CHAPTER 5

THEORY OF RICE CROP PLANT PROTECTION

I. WEED CONTROL

1. Grounding in Weed Control and Weed Control Methods

The problem of weeds has been a problem fatally incidental to the farming from olden times when crop production was started. Much labor, cost, and human efforts have been devoted to the fight against weeds. In present Japan, the transplanting rice culture with submerged irrigation is prevailing widely. This cultural method marks the fourth stage developed through such steps as (i) direct-sowing rice culture without irrigation, (ii) direct-sowing rice culture on periodically irrigated fields, and (iii) direct-sowing rice culture on continuously submerged fields. The greatest contributing factor for the development to the present rice cultural stage can be sought in alleviating weed damage, adding to the purposes to obtain the high rice yield and to secure the stabilized rice yield. Supposing that rice culture in Japan be continued indifferently to the weed emergence, it would show a marked decrease in rice yield, e.g., 20-40 per cent decrease in the case of a transplanting culture of paddy (lowland) rice, and as high as 70–90 per cent decrease in the case of a direct-sowing paddy rice culture or a direct-sowing upland rice culture.

"Weed eradication" from "weed control" must be distinguished clearly. A word "weed eradication" means to eliminate weeds perfectly from fields. If taken into consideration the high cost for weed eradication, it would have a limited significance. A word "weed control" means by implication that the survival of weeds (in number or weight) is controlled to the extent that the competition with crop plants may not become greater. The extent of weed control is determined according to the balance between the cost for weed control and the decreased yield of crops caused by weeds. The latter will be handled in this Chapter.

There are many weed control methods, but these can roughly be classified as follows:

(1) Ecological control method

This method is to control weeds by taking advantage of ecological weak points of weeds. Namely, (i) it is devised to minimize the amount of weeds by keeping the field environmental conditions in the state unsuitable for the emergence and growth of weeds by means of such farm operations as irrigation, tillage, crop rotation, and time of crop planting; or (ii) it is devised to lessen the crop damage due to weed by strengthening the competing ability of crop plants against weeds by carrying out the improvements in fertilizer application, density of planting, or arrangement of plant stand.

(2) Mechanical control method

This is the weed control method by making use of mechanical power. Namely, the emerged or emerging weeds are cut or buried by hand-weeding or intertillage with man-labor, animal-power, or power machinery.

(3) Chemical control method

This is the method to control the emerged or emerging weeds biochemically by using chemicals.

Besides the above, biological control method and physical control method can be cited. In the case of the former, the weed growth and reproduction is checked by the use of insects, micro-organisms, or fish. In the case of the latter, weeds are killed by making use of heat or other physical power, e.g., weed burner, soil burning, etc., but such control methods are not popular in Japan.

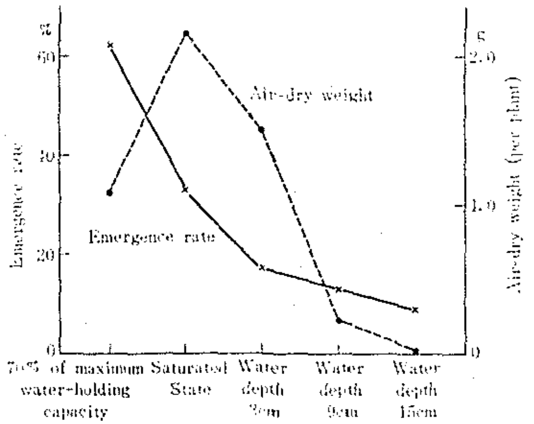
In order to attain the effective weed control, it is most important to have exact knowledge about the actual feature of weeds emerging in the fields, i.e., physiological and ecological characteristics of individual weeds, ecology of weed community, and competing behavior of weeds against crop plants. Each weed control method has its own advantages and disadvantages. Any weed control method can not be applicable to every case, irrespective of kinds and quantities of weeds, place or time. With the full knowledge of the characteristics of each weed control method and the ecological knowledge about weeds, the weed control can be carried out at a low cost without any injury to crop plants.

Under this Chapter, a chemical control method will chiefly be handled, which has developed in recent years and will develop more and more in the future. In the case of paddy rice cropping in present-day Japan, however, the weed control methods basing upon the ecological control methods and the mechanical control methods are prevailed widely. Therefore, the major control methods of these kinds will briefly be described here.

Weed control by deep submergence is the important method among the ecological control methods. Deep submergence is the weed control practice devised by making use of the difference in the optimum soil moisture requirements between paddy rice plants and weed emergence and growth. This method is effective particularly to the control of barnyard grass (*Echinochloa Crus-galli*) which is noxious against paddy rice plants in Japan. As stated later, weeds are, in accordance with the optimum soil moisture for their emergence and growth, classified into hydrophytic, hygrophytic, and mesophytic weeds. Barnyard grass is a species of hygrophytic weeds. It can emerge and grow best at the soil moisture of 80 per cent of the water holding capacity, while the emergence and growth become increasingly poorer according as the submergence increases in depth. When the water depth has reached 10–15 centimeters, barnyard grass cease to grow and most of the plants are dead or floated up (Fig. 5–1). (However, when barnyard grass grow so tall that the leaf tips appear above water surface, the growth can not be checked.) On the contrary, it is rare that paddy rice plant growth is checked by the water at the depth of 10–15 centimeters. The deep submergence at the depth of 10–15 centimeters for about one month before or immediately after the emergence of barnyard grass is effective in controlling barnyard grass or other hygrophytic weeds.

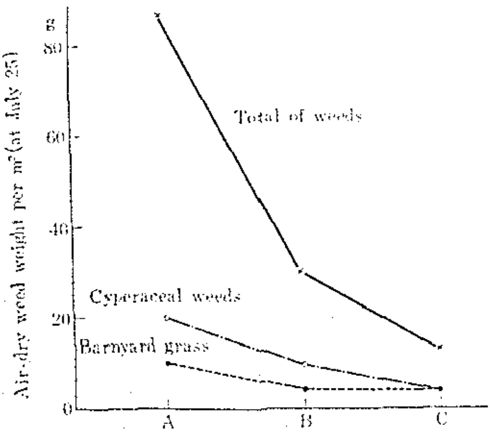
Fig. 5 – 1. Relationship between Water Depth, and Emergence and Growth of *Barnyard Grass*

(ARAI et al., 1954)



Next, the weed control with weeder is an important mechanical control method. By using a weeder, the paddy field soils are turned over or stirred to cut or bury the stems or roots of weeds or to set plants afloat on the surface so that they may be dead (Fig 5–2). It is important to control weeds at the early growth stage in the case of using a hand, animal, or power weeder (e.g., rotary weeder, basket-shaped weeder, etc.), because when weeds begin once to grow vigorously they show so great a regenerating ability that they could not readily be suppressed.

Fig. 5 – 2. Effect of Weeding with Rotary Weeder (ARAI et al., 1954)



Note: A: Non-weeding plot.
B: Rotary weeder weeding plot (one time).
C: Hand-weeding and rotary weeder weeding plot (one time each).

2. Kinds of Weeds and the Physiological and Ecological Characteristics

Kinds of weeds grown on arable land vary owing to the natural environmental conditions (e.g., climate, soils, etc.) as well as to the artificial environmental conditions which depend upon crop culture. KASAHARA (1947, 1951) reported that the weeds emerging on paddy fields in Japan amounted to 43 families with 191 species in all. Although the kinds of weeds are numerous, the principal weeds which are practically serious in paddy rice culture are not so numerous. For instance, KASAHARA pointed out 30 kinds of weeds as "harmful weeds." In future, some changes will take place in the principal weeds in accordance with the changes in the future paddy rice cultural methods and weeding methods, but the kinds of weeds to be taken up at present are limited only to a certain extent.

Life-history of weeds or reaction of weeds against the environment (physiological and ecological characteristics) varies widely according to the kinds of weeds. In any case of the weed control methods, it is necessary to take advantage of weak points of the weeds of the respective kinds with a view to maximizing the control effect. For this purpose, it is very important to make clear the life-history and physiological and ecological characteristics of weeds. The physiological and ecological characteristics of weeds can be made clear by examining the following points.

(1) *Emergenable season*

Seasons for the emergence of weeds are generally fixed according to the kinds of weeds, and the seasonal periodicity is observed. ARAI et al. (1951) classified the kinds of weeds into the following three types basing upon the weed emergenable seasons.

Summer (early) weeds: Summer weeds emerge during the seasons from spring to autumn, reaching a peak in around April, and almost cease emerging from late-autumn to early spring.

Summer (late) weeds: No appreciably great difference is found in the emergenable season from that for the above, except the peak season. A peak emergenable season for the weeds of this type falls in June-July months.

Winter weeds: Winter weeds emerge in autumn and spring seasons, reaching a peak season in around October.

Weeds which come into problem chiefly in the case of a transplanting paddy rice cultural practice are summer (late) weeds. Such difference in the weed emergenable season is ascribed chiefly to the difference in the germination temperature or dormancy of weed seeds.

(2) Soil moisture and weed emergence and growth

ARAI et al. (1955) classified the kinds of weeds into the following three types basing upon the optimum soil moisture-content for the weed emergence and growth.

Hydrophytic weeds: Weeds grow well in the state of submergence.

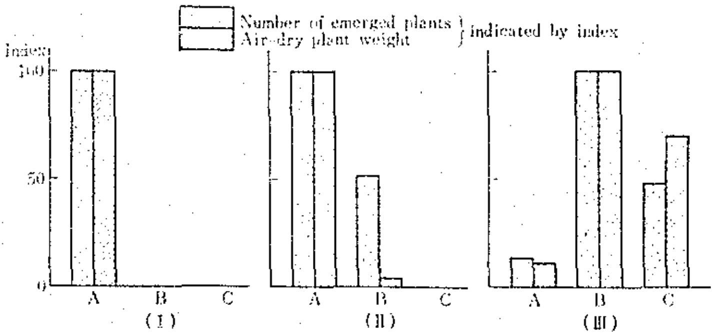
Hygrophytic weeds: Weeds grow well under the water saturated condition.

Mesophytic weeds: Weeds grow well under the dry land condition.

Weeds which emerge in lowlands planted to paddy rice by transplanting practice are confined to hydrophytic weeds (e.g., *Monochoria vaginalis, Rotala indica, Dopatrium junceum,* etc.) and hygrophytic weeds (e.g., *Echinochloa Crus-galli, Cyperus microiria,* etc.). The emergence of mesophytic weeds is not observed. The relation of emergence and growth of *Monochoria vaginalis, Rotala indica,* and *Echinochloa Crus-galli var. orizicola* to the soil moisture-content is as given in Fig. 5–3.

Fig. 5–3. Relation of Emergence and Growth of *Monochoria vaginalis* (I), *Rotala indica* (II), and *Echinochloa Crus-galli* (III) to Soil Moisture Content

(ARAI et al., 1955)



Note: A: Submerged plot (6 cm in water depth).
B: Soil moisture content of 80-90% of maximum water holding capacity.
C: Soil moisture content of 40-60% of maximum water holding capacity.

(3) Propagation methods

Among the weeds are included (1) annual weeds propagating exclusively from seeds and (2) perennial weeds propagating not only from seeds but also from vegetative organs (rhizome, bulb, and stolon).

Besides the above characteristics, there are many important characteristics which must be taken into consideration in connection with weed control, namely: (a) dormancy in seeds, (b) longevity of seeds in soils, (c) dissemination of weed seeds, (d) depth of emergence, (e) regenerating ability, (f) relation between light and growth, and (g) susceptibility to herbicides.

Table 5-1 indicates the classification of weeds and the herbicides applicable for the respective weeds.

