Studies on the Lodging of Rice Plants

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In Japan, rice plants are frequently lodged in their ripening stage by devastating typhoons or rainstorms which result in considerably reducing the grain yield and quality. Lodging has long been recognized as a vital factor in growing rice plants and its importance has been greatly accentuated not only by the possibility of increasing yield through heavy fertilizer applications and dense planting, but also by the advent of cultivation of direct sowing and mechanical harvesters in recent years.

Studies have been made to clarify the mechanism of lodging and yield reduction in lodged rice plants and the results were reported in **the National Institute of Agricultural Sciences Series A-15, 1～175p. (1968).** Outlines of the results are as follows:

Mechanism of lodging

Lodging is due to the interaction between susceptibility to the lodging of the plant and external force. Wind pressure and rain are the main factors of the external forces related to the lodging of rice plant.

Effect of velocity and duration of wind current on lodging

In an experiment conducted on artificial wind (the intensity of turbulence is about 7 per cent, which is nearly the same order of magnitude as that of the wind near the ground) at their full ripening stage, the plant bent at 7 to 8 m/s of wind to about 45°, which was supposed to be the angle susceptible to damages, and nearly to 90° at 12 to 14 m/s. Breaking of culms started at about 7 m/s and almost all culms were broken at 15 to 16 m/s. Increase in bending angle and broken culms was not proportional to the wind pressure but to the wind speed, since the projection area of plants in the wind direction and the drag coefficient decreased gradually with the wind pressure.

On the other hand, broken culms and bending angles increased in a hyperbolic curve against duration of wind treatment, and the increase was remarkable during the first one hour of the treatment. Recovery of the bending angles after the wind treatment decreased with duration of the treatment. These facts seem to be related to the exhaustion of the stem.

Exhaustion of rice stems was detected first at an amplitude of vibration of 10 cm and became increasingly evident with amplitude and duration of the vibration treatment. Exhaustion of the stem bent to a constant angle was negligible so the exhaustion of culms becomes a factor to enhance the lodging of rice plant.

Effect of periodical variation in wind speed on lodging

The proper vibration period of a single tiller was about 0.9 second with little change in the ripening stages. In the case of a same wind velocity, amplitude of the plant vibration varied with the fluctuation period of wind speed. The largest amplitude was found to be 0.9 to 1.0 second of the fluctuation period which is almost equal to the vibration period of the plant. When the plants resonated with wind fluctuation, the flexion and stress of plants increased to about 2.8 and 2.5 times of their respective values of the mean wind speed and the maximum wind velocity without fluctuation (Fig. 1).

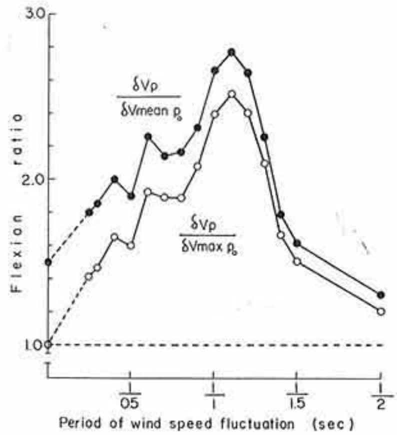

Fig. 1. Ratios of flexion of the ear base in wind with fluctuation to that in wind without fluctuation.

The amplitude of plant vibration decreased with difference between the proper frequency of plant and the frequency of wind fluctuation, although the second and third peaks of the vibration were found at the fluctuation period of about 2 or 3 times of the proper vibration period of the plant. The upper and lower limits of fluctuation were supposed to be about 5.0 and 0.2 second respectively. The fluctuation periods of natural wind near the ground have been considered to be about one second in most cases. Therefore, lodging may be accelerated by the resonance with fluctuation of wind speed.

Effect of rain on lodging

Rain force to the plant can be divided into two parts of weight of rain water depositing on the plant and impact power of rain drops pressing the plant and in this connection several experiments were conducted. In general, weight of the aerial part of the plants increased about 30 to 60 per cent (2.6 to 4.3 gr.) by rain treatment. The increment in weight varied with conditions of the wetting and ripening stages.

