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Comparison of Plant Type between New and Old Rice Cultivars Using Computer Image Analysis*

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Abstract: Computer image analysis of a side-view photograph of a plant was applied to compare the plant type between eight new and seven old Japanese rice cultivars grown in a paddy field. Photographs of these cultivars were taken at heading time (stage 1) and three weeks after the heading (stage 2). The distribution of shoot density (percentage of shoot (leaf+stem+panicle) presence in a unit area) was shown by contour lines as seen in a map. The morphological shape was characteristic to each cultivar and stage, and the difference of the shape of cultivars became more prominent after the heading. The characteristics of cultivars were compared by numerical parameters calculated from the density map. In the old cultivars the shape expanded at the upper part or at the lower-middle part, while new ones had less expanded part, though Koshihikari was an exceptional case. The old cultivars showed prominently dispersing nature at stage 2, while the new ones did not disperse. As for the leaf angle, the new cultivars had more vertical leaves at the upper part than old ones at stage 2. The morphological characteristics of each cultivar and their difference at the heading time and after heading were well displayed by the present Plant-Profile-Processing method (PPP method).
Key word: Computer image analysis, Leaf angle, Leaf distribution, *Oryza sativa* L., Plant type, Rice.

画像解析による新・旧日本水稲品種の草型の比較：岡　正明・日向康吉（東北大農）

要　旨：コンピュータ画像解析を用いて，新・旧水稲品種の草型，すなわち葉配置及び葉角度の推定と比較ができるかどうかを検討した。現在の水稲8品種と旧い7品種を水田に生育させ，出穂期と出穂3週間後に，周辺個体を刈り取った孤立植物体の側画写真を撮影し，それを画像解析して，二次元の植物体密度(葉＋茎＋穂の単位面積当りの密度）分布，葉角度（葉の先端の角度）分布を求めた．各品種はそれぞれ特徴的な植物形を示し，横への突出の仕方によりいくつかのグループに分けられた．更にこれらの特徴を表す数値要因を算出し，新・旧品種で比較した．第一に，植物体の全体的な横への張り出し程度と高さによる凹凸程度を表す指標として，植物体中心軸と5%密度等高線の間の距離の平均と分散を求めた．両時期ともに，新品種と比べ旧品種は横への張り出し程度が大きく，また凹凸程度も大きかった．第二に，植物体の集中程度を表す指標として，植物体密度分布における高密度部分と低密度部分の面積割合を求めた．新品種が集中的，旧品種が分散的であり，出穂後にこの差異がより明確になった．第三に，植物体中部・上部の平均葉角度を比較したところ，旧品種の上部の葉は出穂後に著しく傾くことが認められた．新品種であるコシヒカリは大部分の要因で旧品種に近い値をとった．本実験により，従来認められていた新品種と旧品種の草型の差異が数値的に確認されただけでなく，更に植物体の形などの特徴が明瞭に表示できることがわかり，本 PPP 法 (Plant-Profile-Processing 法）は水稲の葉群配置の評価に使える可能性があると考えた．
キーワード：イネ，*Oryza sativa* L.，画像解析，草型，葉角度，葉分布．

The spatial distribution and direction of leaves and stems of a plant determine the light receiving efficiency of the plant and affect its dry matter productivity[16]. These properties, i. e. plant type, have been improved in new cultivars. For the measurement of these properties, a number of methods have been developed, such as the stratified clip method[4], the point quadrat method[18], the silhouette method[3], etc. These methods, however, both costly and time consuming, could not be applied to a number of materials. Therefore, in practice, the evaluation of these properties in cultivars and growing conditions has been carried out by experience and impression.

In the previous report, a computer image analysis of the side-view photographs of a plant was applied to describe the distribution and direction of leaves of four rice cultivars grown in pots[7]. Although this method has a shortcoming that the treating image is the two dimensional projection of the spatially distributing leaves and stems, the morphological properties of these four cultivars were well characterized. To test this method further, it was applied to the comparison of the plant type between new and old rice cultivars grow-

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Table 1. List of cultivars used in the experiment and their dates of heading.