3. Herbicides and the Herbicide Application Methods

Herbicides which have hitherto been tested are large in number, but these are different in properties with one another. Herbicides can be classified according to the following bases.

(i) Hormone type or non-hormone type;

(ii) Translocating type (herbicides translocating from stems or leaves to the inner parts of a plant) or contact type (herbicides which kill the parts of a plant by direct contact);

(iii) Selective herbicidal action;

(iv) Relative difficulty in the movement of herbicides in soils;

(v) Persistence period of toxicity in soils;

(vi) Relation between temperature and herbicidal activity.

To begin with, the above properties of the respective herbicides are needed to be made clear.

Herbicides are required to be applied so as not inflict any injury on crop plants. It is comparatively easy to control weeds by applying herbicides on the cropless field. In case

Table 5-1. Kinds of Weeds on Paddy Fields in Japan and Applicable Herbicides

(ARAI, 1961)

Classification of weeds	*Foliage application*	*Soil application*
1. Annual weeds		PCP, PAM, DBN*
a. Broad-leaved weeds	2,4-D, MCP, BPA, MCPB, AM, DCPA*	
Monochoria vaginalis (Konagi)		
Lindernia Pyxidaria (Azena)		
Rotala indica var. uliginosa (Kikashigusa)		
Dopatrium junceum (Abunome)		
b. Cyperaceae weeds		
Cyperus difformis (Tamagayatsuri)		
C. microiria (Kayatsurigusa)		
Fimbristylis miliacea (Hideriko)		
c. Gramineae weeds	DCPA*	CDAA
Echinochloa Crus-galli var. oryzicola (Tainubie)		
E. Crus-galli var. caudata (Keinubie)		
E. Crus-galli var. Kasaharae (Himetainubie)		
2. Perennial weeds		
a. Broad-leaved weeds	2,4-D, MCP, BPA, MCPB, AM, ATA*	
Sagittaria trifolia var. typica (Omodaka)		
S. pygmaea (Urikawa)		
Callitriche fallax (Mizuhakobe)		
b. Cyperaceae weeds	2,4-D, MCP, AM, CDAA*, ATA*	
Eleocharis acicularis (Matsubai)		
E. Plantaginea (Kuroguwai)		
Cyperus serotinus (Mizugayatsuri)		
C. globosus var. strictus (Azegayatsuri)		
c. Gramineae weeds	DPA*	
Arundinaria hirta (Todashiba)		
Paspalum Thunbergii (Suzumenohie)		
Isachne globosa (Chigozasa)		
d. Others		
Potamogeton Franchetii (Hirumushiro)	ATA*	
Marsilea quadrifolia (Denjiso)	DPA*	
3. Floating weeds	PCP	
Spirodela polyrhiza (Ukikusa)		
Salvinia natans (Sanshomo)		
4. Algae	PCP, Cupper sulfate	
Spirogyra arcta (Aomidoro)		
Hydrodictyon reticulatum (Amimidoro)		

Note: Asterisk indicates herbicides now under study.

where crop plants and weeds grow together in a field, the weed control by the use of herbicides without any injury to the crop plants can be attained depending upon the differential response of weeds and crop plants to the herbicides as a general principle, namely, by taking advantage of the difference in susceptibility to the herbicides—the difference in susceptibility implying the physiological, morphological, as well as ecological meanings. In view of this, weed control methods by using herbicides can theoretically be divided into those as described below, according to whether or not crop plants are growing at the time of herbicide application, as well as, in case where crop plants and weeds are growing together, according to what is the cause responsible for the difference in susceptibility to the herbicides between crop plants and weeds.

(a) In case where no crop plants are growing: Application of herbicides on cropless fields or application of herbicides before seeding or before planting (or transplanting). The applicable herbicides must be ones having no selective herbicidal action and short in the persistence period of toxicity in soils.

(b) In case where crop plants and weeds are growing together:

(i) Application of herbicides by taking advantage of the difference in susceptibility to the herbicides chiefly due to the physiological (morphological) difference between the crop plants and the weeds. The applicable herbicides must be ones having selective herbicidal action without any injury to the crop plants.

(ii) Application of herbicides by taking advantage of the difference in susceptibility to herbicides chiefly due to the difference in the growth stages between the crop plants and the weeds. In this case, herbicides are applied by keeping the crop plants at an advanced growth stage than that of weeds. It is desirable to apply such herbicides which are absorbed little from stems and leaves and which are less mobile in soils.

(iii) Application of herbicides by making use of the difference in susceptibility to herbicides chiefly due to the ecological differences (e.g., depth of emergence, spreading of roots, etc.). This is a method to kill weed seeds (which have begun to germinate) or young weed plants. Such herbicides as may move little in soils are desirable.

Moreover, with an aim of avoiding any injurious effect of herbicides on crop plants the growth stage of weed to be controlled and the time for herbicide application are strictly limited. The herbicide application methods are divided into "the foliage application" and "the soil application" according to the growth stage of weed. In the case of the former, herbicides are sprayed on the stems and leaves of weeds after emergence with a view to killing the weeds by the herbicides absorbed chiefly from the stems and leaves, while in the case of the latter, herbicides are applied to the soils before the emergence of weeds or immediately after germination with a view to killing the weeds by herbicides absorbed chiefly from the roots. Herbicide application time is divided into (i) application before seeding or transplanting of seedling (pre-sowing or pre-planting treatment); (ii) application for the period from seeding to emergence of crop plants (pre-emergence treatment); and (iii) application in the growth period (post-emergence or post-planting treatment). To sum up, the method of herbicide application is combined to the above-mentioned principle of herbicidal use, as described below:

In the case of (a):	Pre-planting (pre-seeding) soil or foliage application
In the case of (b)-(i):	Post-emergence or post-planting foliage application
In the case of (b)-(ii):	Post-emergence or post-planting soil application
In the case of (b)-(iii):	Pre-emergence soil application

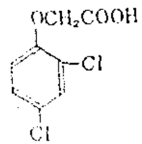
The similar difference as observed in the reactions to herbicide between crop plants and weeds can also be found among species of weeds. For instance, some weeds can be controlled by a certain herbicide, but others cannot be done by it. The weeding effects of herbicides vary according to such factors as properties of herbicides, species of weeds, habitat of weeds, and environmental conditions. The injurious effects of herbicides on crop plants also vary with the properties of herbicides, kinds of crops, crop cultural method, and environmental conditions. In order to use herbicides, effectively and timely, attention must be paid to the three factors: herbicides, crop plants, and weeds.

Next, a brief description will be given as to the mode of action and the methods of application of the principal herbicides now used widely in the transplanting rice culture in Japan.

1. 2,4-D

(1) Chemical structure and mode of action:

This chemical, 2,4-dichlorophenoxyacetic acid, is a plant growth hormone originally synthesized artificially. When 2,4-D of high concentration is absorbed from the stems and leaves of a plant, the physiological function of the plant is affected and loses its balance, and the plant will die at last. The effect of 2,4-D on plants varies with the kinds of plants. In general, broad-leaved annual plants (e.g., *Monochoria vaginalis*) are most susceptible to 2,4-D, followed by broad-leaved perennial plants (e.g., *Sagittaria trifolia*). *Cyperaceae* plants are somewhat resistant to 2,4-D and *Gramineae* plants (e.g., rice, barnyard grass, etc.) are highest in resistance. As a result, 2,4-D is a translocatable hormone-type herbicide displaying a selective herbicidal action, and most effective against broad-leaved plants and less effective against *Gramineae* plants. For this reason, 2,4-D is used as herbicide for the post-emergence or post-planting foliage application purposes. 2,4-D is effective against such weeds as *Monochoria vaginalis*, *Rotala indica*, *Dopatrium junceum*, etc., but not effective against barnyard grass (*Echinochloa Crus-galli*).



(2) Kinds of 2,4-D products

Name	*Active ingredient*
2,4-D Sodium salt	95.0%
2,4-D Amine salt	49.5
2,4-D Ester	
2,4-D applicable in water	18.0
2,4-D granule	1.5

"2,4-D applicable in water" is a fine-grained 2,4-D Ester, hardly soluble in water as being adsorbed to bentonite. "2,4-D granule" is a granuliform "2,4-D applicable in water".

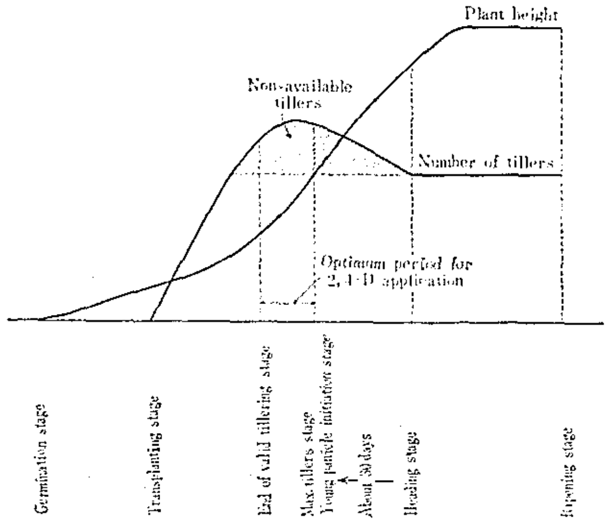
(3) Time of 2,4-D application and optimum dosage

Paddy rice plants are originally high in resistance to 2,4-D, but the resistance varies according to the plant growth stages, namely, higher in resistance at the medium or latter tillernig stage. Tillering is checked by 2,4-D and young panicle primordia are affected adversely by it. As a result, the optimum time of application is limited. The period from the end of the valid tillering stage (generally, 40 days before heading) to the young panicle initiation stage (generally, 30 days before heading) is regarded as the optimum application time (Fig. 5-4). The length of the optimum application period and the application time vary somewhat according to the rice varieties, transplanting time, and temperatures (colder or warmer areas). Though the optimum dosage varies with the regions, around 40-50 grams per 0.1 hectare in 2,4-D acid equivalent is generally accepted as optimum.

(4) Method of 2,4-D application

Both "2,4-D sodium salt" and "2,4-D amine salt" are sprayed in the form of aqueous solution on the drained paddy fields. When applied with sprayer, water of about 50-60 liters per 0.1 hectare is required, though varied with the types of sprayers. Being a foliage application, 2,4-D liquid must be sprayed directly on the weed plants. Paddy fields are irrigated in a half day or one day after spraying. If the paddy fields are kept long in the drained state, there is a fear that the withered plants might be reinvigorated. "2,4-D applicable in water" is sprayed on the submerged fields, in the form of aqueous suspension. The fine grains containing 2,4-D are

Fig. 5 – 4. Optimum Period for 2,4-D Application (ARAI, 1954)

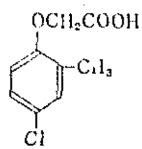


dispersed in water and precipitated slowly on the weed plants. Thus the chemical adhered to the weed plant leaves is absorbed. "2,4-D granule" is also sprayed on the submerged fields without draining surface water by granule applicator or by hand.

