Crop Damage Caused by Drought

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In 1967, Kyushu district of Japan suffered from a severe drought which had not been experienced so far in the past 73 years. The drought lasted for two long periods: from the middle of May to the end of June and from the middle of July to the middle of October. The drought caused severe crop damages, and which developed a serious socio-economic concern.

Crop damage by drought is a complicated calamity; it is influenced by a number of factors, it is chronic in nature, and it has a possibility of recovering from the damage with rainfall after the drought period. Therefore, it has been known quite difficult to make accurate assessment of yield loss caused by drought and to forecast yield decrease at the time of drought.

On the occasion of the drought in 1967, the author carried out a study on the mode of occurrence of crop damage by conducting surveys on farmers' fields as well as on experimental fields and collecting all information related to crop damage in the district.

Drought damage of lowland rice

It had been said that lowland rice is rather resistant to drought. However, as the lowland rice depends on irrigation water, the lack of irrigation water causes cracking of soils of paddy fields, that accerelates further evapolation of soil moisture, and soils become extremely dry. Then, transpiration exceeds water absorption by plants, and wilting occurs.

Water requirement of lowland rice is reported to be 250–300 ml in Japan: 250–300 ml of water is required for producing 1 g of plant dry matter. Using this figure the total amount of water required for a whole growth season is calculated to be about 180 tons per 10 a. This is a physiological water requirement. However, rice is grown in submerged paddy fields. Water duty as expressed by transpiration + evaporation from water surface + percolation − effective rainfall (about 70–80% of precipitation during a growth period) is reported to be 1000 tons (equivalent to 1000 mm) for early-maturing varieties, 1100 tons for medium-maturing varieties, and 1300 tons for late-maturing varieties per 10 a.

When such amount of water is not available, rice plants suffer from drought. Growth stage from transplanting to seedling establishment and that from booting to heading are critical period for water requirement. Effects of drought can be classified as direct and indirect ones: the former is not related to growth stages whereas the latter is closely related to growth stages of plants. Direct effects at the period from planting to heading are reduced tillering, retarded growth, wilting, browning and dieback of leaves and stems, and reduced culm length. On the other hand, indirect effects appear as delayed heading, straight heads, stunted heading, degenerated rachis branches, branched ears, and premature death of spikelets.

Particularly, drought at the period from meiosis stage to milk-ripe stage apt to inhibit fertilization and grain development, causing white heads and empty spikelets. Drought at the later period of grain ripening also causes imperfect ripening, although no direct damage occurs.

Mode of occurrence of damage can be described as follows:

1) Damage at tillering stage

Drought at this stage causes reduced tillering and consequently less number of panicles. However, the less number of panicles can be compensated with increased number of spikelets, when enough water is supplied in a following stage, thus resulting in a less damage. But, when extremely dry condition lasts long, the damage becomes greater due to reduced number of effective panicles and spikelets.

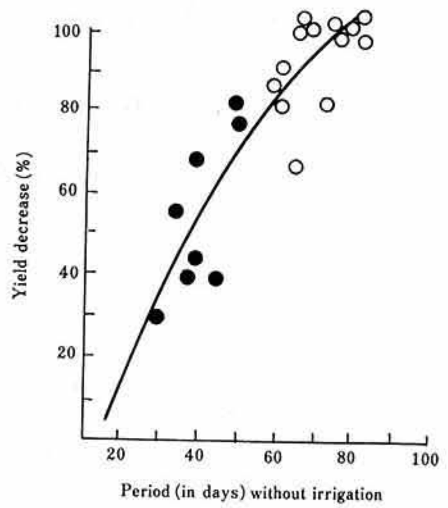
2) Damage at the period from maximum tillers to heading

Direct and indirect effects of drought appear remarkably at the reproductive stage after panicle primordia initiation; such as straight heads, delayed heading or inability of heading. Remarkable decreases in number of effective panicles, in percentage of ripened grains, and in weight of 1000 grains (brown rice) were observed in the 1967 drought.

3) Damage at the period from heading to maturity

Drought at about and after heading time gives adverse effects on grain ripening, such as retarded ear emergence, reduced percentage of ripened grains and decreased number of ripened grains per panicle. Water shortage at milk-ripe stage which requires relatively large amount of water caused an increase of rice screenings and decreased weight of 1000 grains.

For assessing crop damage to be used for crop statistics of Japan, the Ministry of Agriculture and Forestry established "Standard measures for estimating yield decrease of summer crops". Out of 12 measures listed for drought damage, 2 of them were developed by the author based on the study on 1967 drought. One of them is based on environmental indicator, such as time (plant stage) and duration during which no irrigation water was available. Fig. 1 shows a relatoinship of time and duration without irrigation to yield decrease. By utilizing this relationship, forecasting of yield decrease can be made at an early date.