	Reference symbol	Cultivars	Date of heading
New cultivars	①	Akihikari	Aug. 6
	②	Akitakomachi	Aug. 7
	③	Kiyonishiki	Aug. 9
	④	Toyonishiki	Aug. 9
	⑤	Sasanishiki	Aug. 13
	⑥	Satohonami	Aug. 13
	⑦	Koshihikari	Aug. 21
	⑧	Nipponbare	Aug. 28
Old cultivars	[1]	Kamenoo 4	Aug. 6
	[2]	Aikoku	Aug. 8
	[3]	Rikuu 132	Aug. 11
	[4]	Sekitori	Aug. 22
	[5]	Ginbozu	Aug. 22
	[6]	Aikoku 20	Aug. 23
	[7]	Ooba	Aug. 25

ing in a paddy.

Materials and Methods

The eight new and seven old rice cultivars studied were listed in Table 1. The seedlings were transplanted to a paddy field in single planting at 24×24 cm intervals. Chemical fertilizers of N, P_2O_5 and K_2O were applied at a concentration of $4 g/m^2$ each as a basal manure and $2 g/m^2$ each as an additional manure. This amount of fertilizer was a little less than usual to avoid lodging.

Side-view color photographs of a plant were taken at heading time (Stage 1) and three weeks after the heading (Stage 2). Representative four plants at stage 1 and six plants at stage 2 were selected from the canopy of each cultivar except border plants. Their dead leaves which might cause an error in calculation were removed. After cutting off the neighboring plants surrounding the selected plant, photographs were taken from the north side at a distance of about 2.5m under scatter light only. A white board was placed on the south side of the plant as a background and for cutting off the direct sunlight. At the same time, plant height was measured to adjust the plant size in the calculation. Splashes of mud on the background and the leaves of the neighboring plants in printed photographs were removed by painting them with white paint.

The image processing system used was controlled by a minicomputer (NEC MS50) which was a subsystem of the host computer (NEC ACOS system 2020) in the Computer Center of Tohoku University. A photographic image was transferred to the image processing system through a video camera and divided into 512×512 pixels, each having 256 density levels of three primary colors (red, green and blue) for giving digital image data. The distance between two neighboring pixels was adjusted to be actual 0.2 cm by affine transformation. The algorithm for making binary image data described in our previous paper[7] was improved on one point. Because there was a change of brightness from the upper to the lower part of a photograph, the image data was divided into five equal sections in height and a threshold value discriminating plant body from the background was determined in each section.

The binary image of a plant was divided into two half images by a vertical center line of the plant. The half image was divided into sub-areas, each of which corresponded to 5×5 cm of the objective plant. The percentage of the pixels of plant shoots (leaves, stems and panicles) to the total number of pixels in each sub-area was calculated to define the shoot density distribution. An averaged value of the shoot density was obtained by averaging values for each sub-area of the two half images and again averaging for four plants at stage 1 or six at stage 2. Contour lines at 80, 60, 40, 20, 10 and 5% of the shoot density were determined for each cultivars.

In order to calculate leaf angle, an outline of a plant was determined for half image of a plant by the border-following algorithm[8] using the binary image data at first. After extracting the position of a leaf tip on the outline, a line connecting the leaf tip and the middle point of the leaf width at 5 cm apart from the tip was determined, and then an angle between this line and a horizontal line was taken as the angle of this leaf tip. The leaf angles were determined only for the leaf tips that were distributed at the peripheral position of the plant body. The leaf angles in each sub-area corresponding to 5×5 cm of a plant were averaged for two half images and again averaged for plants in replication.