2. *MCP*

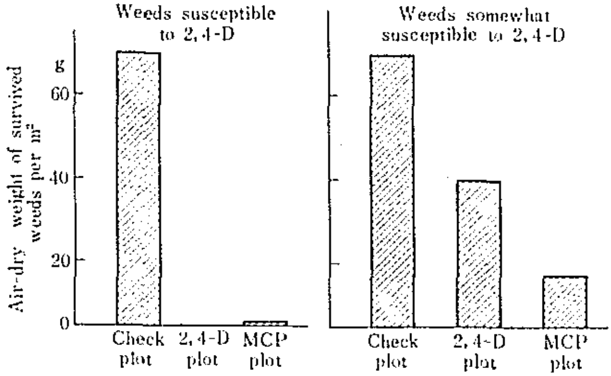
(1) Chemical structure and mode of action

This chemical, 2-methyl-4-chlorophenoxy acetic acid, is a translocatable hormone-type herbicide having the selective herbicidal action, as is the case with 2,4-D. Little or no difference is found in the mode of action between MCP and 2,4-D. However, MCP is somewhat stronger in selective action and



more effective against broad-leaved weeds than 2,4-D (Fig. 5–5), but owing to the less injury to paddy rice plant, MCP can be used in cold areas (where rice plant growth is not so

Fig. 5 - 5. Comparison of Herbicidal Effectiveness between 2,4-D and MCP
(ARAI et al., 1957)



vigorous as in warm area) more safely than 2,4-D.

(2) *Kinds of MCP products*

Name	*Active ingredient*
MCP Sodium salt	22.2%
MCP Kalium salt	47.6
MCP Ester	
MCP Applicable in water	18.0
MCP Granule	1.5

(3) Time of MCP application

Being greater in safety for paddy rice plants, MCP can be sprayed earlier than 2,4-D.

(4) Method of MCP application *and optimum dosage*

Similar to the case of 2,4-D.

3. BPA

(1) Chemical structure and mode of action

BPA is a mixture of sodium and kalium MCP and 2,3,6-trihalogenated benzoic acid (TBA). The mode of action of BPA is almost similar to that of MCP, and the herbicidal effect of BPA is as great as MCP or somewhat less than MCP, but BPA is greater in safety for paddy rice plants than MCP.

(2) Time of BPA application and optimum dosage

Being greater in safety for paddy rice plants than MCP, BPA can be sprayed earlier, namely ranging over the period from rooting to the maximum tillers stage. About 150–250 grams of the product are used per 0.1 hectare.

(3) Method of BPA application

BPA solution is sprayed with sprayer on the drained paddy rice fields.

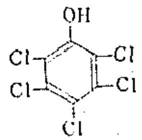
4. MCPB (2-methyl-4-chlorophenoxybutyric acid)

Although less effective against weeds than MCP, MCPB like BPA is less injurious to paddy rice plants. Therefore, MCPB has been used for an early spraying in rice culture in cold regions, but being less effective against weeds than BPA, MCPB is confined to the limited rice area.

5. PCP (Pentachlorophenol)

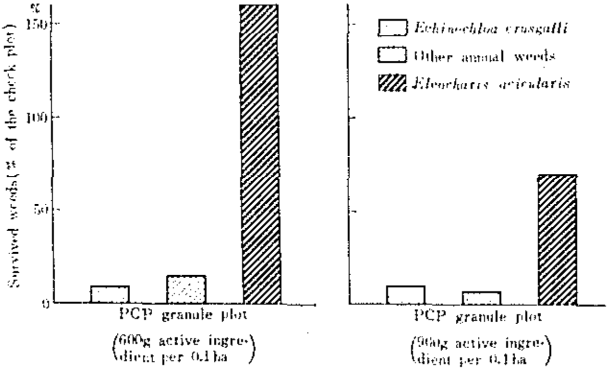
(1) Chemical structure and mode of action

PCP is a contact herbicide of non-hormone type and water-soluble powder having no selective herbicidal action. However, PCP is particularly effective against floating weeds or algae, and a deadly poisonous chemical to fish or shellfish. (The lethal dosage is about 0.2–0.5 ppm.) It is also poisonous to men and beasts. Being characterized by such properties, PCP was used generally



for preplanting soil application, except for the floating weeds or algae. However, by granulating PCP, the chemical inflicts no injury by contact. Thus it has come into use after transplanting of rice seedlings. Because even sprayed on paddy rice plants, PCP granule comes down to the surface soil and does not adhere to rice plants. When applied rationally, PCP is effective against annual weeds of all descriptions including barnyard grass which can not be controlled by phenoxy-group herbicides such as 2,4-D, etc. (Fig. 5–6). PCP is decomposed and inactivated by the action of sunlight (ultraviolet ray) or soil micro-organisms. The persistence period of toxicity

Fig. 5-6. Herbicidal Effectiveness of PCP
(ARAI et al., 1961)



in soils lasts about 10 days.

(2) Kinds of PCP products

Name	*Active ingredient*
PCP Water-soluble powder (Sodium salt)	86.0%
PCP Granule	25.0

"PCP Granule" is a granuliform herbicide of PCP sodium salt, made by being adsorbed to diluent such as bentonite.

(3) Time of PCP application and method

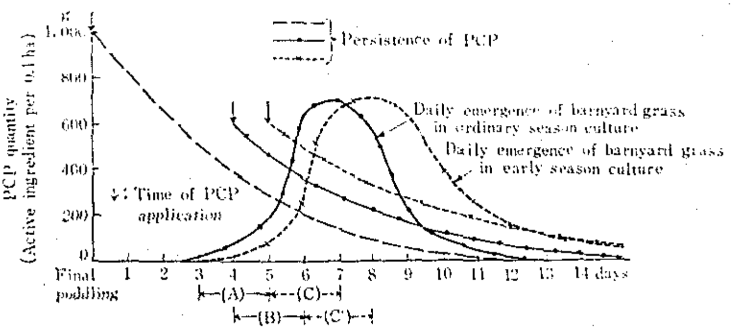
With a view to controlling the weeds which have begun to emerge before or after transplanting, PCP is applied by making use of the difference in growth stage between weeds and paddy rice plants as well as of the difference in susceptibility to PCP due to the difference in spreading of roots between weeds and rice plants. Accordingly, when PCP is applied at a peak time of germination and subsequent emergnece of weed plants, the weed control can be attained most effectively.

"PCP water-soluble powder" is sprayed in the form of water solution after puddling which is operated 1-4 days before transplanting (i.e., pre-planting soil application). Such application method, however, is not desirable because the operation is accompanied by various defects and the injurious effect to rice plant will readily be brought about and less effective in the weed control.

"PCP granule" is applied usually about 5 days after the final puddling (post-planting soil application) in cases when the transplanting is done not later than one day after the final puddling (Fig. 5-7). As the emergence of weeds varies with the fields, PCP granule application time must be adjusted according to the emergence of weeds. PCP granule may of course be used before transplanting. It is applied either with granule applicator or by hand. Attention must be paid so as to spread it evenly. If not, rice plants at some parts would be injured.

Fig. 5-7. Right Time for PCP Application from the Viewpoints of Decomposition and Inactivation of PCP in Paddy Rice Field Soils as well as of Daily Emergence of Barnyard Grass *(Echinochloa Crus-galli)*

(ARAI et al., 1961)



Note: (A): Right time of application in ordinary-season culture.
(B): *Right time of application in early-season culture.*
(C): Application time can be delayed in case of slight emergence of barnyard grass.

(4) Optimum dosage

For the pre-planting soil application of aqueous solution of PCP water-soluble powder, 800–1,000 grams of active ingredient are required per 0.1 hectare, and for the post-planting soil application of PCP granule, 600–800 grams of active ingredient are used.

(5) Precautions

In order to minimize the injury to paddy rice plants, healthy seedlings must be selected for transplanting, and the seedlings are required to be transplanted to paddy fields at the depth of 3 or 4 centimeters. Care should be taken so as not to stir the field soils by intertillage and the like for the 10–14 days after PCP application, because when stirred new weed seeds would come up to the soil surface and would emerge. PCP is less mobile in soils, but when water percolation is great, PCP would move downward into the lower soil layer, thus becoming less effective against weeds and inflicting injury upon rice roots.

Furthermore, for the purpose of controlling floating weeds or algae, PCP solution containing active ingredient of 100 grams diluted with water of 100–200 liters (per 0.1 hectare) is sprayed so that it may fall on the weeds, after the paddy field has been drained at the medium or later tillering stage.

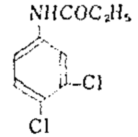
6. *PAM*

PAM is a granuliform mixture of PCP and Allyl MCP (AM). AM is MCP allyl ester and is rather stronger in the selective herbicidal action than MCP of other types. The power to check the germination of weed seeds is also remarkably great. The ratio of mixing is 400 grams PCP (active ingredient) to 30 grams AM (MCP acid equivalent). The use of PAM is similar to the case of the post-planting application of PCP granule, but in the case of an ordinary-season rice culture in warm areas, PAM is, like PCP, not only effective against barnyard grass and other annual weeds, but also effective to some extent against *Eleocharis acicularis*. The persistence period of toxicity of PAM is somewhat longer than that in the case of a single application of PCP. However, in the case of paddy fields in cold areas with high rate of water percolation, the injurious effect of AM is observed, and at this level of PCP dosage, the effectiveness against barnyard grass seems insufficient. For this reason, PAM is now in practical use only for the ordinary-season rice culture in warm areas.

7. DCPA (3,4-dichloropropion anilide)

Chemical structure and mode of action:

This chemical is a contact herbicide of non-hormone type. DCPA manifests a selective herbicidal action greatly effective against barnyard grass and *Cyperus microiria*, though not injurious to rice plant. As a result, DCPA is used as herbicide for the post-emergence or post-planting foliage treatment. No great effect is observed in case where the paddy field soils contain high moisture closely approximate to water saturated condition. Paddy field soils are, therefore, required to be in the dry state to some extent. It is evident that DCPA is very useful in the case of a direct-sowing rice culture on dry paddy fields. Its application to a transplanting rice culture is now under testing.



Besides the above herbicides, the following ones have been found:

Herbicides against annual weeds:
- DBN (2,6-dichlorobenzonitrile), etc.

Herbicides against perennial weeds:
- ATA (3-amino-1,2,4-triazole)
- CDAA (2-chloro-N,N-diallylacetamide)
- DPA (2,2-dichloropropionic acid), etc.

4. Combined Practices of Weed Control Methods

Among the principal weed control methods for a transplanting rice culture are, as referred to above, deep submergence, mechanical weeding with rotary weeder and the like, and weeding with herbicides such as 2,4-D, MCP, BPA, PCP, etc. In order to attain the successful weed control under the various cultural systems, it is necessary to adopt the above-mentioned weed control practices in the systematic combination, because each of the respective weed control methods has its own advantages and disadvantages and is not always effective against weeds of all descriptions, and is not applicable to every case, irrespective of cultural systems, time and environmental conditions.

Weeding system must be established with a view to controlling weeds, with a minimum labor and a minimum cost, to the extent that rice yield may not be reduced by weeds. For this purpose, we must bear in mind such factors as the ecology of weed community emerged in paddy rice fields (such as kinds and quantities of weeds), the state of rice plant growth, the features of each weed control method, and the requierd costs.

The technical characteristics of the principal weed control methods will briefly be described below.

Deep submergence: Deep submergence is effective against hygrophytic weeds (e.g., barnyard grass) which cannot be controlled by 2,4-D and the like, but it has the great disadvantage that this is not applicable unless in the case of paddy fields where irrigation water is controlled freely.

Weed control with rotary weeder: This method can be used for the weed control between rows, but not generally for the control of weeds adjacent to crop plants. A rotary weeder displays its function in checking the growth of perennial weeds which cannot be controlled by herbicides. However, when used at the later rice plant growth stage, there is a fear that the rice plant growth might be retarded. Besides, the width between rows must be large enough to permit a rotary weeder to pass (present weeder is 25 centimeters or more in width), and the seedlings must be transplanted so as to maintain uniform space between hills and between rows.

PCP application: When used at the early emergence stage of barnyard grass or other annual weeds, PCP is very effective. However, when not applied properly, PCP will become less effective against weeds and more injurious to rice plants and fish.