○ : No irrigation at the stage from young panicle formation

● : Suspension of irrigation water from heading to milk-ripe

Fig. 1. Relationship of time and duration without irrigation to yield decrease (1967)

Note: $y=148.53 \log x-177.69$
$\eta=0.883^{***}$
$sd=10.8$

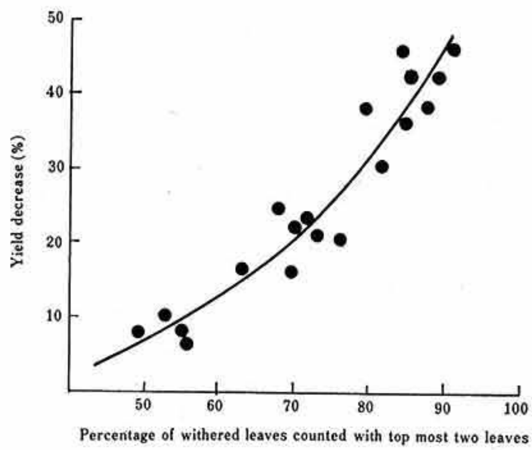


Fig. 2. Relationship between percentage of withered leaves and yield decrease (1967)

Note: $y=40.7-1.53x+0.0176x^2$
$\eta=0.95^{***}$
$sd=4.1$

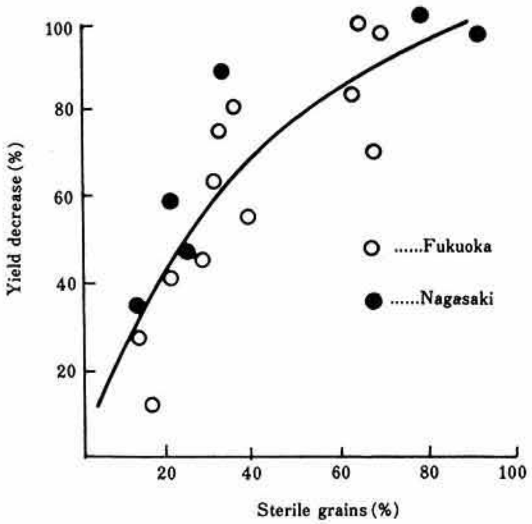


Fig. 3. Relationship between percentage of sterile grains and yield decrease (1967)

Note: $y=77.79\log x-52.6$
$\eta=0.871^{***}$
$sd=14.3$

The second method takes plant damage as an indicator. Degree of wilting, percent withered leaves, culm length index, growth index (culm length × number of tillers), degree of ear bowing, percent damaged panicles, percent degenerated rachis branches, percent straight heads, percent sterility, etc. are used. Two examples are shown in Figs. 2 and 3. By these methods, assessment of yield decrease can be made with an accuracy at an early date as soon as plant damages became apparent.

In case when a single indicator is not enough for assessment, combination of environmental indicator and plant damage indicator or of different plant damage indicators is used. In some cases, major and subordinate indicators are determined or mathematical treatments by using multiple regression are applied. The collation of measures for estimating yield decrease by drought is published by the authors[2].

Drought damage of upland rice

Upland rice is less resistant to drought than other farm crops. In addition, as an early half of tillering stage coincides with a rainy season so-called Bai-u, only shallow roots develop, so that water absorption from deep soil layer is impossible. The following growth stage which requires more water comes to a period from the end of July to the end of August that has the least precipitation in a year. Thus, upland rice suffers frequently from drought.

Water requirement of upland rice is reported to be slightly less than that of lowland rice, i.e., about 300. In case of a crop yielding 300 kg (brown rice)/10 a, a total consumption of water is calculated to be 270 mm. Assuming that 30% of rain water can be utilized by the crop, precipitation of about 800 mm is needed for a whole growth period.

Critical soil moisture limit for grain ripening is between 30% and 40% of water content (on dry soil basis), and that for yield is likely to be 50–60%. According to Hasegawa, with a crop yielded 400 kg/10 a, daily water absorption was less than 1 mm until 50 days prior to heading, and it increased to 6–7 mm at 30 days prior to heading, reaching a maximum (7–8 mm) during a period from 20 days before heading to heading time, followed by a decrease to 4 mm, and after 30 days to less than 2 mm. Close correlation was observed between yield and rainfall at the active tillering stage and at the stage from young panicle formation to beginning of ripening.

Experiences obtained from the 1967 drought indicated that yields more than 250–300 kg/10 a were obtained with average monthly rainfall more than 180 mm for July, August and September whereas no harvest with average rainfall less than 80 mm. Therefore rainfall at least more than 150 mm per month is necessary for stable yields.

Plant damage indicators and mode of yield decrease are similar to lowland rice. Delay of heading, percent damaged panicles, percent withered leaves, percent sterility and culm length index, etc. are used as indicators.

For example, following equations are utilized.

$y=323.4-3.27x$ $(r=0.984^{**})$

where y=yield decrease
x=culm length index, i.e., ratio of culm length of damaged plants to that of un-affected plants.

or $y=17.04+0.989x$ ($r=0.812^{***}$)
where y=yield decrease
x=percentage of damaged panicles
(% white heads + % completely sterile panicles + ½ % partially sterile panicles + % deformed or degenerated panicles)

Drought damage of soybean

Soybean is relatively resistant to drought, because it has tap root growing in deep soil layer with a large number of lateral roots. However, the flowering takes place over a long period. This is a characteristic growth pattern of soybean, and which makes the flowering to be exposed to drought which occurs at any time of the long-lasting flowering period.

Drought at a stage from sowing to seedling elongation causes delayed germination, retarded growth, wilting and die-back of leaves, and reduced number of nodes and branches, which results in reduced number of flowers.

Drought at the flowering period causes severe retardation in flowering and fruiting, in addition to adverse effects on vegetative organs. Reduced number of flower set, occurrence of flower-shedding, and retarded ripening causes yield decrease.

Examples of yield decrease estimation by using an environmental indicator or a plant damage indicator are shown below:

1) $y=-0.3+0.017x+0.299x^2$
where y=yield decrease
x=period (in days) of drought lasted since 30 days after sowing

2) $y=117.9-1.04x$
where x=ratio of total number of pods in damaged plot to that of un-affected plot

3) $y=130.2-1.14x$
where x=culm length index, i.e.,
$$\left(\frac{\text{culm length of damaged plants}}{\text{culm length of un-affected plants}}\right)\times 100$$

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