The algorithms for calculating the distribu-

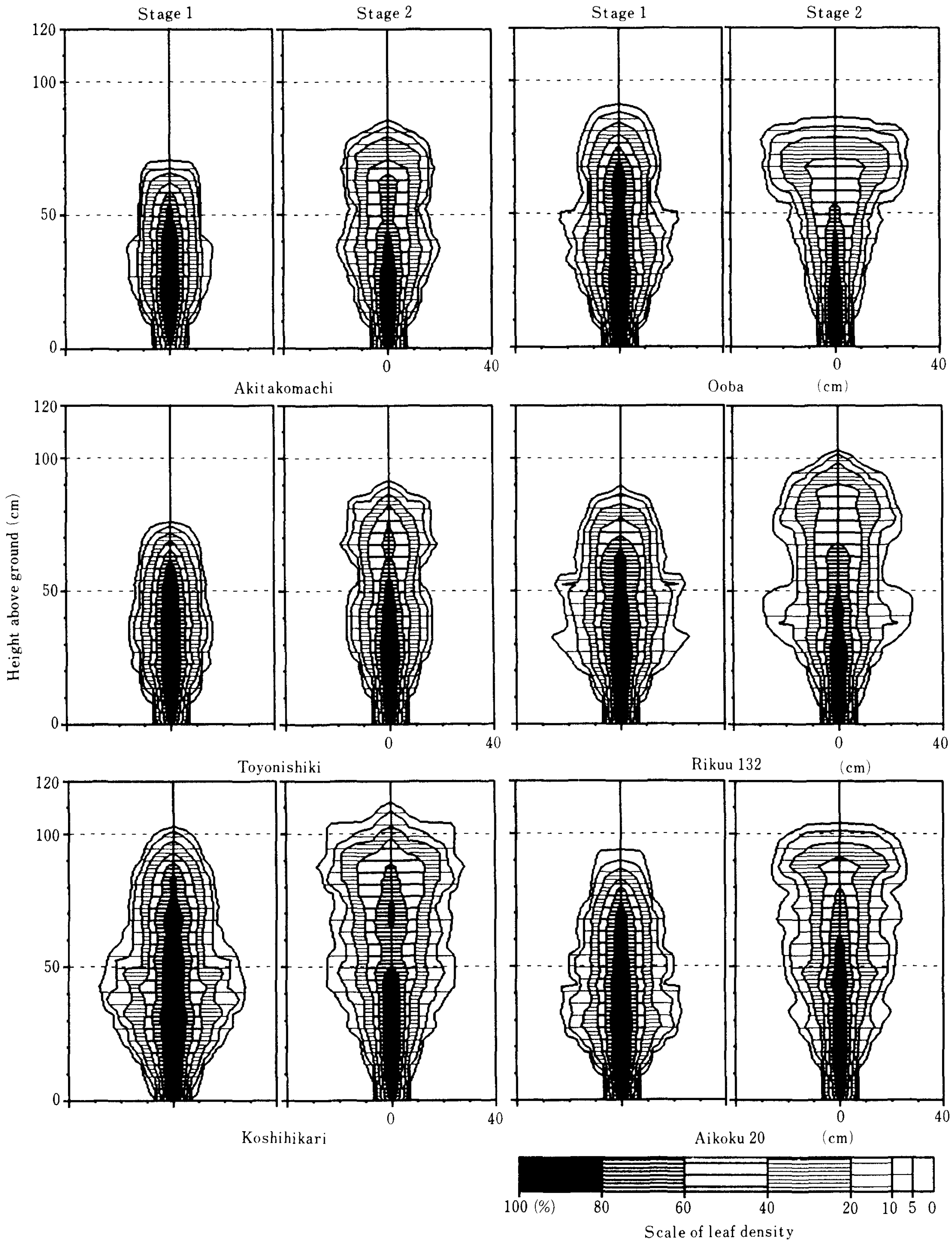

Fig. 1. Two-dimensional distribution of shoot density represented by contour lines in representative three new cultivars (Akitakomachi, Toyonishiki and Koshihikari) and three old ones (Ooba, Rikuu 132 and Aikoku 20) at heading time (stage 1) and three weeks after heading (stage 2).