Table 5–2. *Weeding Effect and Rice Yield under Different Weeding Systems*
(Ordinary Season Culture, Konosu, 1959)
(ARAI et al., 1961)

Expt. plot	*Weeding system, days after transplanting*				*Survived weeds percentage to non-weeded plot*			*Rice yield percentage to customary weeded plot*	*Cost*			
									Labor required for 0.1 ha		*Cost of herbicide per 0.1 ha*	*Total*
	3	*15*	*25*	*35*	*Barnyard grass*	*Other weeds*	*Total*		*Hours*	*Yen**		
					%	%	%	%	hrs.	*yen*	*yen*	*yen*
1. Customary weeding	—	M	H	H	1.0	2.2	1.3	100.0	22.5	2,250	0	2,250
2. Mechanical weeding (A)	—	M	M	—	16.4	12.0	15.1	96.5	9.0	900	0	900
3. 〃 (B)	—	M	M	—	11.6	10.7	11.3	92.5	9.0	900	0	900
4. Mechanical+MCP (A)	—	M	M	MCP 40 g	9.3	0.0	6.5	97.8	7.5	750	105	855
5. 〃 (B)	—	M	—	MCP 40 g	50.5	0.0	34.9	100.7	3.5	350	105	455
6. PCP+mechanical weeding	PCP granule 500 g	—	M	—	0.0	4.0	1.2	96.5	5.0	500	275	775
7. PCP+MCP	PCP granule 500 g	—	—	MCP 40 g	0.0	0.0	0.0	111.3	1.5	150	380	530
8. PCP (A)	PCP granule 500 g	—	—	—	0.1	29.0	9.0	100.0	0.5	50	275	325
9. PCP (B)	〃 1,000 g	—	—	—	0.1	13.6	4.3	100.1	0.5	50	545	595
10. PCP (C)	〃 2,000 g	—	—	—	0.0	2.8	0.9	98.5	0.5	50	1,090	1,140
11. Not weeded	—	—	—	—	100.0	100.0	100.0	79.0	0.0	0	0	0

Notes: Mechanical weeding (A): With rotary weeder
Mechanical weeding (B): With other type weeder
M: Mechanical weeding
H: Hand weeding
Dosage: Active ingredient per 0.1 hectare
* Labor per hour is converted into 100 *yen*.

Table 5–3. Weeding System according to Kinds and Quantities of Annual Weeds

(Arai, 1961)

Type	*Kind and quantity of weeds*		*Weeding system*	*Labor input per 0.1 ha*
	Barnyard grass	*Other weeds*		
A	Small	Small	M+M	9.0
			2,4-D or MCP	1.0
B	Small	Much	PCP	0.5
			M+2,4-D or MCP	3.5–5.5
C	Much	Small	PCP+M	3.0–5.0
D	Much	Much	PCP+2,4-D or MCP	1.5
			PCP+M+2,4-D or MCP	4.0–6.0
E	Very much	Much	PCP+M+M+2,4-D or MCP	6.5–8.5

Notes: M: Mechanical weeding.
2,4-D: 2,4-D and its analogues.
MCP: MCP and its analogues
PCP: PCP and its analogues.

2,4-D, MCP, and BPA application: 2,4-D and MCP are effective against broad-leaved annual weeds or cyperaceae weeds, but not against barnyard grass. In order to eliminate injury to rice plants, 2,4-D and MCP are needed to be applied at the medium or later tillering stage. BPA can be sprayed earlier than that stage, but somewhat less effective against weeds than the above two.

Table 5–2 indicates the weed control effects, rice yields, and the labor input for the principal weeding systems (several weed control methods combined systematically). The total cost (sum of expenses for weed control and the required labor hours in terms of money) is also given in this Table.

The weeding systems indicated in Table 5–3 have been designed by taking into consideration the kinds and quantities of annual weeds as well as the characteristics of the respective weed control methods. However, these weeding systems are for the control of annual weeds. Due to the lack of effective herbicides against perennial weeds (e.g., *Eleocharis* *acicularis, Potamogeton Franchetii,* etc.), the weeding systems applicable to paddy rice fields abundant in such perennial weeds have not been designed as yet. Connected with this, a further study is required.

II. DISEASE CONTROL

1. Principal and Minor Diseases of Rice and the Damage by Diseases

Rice cropping in Japan suffers a great damage every year from diseases of rice. The occurrence of diseases of rice spreads over the paddy fields covering the acreage of about 70–80 per cent of the total rice planted acreage, decreasing about 400,000–540,000 tons of rice every year (equivalent to 4 or 5 per cent of the total rice production).

Principal and minor diseases of rice occurring in Japan are given in Table 5–4. Among the leading diseases inflicting great damage upon rice plants are: blast, sheath blight, bacterial leaf blight, virus diseases, *Helminthosporium* leaf spot, and stem rot.

2. Utilization of Disease Resistant Varieties

For disease control, it is primarily important to plant disease resistant varieties, particularly so in the case of bacterial leaf blight, because any effective fungicides are not available yet. Even though highly effective fungicides for rice blast control are available, the rice blast control can be done more effectively by the planting of blast resistant varieties, saving the labor and costs. In Japan, the tests on disease resistant varieties and the research works for the breeding of disease resistant varieties are now in much progress (Table 5–5). Efforts are made by farmers themselves also to plant disease resistant varieties.

The degree of disease resistance of one rice variety

Table 5-4. Rice Diseases and the Causal Organisms in Japan

Disease	*Causal organisms*
Principal diseases:	
Blast	*Piricularia oryzae* CAVARA
Sheath blight	*Pellicularia sasakii* (SHIRAI) S. ITO [=*Corticium sasakii* (SHIRAI) MATSUMOTO]
Bacterial leaf blight	*Xanthomonas oryzae* (UYEDA et ISHIYAMA) DOWSON
Virus diseases	
Dwarf, Yellow dwarf, Stripe disease, Black-streaked dwarf	Virus that is transmitted by leaf-hoppers
Stem rot, Culm rot	*Helminthosporium sigmoidium* CAVARA or *H. sigmoidium* CAVARA var. *irregulare* CRALLEY et TULLIS
Helminthoporium leaf spot (Brown spot)	*Cochliobolus miyabeanus* (S. ITO et KURIBAYASHI) DRECHSLER
Minor diseases:	
White tip	*Aphelenchoides besseyi* CHRISTIE
Downy mildew	*Phytophthora macrospora* S. ITO et TANAKA
False smut	*Ustilaginoidea virens* TAKAHASHI
"*Bakanae*" disease	*Gibberella fujikuroi* (SAWADA) WOLLENWEBER
Cercospora leaf spot	*Sphaerulina oryzina* HARA
Seed and seedling rot	Spp. of *Pythium*, *Achlya*, *Pythiomorpha* and *Dictyuchus*
Brown leaf blight	*Rhynchosporium oryzae* HASHIOKA et YOKOGI
Leaf smut	*Entyloma oryzae* SYDOW
Brown *sclerotium* disease	*Sclerotium oryzae-sativae* SAWADA
Sheath rot	*Acrocylindrium oryzae* SAWADA
Sheath net-blotch	*Cylindrocladium scoparium* MORGAN
Kernel smut	*Tilletia horrida* TAKAHASHI

differs according to the localities. Even if the varieties are resistant to diseases at present, they will sometimes become susceptible according as the years pass. Blast resistant variety is a case in point. This is due to the fact that there are strains or races different in the pathogenicity though the pathogens are same. More than 14 races of blast fungi have already been found in Japan (Table 5-6). It was also clarified that there are several different strains of leaf blight bacteria classified basing upon the reaction of pathogens to the typical differential hosts of different resistance. As a result, in case where resistant varieties are planted, the existence of ecolo-

Table 5-5. Resistant Varieties for Practical Purposes

Disease of rice	*Rice variety*
Blast	Norin 22, 23, 34, Yaeho, Shimotsuki, Kanto 51, 52, 53, 54, 55, Tedoriwase, Koganenami, Hatsunishiki, Chokai, Imochishirazu, Hakkoda, Ayanishiki, Akibae, Kotobukimochi, Koshijiwase, Etsunan 14, Kamenishiki, Ishikarishirage, Fujisaka 5, Wakaba, Shuho, Ginga, Futaba, Shinjyu, etc.
Sheath blight	Shimotsuki, Taishoakaho, Shonan, Mihonishiki, etc.
Bacterial leaf blight	Benkei, Kiryoyoshi, Shobei, Shigasekitori 11, Doutoku, Toyoho, Kidama, Koganemaru, Akabenkei, Zensho 17, Norin 27, 35, Kono 35, etc.
Dwarf	Norin 1, 37, Hayanorin, Obanazawa 1, 5, Hokuriku 5, 6, Kofuku 401, Zensho 26, Mutsu-hikari, Ayanishiki, Hayashio, Eiko, etc.
Stripe disease	Norin 1, 14, 21, Saitamamochi 10, Tonewase, etc.
Stem rot	Kyomi 4, 17, Toyoasahi, Taishoakaho 66, Toyoho 1, etc.
Brown spot	Norin 6, 23, 37, Ginbozu, Muboaikoku, Kameji, Iwateakaho, Sekitori, etc.
White tip	Norin 8, Tosan 36, 37, 38, 58, Nankai 3, Fukuokaasahi 1, Asahi 1, Asahi, etc.

Note: Use for these varieties is limited according to the localities.

Table 5-6. Classification of Rice Blast Races (1954-1957)

(K. GOTO and T. YAMANAKA)

Group / *Rice variety* \ *Race No.*	*T race group*	*C race group*					*N race group*							*O race group*	*X-type*		
		1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*6*	*7*		*1*	*2*	*3*
Zenith	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Tadukan	M	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Chokoto	R	S	M	M	R	M	R	R	R	R	R	R	R	R	(S)	(S)	
Reishiko	R	S-M	M	M	S-M	M	R	R	R	R	R	R	R	R	(S)	(S)	(M)
Kanto No. 51	R	S	M	M	S	M	R	R	R	R	R	R	R	R	(S)	(S)	(M)
Ishikarishirage	R	S	S	S	R	S	S	S	M	R	R	R	R	R	S	R (M)	S
Homarenishiki	S-M	S	S	M	R	M	S	M	M	S	M	M	R	R	S	S	M
Ginga	S-M	S	S	M	S	M	S	M	M	S	M	M, R	S	R	S	S	M
Norin No. 22	S	S	S	S	S	M	S	S	S	S	S	M	S	R	S	S	S
Aichiasahi	S	S	S	S	R	S	S	S	S	S	S	S	R	R	S	S	S
Norin No. 20	S	S	S	S	S	S	S	S	S	S	S	S	S	R	S	S	S

gical strains or races of pathogenic fungi and bacteria should be taken into consideration.