When the plant was exposed to rain, the breaking strength of culm with leaf-sheath in the position of the third and fourth internodes increased. However, a significant difference in the strength was not recognized as affected by the probable increase in the friction resistance between the culm and leaf-sheath.

The increase of bending angles of the plants at their yellow ripening stage varied with conditions of rain water deposition and collision of raindrops. In the plant exposed to a drizzle spouted from a sprayer on the ground and with a maximum amount of rain water deposit (Rmax), the angle of culm was about 47° and was 30° larger than that of standard plants.

However, in the plant from which the rain water was shaken off (Rmin), the angle was 35°, which was 17° larger than that of standard ones. In the plant exposed to the strongest collision of raindrops (R), the bending angle was 40°, which was 22° larger than that of standard ones. In the plant (R-H) kept out of collision of raindrops in the R– treatment decreased the angle by 0.5° to 1.0° of the R-plant.

Bending moments were also estimated from

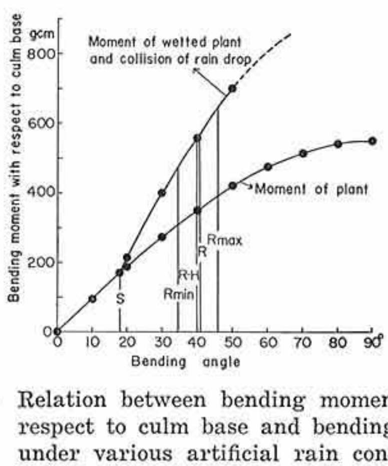

Fig. 2. Relation between bending moment with respect to culm base and bending angle under various artificial rain conditions.

both data obtained by the rain treatment and load test. The result is shown in Fig. 2. The mean moment was estimated to be about 470 to 650 g·cm for treated plants and it is mainly due to both weight of plant and deposited rain water that the plant weight contributed 60 per cent to the total moment in this case. Collision moment of raindrops was only 2 per cent or less of the gross moment.

Resistivity to breaking of the culm with leaf-sheath exceeded the gross moment of the plants exposed to rain so the breaking type lodging cannot be caused by rain without stormy conditions except the weak plants. Although, the broken culms on account of rain with wind of 15 m/s was about 20 per cent larger than that due only to wind, the effect of rain on lodging could be more dominant in the weak wind than in the strong wind because deposition of rain on the plants can be more in the weak wind.

Characteristics of the plant related to bending

Plant characteristics which appeared related to bending resistance were measured and analyzed theoretically. From both data measurement and physical calculation, the following conclusion was obtained. In order to reduce bending angles, it is necessary to shorten the plant height, to enlarge the diameter and cross section of culm, and to stimulate development of the sclerenchyma tissue and vasculer bundles in the culm.

Characteristics of the plant related to breaking

Lodging resistance from breaking was dependent on a number of characteristics. Therefore, it is difficult to find any single index of lodging that can be considered completely reliable. But comparatively high positive correlation coefficients were obtained between lodging resistance and several characteristics such as breaking strength of culm, total area of vasculer bundles in culm and cross section of the culm wall. With the breaking strength of culm constant, comparatively high negative partial correlation coefficients were obtained between lodging resistance and the following plant characteristics as plant height, height of center of gravity and height of center of gravity times fresh weight of the plant.

Indices such as L/B, H/B, L·W/B, H·W/B, L/Wc and H/Wc (L; plant height, H; height of center of gravity, W; fresh weight of plant, B; breaking strength of basal culm, and Wc; fresh weight per unit length of basal culm) exceeded 0.75 in correlation coefficient with lodging resistance. So, these indices can be used to compare the lodging resistances.

Contribution of leaf sheath to lodging resistance

The contribution of leaf sheath to the total breaking strength varied from about 50 per cent to a little more than 10 per cent. The contribution was smallest in the basal internode, and increased progressively with the height of the internode. Such variation is mainly caused by the variation of culm strength. The breaking strength of dead or almost dead leaf sheath was remarkably low compared with that of fresh one.