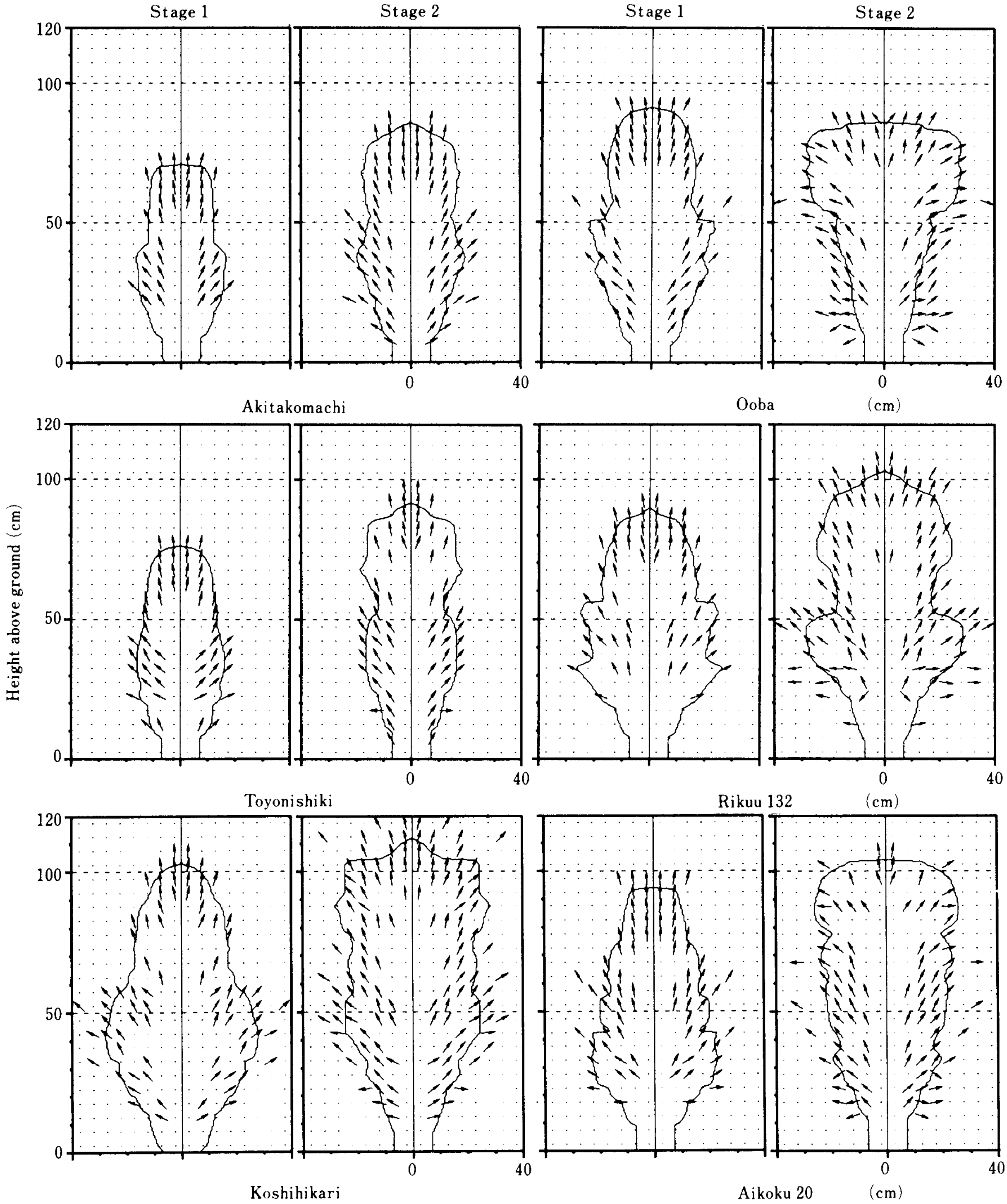

Fig.2. Two-dimensional distribution of leaf angles represented by arrows in three new cultivars (Akitakomachi, Toyonishiki and Koshihikari) and three old cultivars (Ooba, Rikuu 132 and Aikoku 20) at heading time (stage 1) and three weeks after heading (stage 2).

tion of shoot density and leaf angle were detailed in the previous paper[7].

Results

The distribution of shoot density and leaf angle was calculated for each cultivar at heading time (stage 1) and three weeks after the heading (stage 2). The heading date of each cultivar is shown in Table 1. The shoot density distribution is illustrated with new and old three cultivars in Fig. 1. A clear difference was observed among cultivars on the shoot density distribution. At stage 1, in most of the old cultivars the shape was slightly widened at the middle or lower-middle part. It may be referred to as a potbelly type. Contrarily, in many new cultivars the degree of potbelly-type nature was very small or mostly rectangular, except Koshihikari whose shape was similar to the old cultivars. Along the maturation from stage 1 to stage 2, the plant shape changed prominently. In some old cultivars, i.e. Aikoku, Ginbozu and Ooba, the plant shape was widened at the upper part, being like a mushroom. In Rikuu 132, the shape widened at both lower-middle and upper parts. In Sekitori, Aikoku 20 and Kamenoo 4, the shape was widened from the upper to the lower part thoroughly. On the contrary, in many new cultivars the degree of widening was not so prominent as compared with those of old ones, except Koshihikari whose change of shape was similar to those of Aikoku 20, an old cultivar.