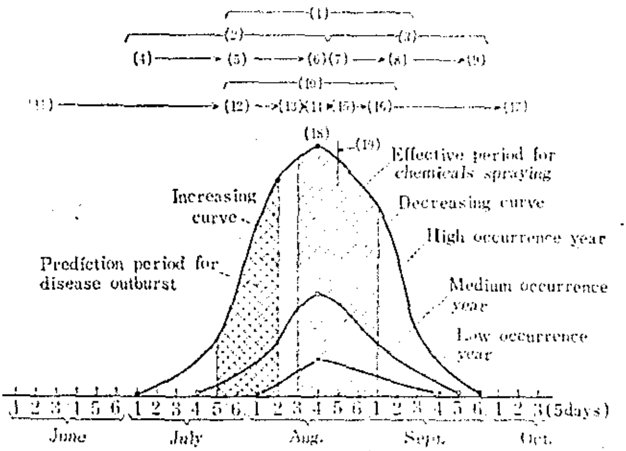
3. Forecast of Disease Outbreak

Even if the efforts are made for minimizing the disease damage by planting disease resistant varieties and with tender care to grow healthy rice plants, sometimes it is unavoidable to get rid of diseases. Particularly, in case where rice cropping is carried out with liberal fertilizer application aiming at obtaining high yields, it runs the risk of occurrence of diseases. Preventive measures are required to be taken with the aid of agricultural chemicals. In Japan, in order to prevent the major diseases such as blast, sheath blight, and stem rot, new effective chemicals such as organic mercurial fungicides, antibiotics, organic arsenic fungicides are used widely. Such fungicides are sprayed or dusted by individual farmers with hand sprayers or dusters, or with power sprayers or dusters in the cooperative control. In recent years, large scale cooperative control by the use of helicopters is becoming rapidly popular in order to control diseases in wide areas simultaneously.

In Japan, with a view to make chemical control more effectively or economically, the disease occurrence forecasting services are carried out throughout the country. Warnings of occurrence of diseases or insect pests are given by the local government authorities basing upon the reports of plant pathologists stationed at several observation sites for each prefecture. The forecast of disease occurrence is attempted by the integrated examination of the regular survey data for pathogens, rice plants, sequence of the diseases, together with weather records and forecasts, and the changes in the fertilizer consumption in the areas. The density of spores of the casual fungi in the air is observed by the spore traps which are equipped at every place in the major rice producing centers. By means of the net work of spore traps, the fluctuations in the density of the spores in the air can be estimated, thus making possible to point out the places where diseases may occur.

In Nagano Prefecture, for example, the observation of the density of conidia of causal fungi of blast has been conducted for a long time by using spore traps. Basing upon the results of such investigation, the occurrence of rotten-

Fig. 5 – 8. Spore Density Curve, Disease Occurrence Forecast, and Optimum Period for Chemicals Spraying



Note:

(1) Disease occurrence

(2) Leaf blast: (4) Incipient → (5) Peak → (6) End

(3) Neck rot, node blast: (7) Incipient → (8) Peak → (9) End

(10) Plant growth period

(11) Transplanting → (12) End of tillering - (13) Booting - (14) Heading - (15) Full heading - (16) Milk ripe stage → (17) Full Ripening

(18) Apex
(19) Optimum time for spraying

neck has been successfully forecasted about 10–15 days before (Fig. 5-8).

Bacterial leaf blight has come to be forecasted by examining the occurrence of bacterial leaf blight on weeds or the amount of bacteriophage of bacterial leaf blight on rice leaves or in paddy field water. In case where the occurrence of diseases has been forecasted, farmers in the areas will cooperate in spraying or dusting fungicides under the direction of plant pathologists and farm advisors.

4. Rice Seed Disinfection

In the case of diseases of rice, there are major seed-borne diseases. Among them are blast, *Helminthosporium* leaf spots, "*Bakanae*" disease, white tip, etc. In the case of seed and seedling rot, though it is not seed-borne disease, seed disinfection is effective for the control. As a result, it is recommended to treat seeds with fungicides before seeding.

1. Seed collection

The collection of seeds from the infected paddy fields and the collection of the infected seeds must strictly be avoided. When the harvesting is delayed, cracks in the seeds would be caused and aggravate "*Bakanae*" disease or seeding rot.

Attention must be paid so as to collect sound seeds timely. If the seeds are scratched in threshing, it would become a predisposing factor. As a result, it is better to thresh with comb-toothed thresher or foot-pedal thresher. When a power thresher is used, it is necessary to lower the speed of rotations (to 300 r.p.m. and less).

2. Selection of seed grains

As the infected seeds are generally less plumpy and low in specific gravity, the seed selection by specific gravity such as salt water selection is practised.

3. Seed treatment

(i) Seed treatment with fungicides

Infections diseases such as rice blast, *Helminthosporium* leaf spot, and "*Bakanae*" disease in which fungi infest on the seed surface are treated with organomercurial compounds.

(a) Seeds are soaked in the solution of 1/1,000 dilution of Uspulun, Riogen, Mernosan, or Microgen-tablet at temperature of 18°C for 6-12 hours. If the temperature of solution of chemicals is lower than 18°C, the soaking hour must be prolonged by one hour each for every 1°C decrease. When the temperature of solutions is below 10°C, it will show a marked decrease in the effect of treatment. Attention must be paid so as to keep the solution at high temperature. It is needless to wash seeds with fresh water after treatment. It is more effective to treat the sprouted seeds with fungicides after soaking dried seeds in water for one or two days than treating the dried seeds. But as there is a fear for damage by fungicides in the former case, attention must be directed to this point.

Modified seed treatment methods: (i) After soaking the seeds in a 1/1,000 solution of Uspulun, Riogen, and Microgen-tablet for one hour, the seeds are covered with wet straw mat for 6 hours. Or after soaking in a 1/200 solution for 10 minutes, the seeds are covered with wet straw mat for three or four hours. (ii) Seeds are soaked in a 1/200 or 1/300 solution of Uspulun, Riogen, or Microgen-tablet for two or three hours, respectively.

(b) Seeds are soaked in 1/1,000–1/2,000 solution of PMF or Mer solution for two or three hours. Washing of seeds with fresh water after the treatment is needless.

(c) Seeds are soaked in Ruberon-tablet solution (5 tablets per 10 liters water) for four to six hours, or soaked in Riogen-tablet solution (5 tablets per 10 liters water) for three to eight hours. The sterilizing effect will not show any decrease even at low temperature with these solutions. Constituents of the above organic mercurial compounds are prescribed below:

Uspulun:	Methoxyethyl mercuric chloride (containing 2.5% mercury)	4.2 %
Riogen:	Phenyl mercuric acetate (containing 1.1% mercury)	1.85%
Microgen-tablet:	Phenyl mercuric acetate (containing 2.7% mercury)	4.5 %
Mernosan:	N-ethylmercuri-p-toluene-sulfonanilide (containing 3.2% mercury)	7.7 %
PMF or Mer:	*Phenyl mercuric dinaphthylmethane* disulfonate (containing 4.0% mercury)	10.0 %
Ruberon-tablet:	Ethyl mercuric phosphate (containing 2.5% mercury)	3.4 %
Riogen-tablet:	Phenyl mercuric acetate and ethyl mercuric chloride (containing 2.4% mercury)	3.5 %

(ii) Hot water treatment

The nematodes pathogenic to white tip hide themselves into the inner part of hulls. As a result, it can not be treated effectively with fungicides. Hot water treatment is effective.

(a) After soaking the seeds in fresh water at temperature of 20°C and under for 16–24 hours, the seeds are soaked in hot water at temperature of 50–52°C for 5–10 minutes. Immediately thereafter, the seeds are cooled with water.

(b) For the purpose of quick treatment, the dried seeds are soaked in hot water at temperature of 56–57°C for 10–15 minutes, and then cooled.

Moreover, it is more effective to spray a Parathion emulsion (46 per cent) after anthesis, together with the hot water treatment of seeds.

5. Characteristics of the Major Diseases and Their Control Method

1. *Blast*

Blast is the most serious disease of rice in Japan. The infected paddy fields reach about 753,000–1,376,000 hectares every year, or a decrease in the annual rice production of approximately 40,000–144,000 tons. The decreased production of individual paddy fields accounts for 10–20 per cent, but in some cases, the decrease will reach as high as 80 per cent or more. Blast attacks on plant leaves, nodes, necks, and sometimes on young grains or glumes, thus showing the decrease in rice production and the deterioration in rice quality.

On the infected leaves, small dark green spots appear at first, and the spots grow larger. The inside of the spots assumes ash-color, the spots are fringed with reddish brown color, and their external part becomes yellow. The spots are shaped into a spindle or a long-spindle form. In the case of rotten-neck, the part of the nodes of the stems assumes light or dark brown color. The infected areas spread up and down. When the neck is attacked at earlier stage, panicles will assume white color and will stand erect. The infected rachis branches assume brown or dark brown color. The infected nodes turn black and become readily breakable. The infected grains in whole or part will assume dark gray color at first and then will turn dark ash color, thus resulting in poor ripening or sterility.

In Japan, two types of blast occurrence are observed: (i) the northern type blast, in which leaf blast or seedling blast occurrence is not so serious, but the damage by rotten-neck is serious, affecting directly the rice yield to a considerable extent; and (ii) the southern type blast, in which in some years rotten-neck may occur severely, but in general seedling blast or leaf blast occurrence after transplanting is severe. In some cases, the rice plant growth will be checked and the infected leaves will die. As a result, rice plants will become dwindled markedly. The medium type blast may also be observed according to the climatic conditions or the rice cultural practices.

In general, the causal fungi of blast winter in the infected straws or grains. It has recently been found that there exist several species of graminaceous weeds which carry blast fungi. The conidiospores of blast fungi germinate well (76.6 per cent) with the aid of dew on the leaves, but at the saturated relative humidity, they will not germinate well, and at relative humidity below 96 per cent they cannot germinate. The optimum temperature for the germination of conidiospores and the formation of appressoria is 20–30°C (in the case of pH 5.4), but rice plants are mostly infected with blast at temperature of 20–24°C. When cool or wet spells last long from transplanting to tillering stage and when the relative humidity at heading stage is high, rice blast will occur severely.

Control measures: For the blast control, the following measures are recommended.

Cultural cares: (i) Planting of blast resistant varieties is required; (ii) timely transplanting must be practised because rotten-neck will occur severely when transplanting is delayed; (iii) care should be taken so as to promote the rice plant growth and close seeding or close planting must be avoided; (iv) irrigation of cool water must be avoided; (v) care should be taken of drainage, and too early drainage at ripening stage should be avoided; and (vi) too liberal or too delayed application of nitrogenous fertilizers should be avoided.

Sanitary measures: (i) The infected straws or hulls must be decomposed fully by using them as compost materials, the infected straws or hulls should not be left alone around paddy fields; (ii) fresh hulls should not be used as cover materials in rice nursery beds; and (iii) the infested seedlings should not be transplanted.

Preventive measures: (i) Seed selection, e.g., through the salt water selection the infected poor seeds should be picked out; (ii) seed treatment, e.g., seeds are required to be treated with organomercurial compounds; (iii) spraying or dusting of fungicides over paddy fields, e.g., spraying of Bordeaux mixture, copper fungicides, copper mercurial fungicides, organomercurial fungicides (wettable powder or emulsion), antibiotics (wettable powder), or dusting of organomercurial powder or antibiotic powder.

For leaf blast prevention, about 0.4 per cent Bordeaux mixture of doubled amount of lime or organomercurial compounds is applied at the rate of 1,000–1,500 liters per hectare before booting stage, or organomercury powder or mixture of antibiotic and mercurial compound (Blasticidin S-M dust) is dusted at the rate of 35 kilograms per hectare. Application of these fungicides is preferable to be made before infection or immediately after infection. It is better to avoid too late application after infection, because its effect will become less.

Rotten-neck control is done at the booting stage and immediately after the end of flowers. For this purpose, about 0.3 per cent Bordeaux mixture of triple amount of lime or organomercurial compound is sprayed at the rate of 1,500–1,800 liters per hectare, or organomercury dust or antibiotics-mercury mixture is dusted at the rate of 35–50 kilograms per hectare (Table 5–7).

Table 5 – 7. Effect of Fungicides on Rotten-Neck (Tohoku Agr. Exp. Sta.)

