded 50 cm length and 20 cm width. Leaves above the 8th position had thick midribs and were rigid (data not shown). The ratio of leaf width to leaf length was high (ca. 0.8) at the initial growth stage but with ontogenesis, the ratio gradually declined to about 0.5—0.6 for the 21th leaf. The terminal leaf (22th) tended to be rounded and its width/length ratio was about 0.9.

4. Leaf inclination and azimuth with growth

Fig. 3 shows the leaf inclinations of upper three leaves on maternal shoot and a primary lateral shoot. In early stage of plant development, leaves had large inclinations (i.e. horizontal leaf) and with growth progressed, their inclination declined (i.e. toward erect leaf) and finally, in the late autumun, they increased again. There were similar tendencies in leaves on both maternal and lateral shoots. Generally, the uppermost leaves had the smallest inclinations. The diurnal change of leaf inclination was very small (<10°, data not shown).

Fig. 4 shows the leaf area distribution around a hill in terms of azimuth angle. In early growth stages, the leaf canopy developed toward the space between the row. After July 25, however, leaves developed towards vacant spaces and by September 17, there was no azimuthal preference in leaf orientation.

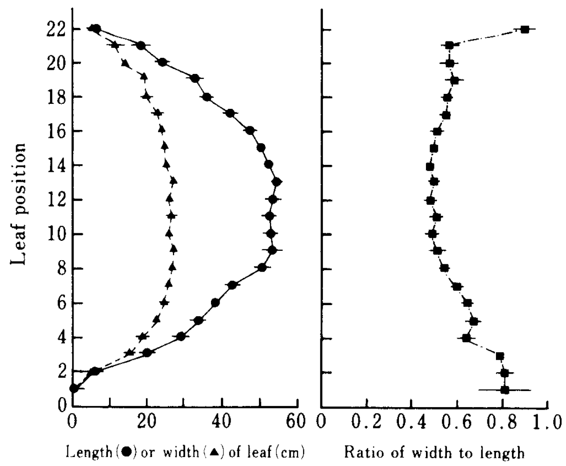

Fig. 2. Ontogenetic changes in length and width of leaf blades developed on maternal shoot, and their ratios (1989). Horizontal bars indicate 2×S.E.

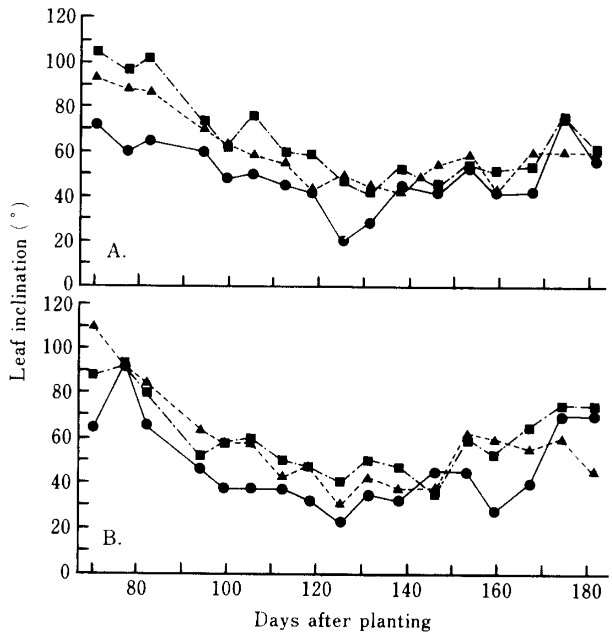

Fig. 3. Ontogenetic changes of inclination in upper three leaves of a canopy (1989). A : Maternal shoot, B : primary lateral shoot.
● : Uppermost leaf, ▲ : 2nd leaf, ■ : 3rd leaf.

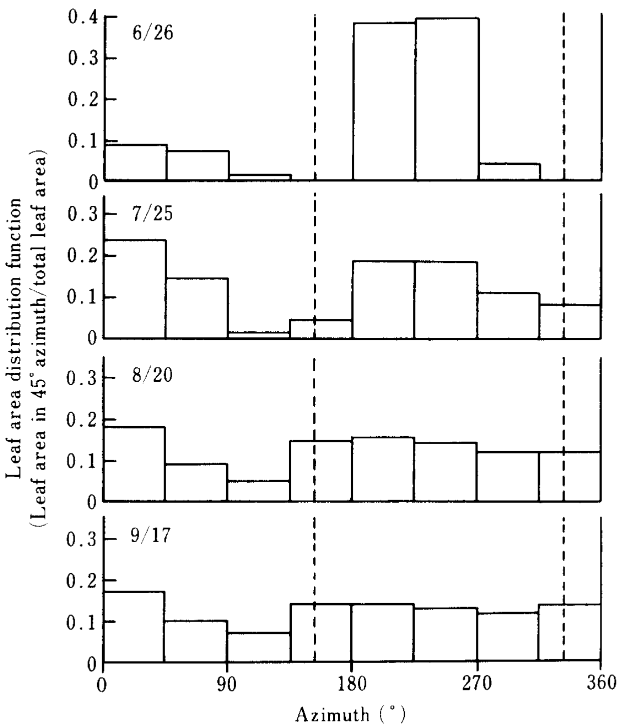

Fig. 4. Leaf area distribution around a hill in terms of azimuth (1989).
Azimuth is shown clockwise from north (0°) and dashed lines are a row crossing a hill.