Variation of lodging with ripening stages

Incidence of lodging increased with number of days after heading. Such an increase in lodging is due to increase in bending moment

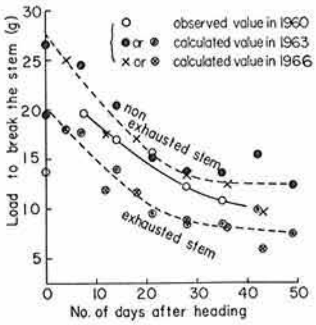

Fig. 3. Plot of observed values of load at the ear base to break the stem and of calculated ones for exausted and non-exhausted stem at different ripening stages.

based on plant weight and height of center of gravity and weakening strength of basal culm and leaf sheath. As an example, actual load at the ear base to break the stem and calculated load for exhausted and non-exhausted stem at different ripening stages are shown in Fig. 3.

Effect of transplanting depth on lodging

Wind treatment and load test were made in the plants transplanted in different depth, and the following conclusions were obtained: 3 cm depth of transplanting is optimal for reducing lodging damage as well as for obtaining high yield.

Effect of lodging on ripening and yield of grains

Effect of types and severities of lodging

All of the lodged plants showed lower yields because of increase in percentage of empty and abortive grains and of a little reduction in the weight of 1,000 ripened grains. Yield reduction was greater in broken plant than in bent plant. Heavily bent plants also resulted in greater reduction of yield than light bent ones. From the rate of reducing yield, a critical angle of bending seems to be about 30° to 45°, although the angle will change with the density of plant and time of lodging.

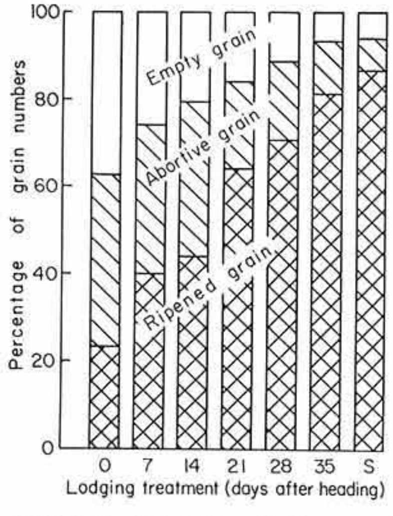

Fig. 4. Ripening damages of the grains in treatment of different stages.

Effect of times of lodging

As shown in Fig. 4, yield reductions and ripening damages were greater in the plant lodged at early ripening stages than at later stages. The yield reduction in the plant lodged shortly after heading was caused by increased empty and abortive grains, but the reduction in plant lodged at a later stage was attributed mainly by increased abortive grains.

Enhancement of lodging damage by viviparous germination

It was found that the viviparous germination started in the grain which was sampled at about 2 weeks after heading, and the germination ratio of an immature grain sampled at the same day after heading was larger in the short-term variety than in the long-term variety. In germination of immature grains developed to different degrees (D%), dry weight of hulled grains (Yh%) and of polished grains (Yp%) can be roughly estimated by the following formulae;

$Yh=D-18\mathbf{X}-2$, and $Yp=D-19\mathbf{X}\div 8$,
where **X** means the length of germ bud in cm.

Protection against lodging damages

Raising-up treatment was effective for recovering the inferior ripening and yield depression due to lodging. The treatment is an effective means to improve such undesirable conditions as worsening of climatic conditions, depression of photosynthesis, hindrance of absorption and translocation of nutrients and of water, and incidence of viviparous germination. Effect of the raising-up treatment was large in the plant lodged at an early ripening stage and those treated shortly after lodging. When we raise the plants up after loding, care must be taken to ensure that the stem and leaves are loosely bound, and that sunlight can penetrate well.

The causes of yield reduction in lodged plants

Photosynthesis in lodged plants

The amount of photosynthesized matter accumulated in the upper parts of the plant and its downward translocation through the stem was reduced in the lodged plants. The hindrance of photosynthesis was enhanced with shading and with the number of days after lodging.