Fungicides	*Infected panicles*
Blasticidin S–M dust	23.3 %
Organomercurial compounds	34.8
No fungicides	69.8

Node blast and rachis-blanch-rot control: At the booting stage and two or three days after heading, dusting is made at the rate of 35–50 kilograms per hectare. When attacked by a typhoon, it is desirable to dust once more immediately after the typhoon.

When copper compounds like Bordeaux mixture are applied, japonica type rice plants will be affected by copper compounds and sometimes result in the decreased rice yield by about 5–10 per cent. In view of this, antibiotics or organomercurial compounds have recently come into use in Japan. While the application tests on phenyl mercury compounds (e.g., phenyl mercuric acetate or N-phenyl mercuric-p-toluene-sulfonanilide) and N-tolyl mercuric-p-toluene-sulfonanilide conducted at the experiment station in Ceylon proved to be highly effective, as is the case with the tests in Japan, but the tests evidenced that some indica type rice varieties were severely injured. In the case of a country planting rice varieties of low resistance to the fungicides, ethyl mercuric compounds will be the only organomercurial compounds which can be applicable to any varieties without injury, though the effect is unsatisfactory. Most of the indica type varieties are resistant to the injury by antibiotics.

Fungicides used as sprays and dusts are as follows:

Copper fungicides:	Basic copper chloride or basic copper sulfate containing 16, 10 or 2% copper
Copper mercury fungicides:	Basic copper chloride or basic copper sulfate 2–3% copper, blended with phenyl mercuric acetate, ethyl mercuric phosphate etc., containing 0.15-0.08% mercury
Organomercurial sprays:	
Ceresan spray	Phenyl mercuric acetate containing 2.5% mercury
Meran spray	N - tolyl mercuric - p - toluene-sulfonanilide, phenyl mercury acetate containing 4.8% mercury
Fumiron spray	N - phenyl mercuric - p - toluene - sulfonanilide, ethyl mercury phosphate, ethyl mercury urea containing 4.8% mercury
Microgen spray	Phenyl mercuric acetate containing 2.5% mercury
Mer spray	Phenyl mercuric dinaphthylmethane disulfonate, etc., containing 4.0% mercury
Organomercurial dusts:	
Ceresan lime dust	Phenyl mercuric acetate containing 0.25% mercury
Ceresan lime 166 dust	Phenyl mercuric acetate containing 0.16% mercury
Riogen dust	Phenyl mercuric acetate containing 0.25% mercury
Ruberon lime 15 dust	Ethyl mercuric phosphate containing 0.15% mercury
Ruberon lime 30 dust	Ethyl mercuric phosphate containing 0.30% mercury

Fumiron dust	Phenyl mercuric iodide containing 0.30% mercury
Meran dust	N - tolyl mercuric - p - toluene-sulfon-anilide, phenyl mercuric acetate containing 0.20% mercury
Mer dust	Phenyl mercuric dinaphthylmethane disulfonate containing 0.15% mercury
Antibiotics:	
Blasticidin S-M dust	0.1% Blasticidin S and phenyl mercuric acetate containing 0.1% mercury

2. *Sheath Blight*

Sheath blight is a fungus disease widely found on rice throughout the country. Approximately 625,000–890,000 hectares of paddy fields are affected every year, showing a decrease in the rice production of around 78,000–143,000 tons for each year.

This disease appears in early summer, and becomes severe in August and September. Spots occur mainly on the leaf sheaths and afterwards may sometimes spread over the leaves. They are at first greenish-grey oval-shaped ones of about 10 millimeters long each, and develop gradually into the ash-colored cloud-shape spots fringed with dark-brown color. Sclerotia of pathogen detached from diseased tissues winter in paddy fields. When paddy fields are brought under irrigation in next spring, many sclerotia will float on the water surface and inroad into the inner part of leaf sheaths through their seams, thus spreading infection. The fungi of this species are omnivorous and attack various weeds around paddy fields.

Control methods: (i) It is desirable to abstain from excessive nitrogenous fertilizer application; (ii) straws of the infected rice plants should be used as compost materials so that straws can be decomposed fully and should not be left alone in paddy fields; (iii) rice varieties more resistant to sheath blight must be planted; (iv) fungicides are required to be applied. Tuzet (Monzet) or Asozin (wettable powder or dust) is recommended (Table 5–8).

Table 5-8. Effect of Organic Arsenic Compounds on Sheath Blight
(Chugoku Agr. Exp. Sta.)

Compounds	*Rate of damage*
Monzet (1/2,500)	1.9 %
Asozin (1/2,000)	1.6
No fungicides	30.6

Tuzet (Monzet) contains:

20% Urbazid (Methyl arsine-bis-dimethyl-dithio-carbamate);
40% TMTD (Thiram) (Tetramethyl-thiuramid-sulphide); and
20% Ziram (Zinc-dimethyl-dithio-carbamate).

Asozin contains 50 per cent Methylarsin sulphide. Tuzet (1/2,500–1/3,000 solution) or Asozin (1/2,000 solution) is applied at the rate of 1,000–1,500 liters per hectare one or two times during the period from young-panicle formation stage to booting stage. In the case of dust, 30 kilograms are dusted per hectare.

3. Bacterial Leaf Blight

Paddy fields covering 264,000–410,000 hectares are affected every year by bacterial leaf blight, inflicting a serious damage upon rice production throughout the country. Bacterial leaf blight occurs in every part of the country, particularly occurs frequently in the paddy fields which may readily be flooded due to the nearness to coasts, river basins, lakes or reservoirs and which are lying in the level area consisting of fertile alluvial soils.

Symptoms are observed mainly in late summer or in early autumn, but the disease sometimes occurs in the nursery stage. Leaves are fringed with wettish discolored parts and the discolored parts become yellow and enlarge rapidly, thus spreading to the inner parts of leaves.

Pathogen can survive to the next rice growing season in the infected straws or grains. Besides rice plants, such weeds as *Leersia oryzae* var. *Japonica* HACK or *Zizania latifolia*

HANCE are affected by bacterial leaf blight. The former is regarded as an important pathogen source just like an infected straw is. In the case of such weeds, pathogen winters in the rhizome or in the rhizosphere. Pathogen is usually carried by mud water at flooding time and the lower leaves of rice plants are infected with bacterial leaf blight.

Bacterial leaf blight will occur severely under the weather with plentiful rainfall, strong wind and temperature of 22–26°C (neither too high nor too low). As a result, this disease will break out after typhoons. When the flooded seedlings or the infected ones are transplanted, the disease will occur severely at the early plant growth stage. By the excessive application of nitrogenous fertilizers the occurrence of this disease will be accelerated.

Control measures: (i) Planting of bacterial leaf blight resistant varieties is recommended; (ii) seeds are soaked in a 1/1,000 solution of organomercurial compounds for 6–12 hours; (iii) paddy fields must be kept free from flood; (iv) rice nurseries are required to be kept free from flood; (v) excessive nitrogenous fertilizer application is avoided; and (vi) 3 per cent Bordeaux mixture of double amount of lime or copper compounds (1 lb. in 189.5 liters of water), or antibiotics (streptomycin, cellocidin, etc.) are sprayed thoroughly over the lower leaves at the end of tillering stage, and the second spraying is tried about 10–15 days prior to the booting stage.

4. *Virus Diseases*

Virus diseases of rice plants found in Japan are divided into four kinds: dwarf, stripe disease, yellow dwarf, and black-streaked dwarf. Virus diseases occur mostly in warm parts, the Kanto District and westward. With the increasing acreage of early seasonal rice culture, the occurrence of virus diseases in these parts are becoming increasingly severe. About 93,000–175,000 hectares are affected every year by dwarf, and about 27,000–202,000 hectares by stripe disease, inflicting great damage upon rice production. The symptoms

Table 5 – 9. Symptoms of Virus Disease

	Dwarf	*Yellow dwarf*	*Stripe-disease*	*Black-streaked dwarf*
Growth in general	Marked stunting	Marked stunting	Slight stunting	Marked stunting
Tillering	Excessive	Excessive	Depressed	Depressed
Symptoms on leaves	Conspicuous yellow-white specks along the veins, often coalescing to form interrupted streaks	Chlorosis	Yellowish mottles or stripes along the veins. Newly emerged leaves fail to unfold, lack in vigor, and die early	A few, short black streaks on the lower surface of leaf blade, and on the surface of leaf sheath

of virus diseases are as shown above.

Virus diseases are transmitted merely by specific species of leafhoppers. Namely,

Dwarf: *Nephotettix apicalis cincticeps* UHLER *Nephotettix apicalis* MOTSCHULSKY, and *Inazuma dorsalis* MOTSCHULSKY;
Yellow dwarf: *Nephotettix apicalis cincticeps* UHLER, and *Nephotettix bipunctatus* FABRICLUS;
Stripe-disease and black-streaked dwarf: *Delphacodes striatella* FALL.

When vectors become viruliferous, they retain their infectivity almost as long as they live. As a result, a single vector (leafhopper) can transmit infection to a great number of plants. In the cases of dwarf and stripe-disease, the viruses can be transmitted to their offspring through the eggs of the viruliferous insects. Besides rice plants, many species of graminaceous crops or weeds may be infected with stripe-disease or black-streaked dwarf, but the winter of the viruses is done mostly by wintering vector larvae. After young panicle formation stage, rice plants are not infected by dwarf, stripe-disease, and black-streaked dwarf, while rice plants are infected by yellow dwarf even after the young panicle formation stage.

Control measures: (i) Attention must be paid to the rice cultural season, because in the case of too early or too late seasonal rice culture, leafhoppers gather too much and virus diseases will occur frequently; (ii) insecticides must be sprayed at the later nursery stage and the tillering stage after transplanting (both stages fall on the main infection period). Namely, 0.02 per cent Parathion, 0.04 per cent Malathion and 0.03 per cent NAC (Sevin) are applied at the rate of 900–1,500 liters per hectare, or 1.5 per cent Parathion dust, 1.5 per cent Malathion dust, 1.5 per cent Diazinon dust, and 3 per cent BHC dust (restricted only to the case of small brown planthopper control) are dusted at the rate of 20–30 kilograms per hectare (any great effect can not be brought about unless spraying or dusting is operated cooperatively ranging over the wide areas); and (iii) in order to prevent the secondary infection, the infected hills must be rogued at the earlier stage.

5. *Stem Rot*

About 35,000–96,000 hectares of paddy fields are infected with stem rot every year. Stem rot occurs widely all over the country, particularly much in the central and southern parts of the country. A damage is particularly severe in such areas as ill-drained paddy field areas, areas of excessive nitrogen application or potash-deficient areas.

The surface of leaf sheaths at the water surface is streaked lengthwise with black color. According as the disease aggravates, the same spots will develop in the inner part of leaf sheaths, stems will become softened and rotten, and the tops will discolor. When infected severely, rice plants will lodge. Numerous small black sclerotia develop in the internal parts of the culms of the infected hills.

Wintering of pathogen is done in the form of sclerotia, and which cause the primary infection in next year. The sclerotia are usually plowed under the soils together with stubbles by plowing after harvesting of rice. In next spring, on the occasion of harrowing before transplanting and weeding after transplanting, a great number of sclerotia will float on the irrigation water and attack rice plants.

Control measures: (i) In the case of the infected paddy fields, with a view to minimizing the survived sclerotia, the infected hills are cut as closely as possible to the surface of the ground so that the infected culms may not remain; (ii) As the stem rot will occur severely when potash supply is poor, potash fertilizers or wood ash must be supplemented, and care be taken so that nitrogenous fertilizers may not applied too liberally; (iii) high ridge cultural practice is desirable because it minimizes the infection; (iv) water-logged paddy fields are desired to be drained; (v) planting of late-maturing varieties is desired, if possible, because early-maturing varieties are very susceptible to stem rot; (vi) at the tillering stage (at which sclerotia attach and invade into rice plants) the irrigation water is kept shallow in depth, and too early draining after heading must be avoided; and (vii) it is effective to spray into the hills with organomercurial compounds (phenyl mercuric acetate, dust or spray of Ceresan lime, Riogen, Microgen, Meran, etc.) two times during the period from young-panicle formation stage to the early stage of internode elongation (Table 5-10).