An intervarietal difference was also observed on the leaf angle distribution as illustrated in Fig. 2. At stage 1, all cultivars had slightly inclined leaves at the middle part and nearly vertical leaves at the upper part. At stage 2, the leaves at the upper part stood vertically in most new cultivars, while they inclined more or less in old ones.

In order to characterize the shoot density distribution numerically, two parameters were calculated. Horizontal distance between a vertical plant-center axis and the contour line of 5% density was measured at ten positions from 2/6 to 5/6 of plant height at equal intervals. Their mean and variance were calculated. The mean may indicate a general tendency of expansion of plant shape and the variance may indicate the unevenness of plant shape from base to top. The potbelly and mushroom types are expected to have a large value of the variance parameter. Scatter diagrams of cultivars on the mean and variance parameters at stage 1 and 2 are shown in Fig. 3 A and B, respectively. At stage 1, the old cultivars tended to have larger value of the unevenness parameter than new ones, while little difference of the general expansion parameter was recognized between them. One exceptional case was Koshihikari which showed expansion at the middle part of the body resulting in a large value of the unevenness parameter, even though it belongs to new cultivars. At stage 2, the value of the general expansion parameter became larger, especially in old cultivars. The value of the unevenness parameter was generally larger in old cultivars than in new ones. These evidences indicate that the plant shape have become more slender and more rectangular in new cultivars than in old ones.

To compare the degree of tissue dispersion in a plant, two parameters were calculated, i.e. the percentages of area of high density (more than 60%) and of low density (5-20%) to total area (5-100%) in the shoot density distribution map. Scatter diagrams of cultivars on the two parameters are shown in Fig. 4. The cultivars distributed near the upper left side of the diagram tended to have a sparse distribution of shoot, while those near the lower right side had a dense distribution. The old cultivars tended to have more sparse distribution of shoots than new ones, and this tendency became more prominent at stage 2 than at stage 1. Koshihikari was an exceptional new cultivar whose shoot distribution was as sparse as those of old cultivars.

Leaf angles were compared at both the middle and upper parts. The mean angle of leaves that distributed from 2/6 to 3/6 of plant height was calculated to indicate the leaf angle at the middle part. Similarly, the mean value of leaf angle from 5/6 to top was taken to be the leaf angle at the upper part. Scatter diagrams of cultivars on the leaf angle at the middle and upper parts are shown in Fig. 5. At stage 1, the leaves at the upper part stood nearly vertically in all cultivars. The leaf angle at the middle part differed in each cultivar, but no clear difference was observed between new and old cultivars. At stage 2, the leaf angle at the middle part slightly changed as compared with that at stage 1. At stage 2, however, the leaf angle at the upper part greatly decreased in old cultivars, while in new ones the change was slight. Three cultivars, Sasanishiki, Koshihikari and Nipponbare showed a little tendency to decrease the leaf angle at the upper part, though they are new cultivars. In other new cultivars, leaves at the upper part were kept vertical after heading. The leaves of Aikoku tilted horizontally during both stages in the middle part.

Discussion

The plant shape defined in the present experiment was the projection of a plant body to the two dimensional plane. Therefore, rear leaves were not measured. The values of shoot density at high density parts may be underestimated, though these values at low density parts may be near the real value. Values of leaf angle may be slightly overestimated because the actual leaves occupy three dimensional space. Neighboring plants were cut in order to take good photographs. Some cultivars, especially old ones having elastic stems, supported each other in a population after heading. The dispersing nature of old cultivars may be emphasized by the removal of neighbors. Accordingly, the values measured by the present method are not always exact. Our preliminary study, however, showed a close curvilinear correlation between the real leaf area measured by the stratified clip method and the projected shoot area at each stratum in the middle-upper part of the plant body[6]. The points causing errors shall be improved in the future through the use of data-processing methods for estimating three dimensional values from two dimensional ones and the development of new photographic equipments.