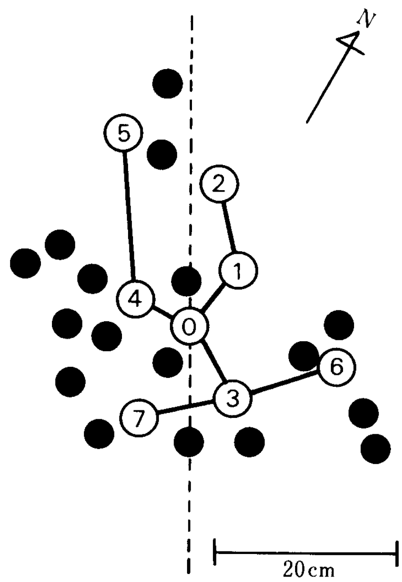

Fig. 5. Appearance of shooots and distribution of rhizomes (1989).
⓪ : Maternal shoot, ①-⑦ : lateral shoot numbered by appearance, ● : rhizome, — — — : row.

5. Appearance of shoot and distribution of rhizome

Fig. 5 shows the location of shoots and rhizomes of a representative plant grown in 1989. The lateral shoots invaded vacant space between rows and hills within a 40 cm × 40 cm area of the maternal shoot. The rhizomes, which were formed latter growth stages, located near the lateral shoots because new shoots did not initiate from rhizomes by low temperatures.

Discussion

Edible canna has large, broad and thick leaves and, therefore, we expected initially that the production structure of this crop was similar to that of dicotyledons. The stratified clipping (Fig. 1) indicated tendency that this crop had such structure as shown previously[10], though the nonassimilatory organ in our experiment was distributed in a manner intermediate of typical broad leaf and grass species distributions.

One of the important characteristics of this crop was to sustain long-lived, high leaf area (LAI > 9 for 2 months) which was distributed on tall stand (2.5—2.8 m height) and this could be the basis of its high productivity (2, 600—4,000 gDW m^{-2})[4]. Oka et al[12]. also reported high LAI (6—10) of edible canna during the latter part of ontogenesis.

Generally, the light extinction coefficients (K) of erect leaf population as in grass species are 0.3—0.5 and those of broad leaf species are 0.7—1.0[10]. In this study, we observed that edible canna had a high K value (1.34) at the 2nd sampling but it decreased to 0.4—0.5 during ontogenesis (Fig. 1). The initial K value (1.34) was equivalent of that in *Petasites japonicus* Fr. Schmidt (K = 1.4) and this reminded us its horizontal arrangement of large, broad leaves[10]. However, the K values at the latter growth stages of edible canna were 0.4—0.5 and these were equivalent to those in rice which had erect leaf canopy[13,14].

The strategy of edible canna in relation to light interception is to develop horizontal leaves to cover ground surface during its early growth stage when total leaf area is low. As growth proceeds, the upper leaves of edible canna are arranged so as to increase light interception by the crop canopy. This results from more erect leaf angle of upper leaves and stem elongation which distributes the leaves vertically in space (Fig. 1 and 3). Similar changes have been observed in rice[7] and barley[16]. The timing and degree of change may, however, be affected by climate, planting density, nutrient supply, etc.

The production structure of edible canna is rather that of broad leaf but the fact that its K value (0.4—0.5), except early growth stage, is close to rice can be ascribed to the inclination and morphology of leaves. The leaf blade is supported by leaf sheath which covers the stem to keep the leaf inclination angle small (Fig. 3). This situation is similar to grass species. Furthermore, the large leaf has a high ratio of leaf width to leaf length (Fig. 2) relative to grass species and has thick, tough midrib. These two components enable to keep an excellent light-intercepting characteristics under its tall stand. If edible canna had leaf blades on expanded petioles[2] like cassava, another root crop of warm climate origin with 4—5 optimum LAI, it might be impossible to take an excellent geometry under very high LAI.

Compared to the production structure of rice reported by Takeda[13,14], a remarkable difference is the pattern of absorption of light with depth in the canopy. In edible canna, the light absorption by the canopy is very large from its early growth and relative light intensity at the soil level declines to less than 1% of the top of canopy (Fig. 1). Edible canna has higher ratio of assimilating organ in the population and at the late growth stage, still allocates lower layers relative to the case of rice. This reflects edible canna's broad adaptability to light environment in terms of photosynthesis[3] and growth[1,12].

The role of thick and tall stem of edible canna is solely to support leaves so that plants can partition living materials to leaf, rhizome and roots throughout the growth season, though the preference of partition has ontogenetic drift. This situation is somewhat different with maize[12] which holds ear(s) in the middle portion of canopy.

The development of leaf canopy started toward inter-row direction followed by along-low (Fig. 4). This is reasonable in terms of light utilization with less mutual shading and is similar to observations in rice[7], corn[15], soybean[6], and barley[16]. The location of primary and secondary shoots of edible canna substantially contributed to the development of canopy above mentioned (Fig. 5). The allocation of rhizomes indicates potential shoot appearance in peripheral parts of a hill if weather condition is suitable for subsequent growth.

These experiments show that edible canna has a canopy structure which contribute to high productivity through efficient use of light and a long-lived, superior stand geometry.

Acknowledgments

We thank Prof. Dale N. Moss of the Oregon State University for reading the manuscript. We also thank Dr. Keo Intabon and Mr. Takuya Ichihashi for their technical assistance.

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* Translated from Japanese by the present authors.
* Japanese with English summary.