Table 5-10. Effect of Fungicides on Stem Rot
(Akita Pref. Agr. Exp. Sta.)

Fungicides	*Damage rate*
	%
Organomercurial compounds	3.7
Copper compounds	53.1
No fungicides	60.5

6. *Brown spot (Helminthosporium leaf spot)*

About 58,000–96,000 hectares of paddy fields are infected with brown spot every year. Brown spot occurs all over the country, particularly severely in *Akiochi* disease soil areas. Phathogen of brown spot winters in the infected seeds or straws. On the occasion of germination of the infected seeds, seedling blight will occur. Brown spot occurs by the dispersion of conidiospores from the piled-up infected straws to near-by rice plants.

Control measures: (i) In order to prevent the occurence of brown spot, it is desirable to ameliorate the paddy field soil, viz., in the case of *Akiochi* areas (e.g., sandy soil or peat soil), it is desirable to admix the red soil (45 tons per hectare) to the paddy field soil in order to supplement minerals and clay materials. At that time, it is important to apply composts and stable manures to the fullest extent; (ii) "turning-over" plowing is required to be practised in the case of ill-drained paddy fields; deep plowing in the case of shallow top soil; and ill-drained paddy fields must be converted into well-drained ones; (iii) together with deep plowing, organic fertilizers (composts and stable manures) are required to be applied to the fullest extent; (iv) potash must be applied adequately, and in order to prevent fertilizer-deficiency, the application of ammonium sulfate in the form of ball fertilizers or solid fertilizers or split application is preferable, e.g., in the case of sandy soils it is effective to apply nitrogenous fertilizers splitting at two or three times. In this case, the final application must be done not later than the young-panicle formation stage; (v) in the case of *Akiochi* soils, the application of fertilizers containing no sulfate-radical is preferable, because due to the application of fertilizers containing sulfate-radical (e.g., ammonium sulfate or potassium sulfate), hydrogen sulfide occurs, thus causing root-rot and brown spot; (vi) planting of brown spot resistant varieties is recommended (in practice, there are some varieties somewhat resistant to brown spot); (vii) as is the case with blast, seeds must be treated with organomercurial fungicides; and (viii) spraying of Bordeaux mixture is undesirable, except the paddy fields infected severely with brown spot.

III. INSECT PEST CONTROL

1. Foreword

1. Significance of insect pest control

Damage by insect pests can be cited as one of the greatest injuries to crop plants. It is well known that in every country a great amount of losses are caused every year by the insect pest damage. Losses caused by insect pest damage result not only in the decreased production of the crops but also in the failure in farmers' crop planning due to the disturbance in the cropping sequence. Timely shipment of farm products may sometimes become impossible and the labor distribution will be greatly affected adversely. As a result, insect pest control measures should be taken with a view to securing the stability of crop farming. In the past, the damage inflicted by insect pests is used to be regarded as unforeseen disasters, but, in the future, further efforts should be made to find more effective insect pest control methods and to bring them into practice in order to prevent insect pest damage beforehand.

2. Problems in practising insect pest control

The occurrence of insect pests prevailing now in Japan dates back to very early times. When we consider that these insect pests have survived and continued to multiply up to now by overcoming the great natural disasters, we cannot but recognize that their vitality is powerful and their adaptability for the environmental conditions is great. In fighting against fearful insect pests, their mode of life must be clarified to begin with. In view of the past performance in the field of insect pest control, we are aware of that the stability of cropping is not always secured partly due to the limited control measures. Since agriculture is one of the enterprises, the insect pest control must be carried out in conformity with individual farmers' limited economic conditions, namely, an effective insect pest control must be practised within farmers' limited capital and labor input. These are the prime factors to be taken into consideration. Farmers' knowledge level is another important factor to be taken into consideration. The insect pest control technical level and the ability to practise insect pest control methods vary according to the farmers' own qualifications. Various environmental conditions, such as topography, size of area, and climatic conditions are also to be taken into consideration. If not, the expected effect can not be obtained.

To sum up, when taken into consideration the inevitable restrictions on the insect pest control practices and the fact that insect pests themselves are a fairly powerful enemy, it is by no means wise to adopt so reckless control measures that may lead to the bankruptcy of farmers' economy. It is rather preferable to attain the desired insect pest control while protecting farmers' economy by attacking the most weak points of insect pests, and to attain the ultimate success in the farm cropping.

2. General Descriptions of Insect Pest Control

1. Occurrence of insect pests and changes in their occurrence

To begin with, it is necessary to know the exact name of the insect pest to be controlled, the duration and extent of its occurrence, and its damage rate. However, even in the same area, the frequency and rate of insect pest occurrence will differ from year to year, and some insect pests that caused no appreciably great damage in the past have often become terrible in the course of time, for example, rice leaf miner (*Agromyza oryzae* MUNAKATA), rice stink-bug (*Lagynotomus assimulans* DISTANT), and black rice bug (*Scotinophora lurida* BURMEISTER). Such changes in the occurrence of insect pests are considered to have been caused chiefly by the climatic conditions, presence of natural enemies, planting, and other artificial measures. A further effort is required to be made in order to make clear the causes for such changes. The changes in the insect pest occurrence can roughly be divided into two categories: changes in the rate of occurrence and changes in the time of occurrence. The former can be subdivided into chronical occurrence (regular occurrence every year) and abnormal occurrence (outbreaks only in some years suddenly, though little or no occurrence in other years). Among the insect pests chronically occur are: rice stem borer (*Chilo Suppuresalis* WAKER), paddy borer (*Schoenobius incertellus* WAKER), rice leaf miner (*Agromyzu oryzae* MUNAKATA), and rice plant skipper (*Parnara guttata* BREMER et GREY). Among the abnormal outbreak of insect pests are: zigzag-striped leafhopper (*Delloccphalus dorsalis* MOTSCHULSKY), smaller brown plant hopper (*Delphacodes striatella* FALLEN), brown planthopper (*Nilaparvata lugens* STAL) and rice crane fly (*Tipula aino* ALEXANDER). However, it cannot always be said so by regions and districts. The insect pest propagation is affected not only by their proper biotic potential, e.g., the number of eggs laid by one female insect, hatching rate, number of insects growing up, rapidity of growing-up, and frequency of occurrence, but also affected by the environmental resistance against the insect pests e.g., the effect of environment to suppress insect propagation, and the effect of propagated insects themselves in suppressing or promoting the further propagation. The environmental resistance against the respective insect pests is not always fixed, but varies according to the years and areas. As a result, even in the case of the same species of insect pest it sometimes occurs chronically or abnormally. In general, however, when an insect pest occurs chronically, its procreative power is less, but in the case of an abnormal outbreak the procreative power fluctuates up to a great extent. Some insect pests seem to show periodical increase or decrease in occurrence, while others break out suddenly without showing any evil omen even in the previous season. In the case of the former, the customary control measures can safely be taken, but in the case of the latter, the appropriate control measures should be taken based upon the results of the forecast for the occurrence.

It is clearly recognized that the time of occurrence of insect pests varies widely from year to year. This fact seems to be caused by different environmental conditions, particularly, by the different climatic conditions. Each insect requires its own sum of accumulated temperature for completing their growth. Also, the growth is affected by the critical temperatures, maximum and minimum. The effective temperatures to be given for the growth of certain insect pests, therefore, vary according to the climate in the respective years. The time of occurrence of certain soil insect pests is influenced also by the soil moisture. (Soil moisture has a positive correlation with precipitation.) In the case of an early seasonal rice culture practice, owing to the earlier harvesting the insect pests against paddy rice plants will lose their host crop and become deprived of the supply of feeds in the course of their growth, resulting in a lower rate of occurrence. Thus, the environmental conditions which effect the occurrence of insect pests vary from year to year. Therefore, basing on the response of insect pest to the given environmental condition the mode of occurrence must be forecasted. The exact forecast about the insect pest occurrence is of prime importance for the insect pest control measures. The occurrence of insect pests is affected greatly by the environmental resistance which may vary with such physical conditions as supply of feeds, presence of natural enemies, and antagonistic relation within the same kind or between the different kinds of insect. As to the effect of climatic conditions, the death rate of the larvae of the first generation rice stem borers (*Chilo Suppresalis* WAKER) and that of the larvae of the second generation rice leaf miners (*Agromyza oryzae* MURATA) will be raised according as the summer temperature rises higher than the optimum temperature for their growth. When the precipitation at the peak egg-laying stage is higher, the hatching rate of rice crane flies (*Tipula aino* ALEXANDER) will rise. Conditions of crop plants, as a food source for insect pests, effect the occurrence of insect pests, depending upon whether or not the crop plants are in appropriate stage, of appropriate variety or under appropriate cultural practice which favor feeding of insects. For instance, most of the larvae of rice stem borers and paddy borers will die when they attack the rice seedlings growing in the nursery at high seeding rate due to the lack of parenchyma among vascular bundles, while they can readily breed when they bore into the seedlings grown with heavy application of nitrogenous fertilizers because the stems and leaves of the seedlings become softened.

2. *Forecast for the insect pest occurrence*

Since the insect pest occurrence varies with the years and environmental conditions, it is not right to repeat the insect pest control practice in a definite season every year. In order to obtain the effective control, insect pests must be controlled basing upon the results of the exact forecast for the insect pest occurrence for each year. As the available forecasting methods, the following three methods can be cited: (a) field observational forecasting method; (b) statistical forecasting method; and (c) theoretical forecasting method.

(a) Field observational forecasting method

The rate of occurrence of insect pests is forecasted by keeping the field observation. For this purpose, the general knowledge of the life history of insect pests and the forecasting ability of forecasters are required. In the case of planthoppers or leafhoppers (having relatively short life time and great biotic potential, with violent changes in the occurrence), it is possible to forecast the occurrence in a short term in the limited area. Although by this method the forecast can be made immediately before the occurrence, it is rather exact, because the forecasting is based on the actual trend of occurrence. This method, therefore, can be successfully applicable in combination with other forecasting methods, in case where the occurrence of insect pests in the fields has been disturbed artificially, e.g., by the spraying of insecticides. However, in obtaining a successful forecast, it will require the technical skill and the continued efforts on the part of forecasters. In view of this, this forecasting method can not be used so widely.

(b) Statistical forecasting method

This method is adopted widely as the principal forecasting method. In former days, the environmental conditions, particularly, climatic conditions were used as the index, and it was a relatively long-term forecasting method. However, such method does not hit when the occurrence of insect pests has been disturbed by the artificial measures. In recent years, therefore, it has been changed to aim a relatively short-term forecasting, using the results obtained by the field observation. In order to attempt such statistical forecast, the statistical data for several years are required. With a view to finding out the definite relations between the time and the rate of occurrence of the insect pests to be controlled and the environmental elements, a certain number of the possible combinations should be examined. For instance, in case of the forecast for the peak moth-emergence date of rice stem borers, an optional date is taken up, and is expressed by "zero" and the number of days up to the peak emergence date for each year is laid down as variables of Y axis on the graph instead of an actual peak moth-emergence date for each year (because the latter can not be laid down on the graph). On the other hand, the numerical value indicating the environmental elements (referred to element of index) for each year is laid down as variables of X axis on the graph. If the dots on the graph are aligned regularly, the correlation between X and Y should be considered to be great. Then the coefficient of correlation between the two is computed.