Many reports have indicated that the distribution and direction of leaves and stems affect the light receiving efficiency[2)14] and assimilation system[16]. These properties are an important factor in determining the dry matter production and are functions of genetic traits as well as cultural conditions of a plant. Objective description of these properties is needed.

The purpose of the present experiment was to demonstrate that the computer image analysis, in spite of its shortcomings as mentioned above, could be utilized for characterizing the distribution and direction of leaves by making a comparison between new and old cultivars. Hayashi[1] has indicated that there are intervarietal differences of leaf angle, especially in flag leaf angle, and the difference becomes larger after heading. Murai et al.[5] have reported that in new cultivars in Hokkaido the flag leaves are more vertically distributed at maturity stage than in old ones. Changes of canopy structure between old and new cultivars in the warmer part of Japan was also pointed out by Takeda et al.[12)13] Most of these points were again suggested in the present experiment.

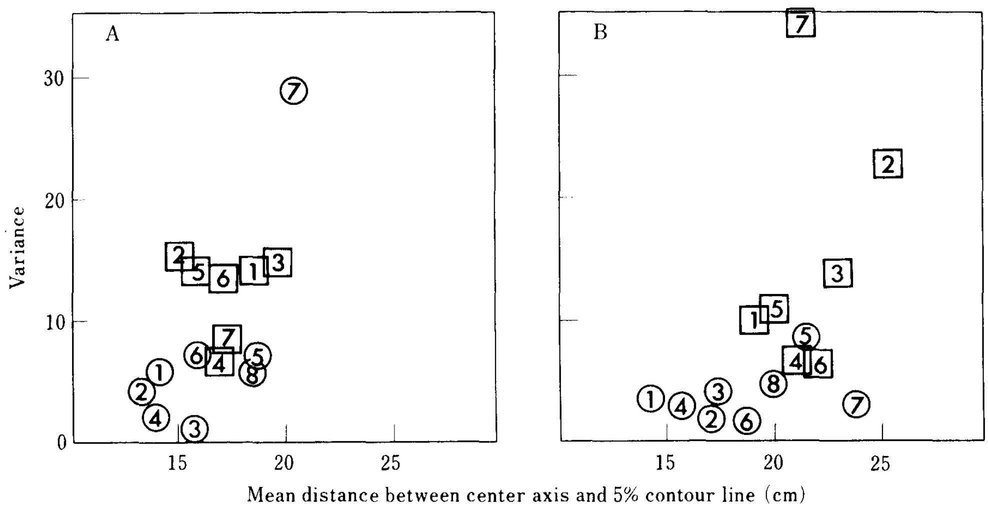

Fig.3. New (○) and old (□) cultivars scattered according to the general expansion and unevenness parameters at heading time (stage 1, A) and at three weeks after heading (stage 2, B). Explanation of these parameters are in the text. Cultivars are numbered as shown in Table 1.

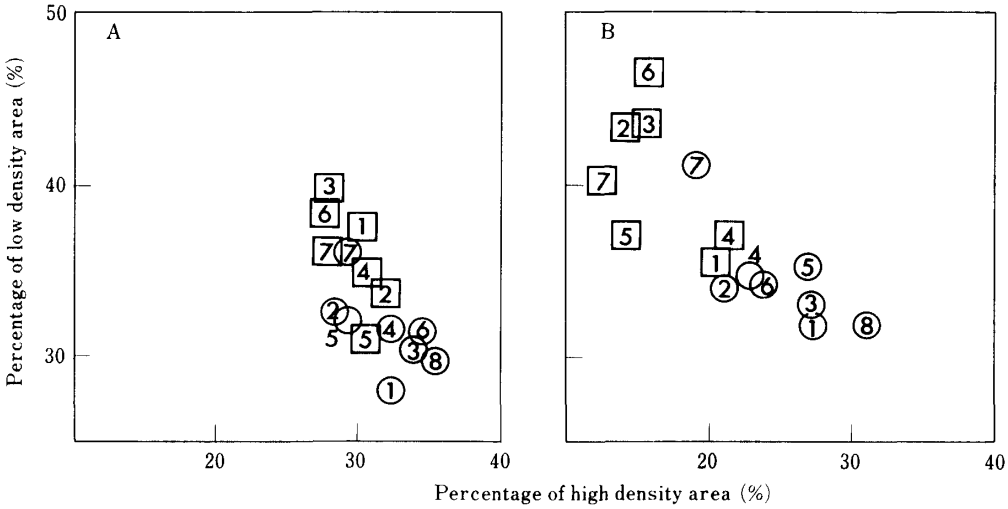

Fig.4. New (○) and old (□) cultivars scattered according to their percentages of high density area (more than 60%) and low density area (5—20%) to the total area (5—100%), in the shoot distribution map, at heading time (stage 1, A) and at three weeks after heading (stage 2, B). Cultivars are numbered as shown in Table 1.