Chlorophyll content in the leaf blades except the top one of lodged plants was less than that of the standard. The decrease in chlorophyll content in lower leaves was more marked in broken plants than in bent plants, and became progressively manifest with the number of days after lodging. Concentrations of various pigments in the third leaf blade sampled at 2 weeks after lodging are shown in Fig. 5.

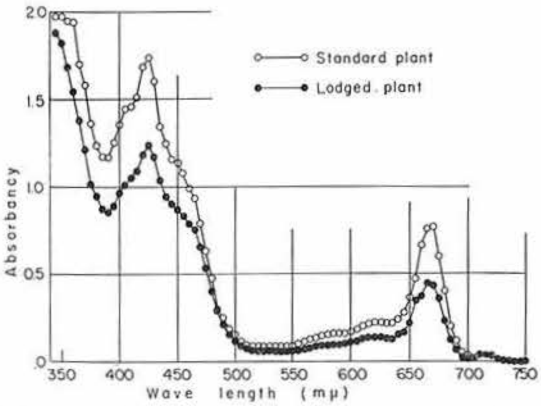

Fig. 5. Effect of lodging upon the pigment content in the third leaf blade (absorption spectra of acetone extract).

Nutrient and water absorption and their translocation in lodged plants

The amount of phosphate (labelled with radioisotope ^{32}P) translocated through the stem to the upper part of the plant was the most in the standard plants, but the least in broken plants. The phosphate in heavily bent plants was between the standard and broken plants. The translocation hindrance varied with the time of lodging and was larger in the case of lodging at the early stages of ripening than in the case of lodging at later stages.

The same tendencies were recognized on the hindrance of transpiration of water in lodged plants. In the case of a constant suction pressure, the flow rate of water through the culm decreased markedly in the broken plants and the rate of bent plants did much less. Suction pressure at the basal culm also decreased in lodged plants and it was more conspicuous in the lodged plant under field condition with mutual shading of leaves than in the lodged plant under the standard conditions.

The cross sectional area of vessels and sieve tubes in the culm decreased to a large extent when the plant was lodged shortly after heading. The effect of the raising-up treatment on recovering the cross areas was marked in plant lodged at earlier stages. This effect seems to

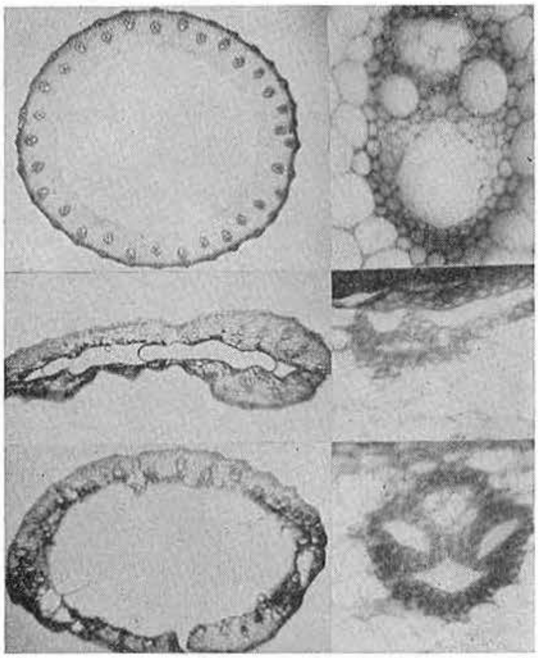

Fig. 6. Anatomical aspects of the culm near the broken point in standard, lodged and raised-up plants (upper; standard, middle; lodged, and bottom; raised-up after lodging).

have a negative relation to rigidity of the culm tissues. Anatomical aspects of the culm near the broken point are shown in Fig. 6.

Micro climatic conditions in lodged plant community

Climatic conditions as low light intensity, low temperature during day times and high at night, restricted aeration and humidity as high as near saturation in the middle and lower parts of the lodged plant community more evident in the broken treatment than in the bent treatment and are increasingly met with high density of plant and bending angle.

From the foregoing results, it can be concluded that the hindrances of photosynthesis and of absorption and translocation of nutrients and water are directly the major causes of decreasing yield in lodged plants, and worsening of climatic conditions is an indirect cause of the yield depression in lodged plants.