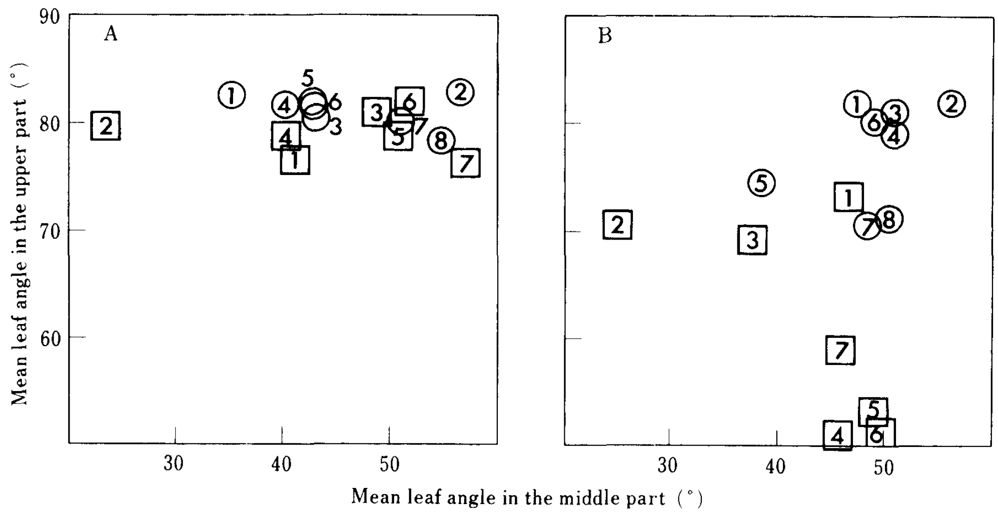

Fig.5. New (○) and old (□) cultivars scattered according to the mean leaf angles at a middle part (2/6—3/6 of plant height) and at an upper part (5/6—6/6 of plant height), at heading time (stage 1, A) and at three weeks after heading (stage 2, B). Cultivars are numbered as shown in Table 1.

Further, this method has revealed that in old cultivars, there are difference in the plant shape after heading, e.g. mushroom and potbelly types. Such shapes may affect the degree of mutual shading with neighboring plants. Prominent change of plant shape from stage 1 to 2 was also noticed in the old cultivars. Such change may be unfavorable for keeping the light-receiving-efficiency high through maturation. New cultivars seem to keep high light-receiving-efficiency by strong culms and little amount of dispersion. Koshihikari, one of the new cultivars, showed a plant type similar to that of old ones. This cultivar is the oldest among the new eight cultivars used in this experiment, and its properties seem to be associated with easiness of lodging.

In the studies of leaf distribution, several methods have been applied, such as the comparison of vertical distribution of leaf areas by the stratified clip method[4] and the statistical analysis of vertical distribution of leaf weight[15]. In order to analyze both the vertical and horizontal distributions of leaf area and leaf angle, Ito et al.[3] applied the silhouette method. However, this method is time-consuming and laborious. Recently, an optical radar system[17], a crop radar system by laser beam[9] and a magnetic sensor system[10] have been proposed for measuring the three dimensional leaf distribution of a plant, and an optical diffraction analysis for the estimation of foliage angle distribution[11]. But these techniques have yet been put to practical use. The advantage of our method is that both the shoot density and leaf angle are conveniently estimated from the same photograph. The computer makes the data-processing time short and enables us to handle many materials. The objectively described shoot density map may be utilized for making images about the spatial properties of plants, though the values are approximations. We would like to propose that this method could be utilized for the description, characterization and evaluation of plant type, and to call this the Plant-Profile-Processing method (PPP method).

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