The results obtained at the Nagano Prefectural Agricultural Experiment Station is cited as an example. In the case of this example, the peak emergence date of the first generation rice stem borer moths (Y) was taken as forecasting item, and the minimum temperature for each day from April 11 to May 31 for each year (X) as elements of index. For this purpose, data in 19 years (n) from 1931 to 1949 were used. Table 5–11 was thus obtained by the usual method of calculation.

Table 5 – 11.

n	X	Y	$X-\bar{X}$	$Y-\bar{Y}$	$(X-\bar{X})^2$	$(Y-\bar{Y})^2$	$(X-\bar{X})(Y-\bar{Y})$
1931	5.7	32	−1.0	5.2	1.00	27.04	−5.20
1932	6.7	29	0	2.2	0	4.84	0
1933	7.9	21	1.2	−5.8	1.44	33.64	−6.96
1934	6.3	29	−0.4	2.2	0.16	4.84	−0.88
1935	7.4	25	0.7	−1.8	0.49	3.24	−1.26
1936	6.1	24	−0.6	−2.8	0.36	7.84	1.68
1937	8.0	28	1.3	1.2	1.69	1.44	1.56
1938	7.5	21	0.8	−5.8	0.64	33.64	−4.64
1939	6.4	26	−0.3	−0.8	0.09	0.64	0.24
1940	6.3	26	−0.4	−0.8	0.16	0.64	0.32
1941	6.7	25	0	−1.8	0	3.24	0
1942	6.0	26	−0.7	−0.8	0.49	0.64	0.56
1943	6.0	29	−0.7	2.2	0.49	4.84	−1.54
1944	7.8	26	1.1	−0.8	1.21	0.64	−0.88
1945	5.2	30	−1.5	3.2	2.25	10.24	−4.80
1946	6.8	21	0.1	−5.8	0.01	33.64	−0.58
1947	5.7	39	−1.0	12.2	1.00	148.84	−12.20
1948	8.0	20	1.3	−6.8	1.69	46.24	−8.84
1949	7.4	32	0.7	5.2	0.49	27.04	3.64
T.S.	127.9	509			13.66	393.16	−39.78
M	6.7	26.8			0.7189	20.693	−2.0936

Note: n: Survey years.
X: Daily average mini. temperature from April 11 to May 31.
Y: Date of peak moth emergence of the first generation rice stem borer moths.
$X-\bar{X}$: Difference between "X average for 19 years and X for each year".
$Y-\bar{Y}$: Difference between "Y average for 19 years and $\bar{Y}$ for each year".

Correlation coefficient and mean deviation can be obtained by using the following equations:

$$\sigma x=\sqrt{\frac{\Sigma(X-\bar{X})^2}{n}}=\sqrt{\frac{13.66}{19}}=\sqrt{0.7189}=\pm 0.848,$$

$$\sigma y=\sqrt{\frac{\Sigma(Y-\bar{Y})^2}{n}}=\sqrt{\frac{393.16}{19}}=\sqrt{20.693}=\pm 4.548,$$

$$r=\frac{\Sigma(X-\overline{X})(Y-\overline{Y})}{n\cdot\sigma x\cdot\sigma y}=\frac{-39.78}{19\times0.848\times4.548}=\frac{-2.0936}{0.848\times4.548}=-0.5429,$$

$$\sigma r=\frac{1-r^2}{\sqrt{n}}=\frac{1-0.2949}{4.359}=\pm0.16,$$

where σx : Standard deviation for the variable on X axis,
σy : Standard deviation for the variable on Y axis,
n : Number of survey years,
r : Correlation coefficient.

As shown above, the result obtained indicates very little correlation. Correlation expresses a functional relationship and can be measured based upon the regression line describing the functional relation between the variables of X and Y (Fig. 5-9). The equation describing the regression line obtained by using the method of least squares is the emergence forecasting formula we wish to obtain. In case where there is a correlation between the two values (X and Y), X is a function of Y, and the equation used to find the function is known as the regression equation of Y on X. When this equation is linear, it is represented by

$$Y=ax+b \quad (a,\ b:\text{constants}).$$

The values of a and b are computed as below by using the method of least squares (Table 5-12 is applied).

$$a=\frac{\Sigma(X)\Sigma(Y)-n\Sigma(XY)}{\{\Sigma(X)\}^2-n\Sigma(X^2)}=\frac{(127.9\times509)-(19-3386.6)}{(127.9)^2-(19\times874.61)}$$

$$=\frac{65101.1-64345.5}{16358.41-16617.59}=\frac{755.7}{-259.18}=-2.9158,$$

$$b=\frac{\Sigma(X)\Sigma(XY)-\Sigma(X^2)\Sigma(Y)}{\{\Sigma(X)\}^2-n\Sigma(X^2)}=\frac{(127.9\times3386.6)-(874.61\times509)}{(127.9)^2-(19\times874.61)}$$

$$=\frac{433146.14-445176.49}{16358.41-16617.59}=\frac{-12030.35}{-259.18}=46.416,$$

Then $Y=-2.9158X+46.416$.

This is the equation which we want to obtain. In order to know the peak emergence date of the first generation rice stem borer moths, the value of Y can be obtained by replacing

Table 5 – 12.

n	X	Y	X^2	XY
1931	5.7	32	32.49	182.4
1932	6.7	29	44.89	194.3
1933	7.9	21	62.41	165.9
1934	6.3	29	39.69	182.7
1935	7.4	25	54.76	185.0
1936	6.1	24	37.21	146.4
1937	8.0	28	64.00	224.0
1938	7.5	21	56.25	157.5
1939	6.4	26	40.96	166.4
1940	6.3	26	39.69	163.8
1941	6.7	25	44.89	167.5
1942	6.0	26	36.00	156.0
1943	6.0	29	36.00	174.0
1944	7.8	26	60.84	202.8
1945	5.2	30	27.04	156.0
1946	6.8	21	46.24	142.8
1947	5.7	39	32.49	222.3
1948	8.0	20	64.00	160.0
1949	7.4	32	54.76	236.8
T.S. 19 years	127.9	509	874.61	3,386.6

Notes: n: Survey years (1931∼49).
X: Average minimum temperature for 51 days from April 11 to May 31.
Y: Average peak emergence of the moths for the entire emergance period of the first generation months (counted from May 30).

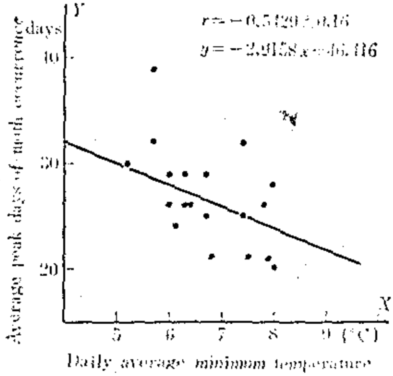
X of this equation by the element of index in that year, and the definite date of the peak moth-emergence can be obtained by counting from the day, May 30 ("zero" date).

In formulating the equation, it is important to exclude the exceptionally abnormal combinations of X and Y out of the data, and to pay special attention to the significance of the correlation coefficient because the number of available samples (n) are sometimes too small.

Next, since the forecasting equation was formulated by excluding the exceptional samples out of the data, this equation is not applicable to the forecast for the abnormal occurrence or sudden outbreak. Since the application of this equation is confined to the conditions similar to the case of the samples adopted, it is hard to apply this equation to the case where some changes have, due to the artificial measures, taken place in the environmental conditions from those at the time of the formulation of this equation. Moreover, in formulating the forecasting equation, it is practically impossible to collect many samples ranging over wide areas, and the environmental conditions for insect pest occurrence vary from one area to another. As a result, the forecasting equations are required to be formulated according to the environmental conditions of the respective regions.

Fig. 5 – 9. Regression Line Describing the Relation between Y and X

(Nagano Prefectural Agr. Exp. Sta.)



3. Theory and practice of insect pest control

The term "insect pest control" is liable to remind us of killing the insect pests which may occur in the field, but this is a matter of minor importance. The importance of the insect pest control should be placed on the protection of crops from being damaged by insect pests. To kill insect pests is not necessarily an ultimate object. Insect pest control effective in protecting crops at a minimum expense is of most importance. For this purpose, three measures can be recommended: (a) suppression of the insect pest breeding by strengthening the environmental resistance of fields against the propagation of insect pests; (b) protecting crop plants from being damaged by insect pests by improving or changing the crop cultural methods; and (c) checking the insect pest breeding by introducing natural enemies.

(a) Suppression of the insect pest breeding by strengthening the environmental resistance of crop fields against insect pests

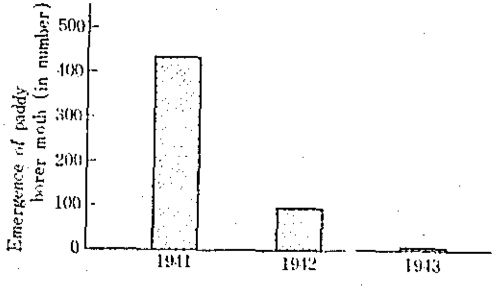
Environmental resistance of crop fields against insect pests varies with the regions, sometimes it varies considerably even with the parts of the same village. This is due to the differences in climatic conditions, topography, irrigation water, soil types, cultural methods, and fertilizer application methods. In any case, it is desirable to grow crop plants in the areas of high environmental resistance. In Japan, the higher the summer temperature, the higer the death rate of the first generation larvae of rice stem borers and the second generation larvae of rice leaf miners. When the temperature is low in the hibernating period, the occurrence of paddy borers and rice plant skippers in next summer becomes less, and it is also generally known that the more the precipitation in hibernating period, the higher the death rate of paddy borer larvae. Changes in the environmental resistance will be brought about by artificial measures, in addition to the local climatic conditions. For instance, due to the clearing away of forest trees surrounding the field, changes in topography or due to the changes in the cultural methods such as planting density, planting arrangement, cultural season or irrigation practices, changes will be brought about in the micro-climate and micro-environment, thus affecting the living of insect pests. For instance, the occurrence of planthoppers is checked by the transplanting in rows (wide spacing between rows with narrow space within rows), and the death rate of the larvae of rice leaf miners will become higher or the damage by northern rice katydids (*Homorocoryphus jezoensis* MATSUMURA et SHIRAKI) will decrease when the "continuous irrigation with running water" has been stopped. To sum up, it is important to hold the insect pest breeding in check by strengthening the environmental resistance of crop fields to insect pests by natural or artificial means.

(b) Protecting crops from being damaged by insect pests by *improving or changing the crop cultural methods*

Feeds taken by insect pests vary with the kind of insect. Some species of insect pests feed on plants of various descriptions, but most of the insect pests feed chiefly on crop plants. Monophagous insect pests, e.g., paddy borers (*Schoenobius incertellus* WALKER) depend exclusively upon rice plants. As a result, the growth of such insect pest is affected greatly by the quantity and quality of rice plants available as feed. Paddy borers can not bore into the rice plant after the stage of 10 days subsequent to heading, because the stem and rachis become hard. Accordingly, the damage by the first generation larvae can be relieved either by early seasonal culture of early-maturing varieties or by late-sowing or late-seasonal culture. (Seeding or transplanting is delayed until the end of the period of emergence of the first generation moths respectively.) Such effect is shown in Fig. 5-10.

The damage caused by the rice stem borers can also be relieved by shifting the period of rice cultivation, viz., when the transplanting date is delayed to escape from the egg-laying at the peak emergence of moth, the damage by the

Fig. 5-10. Decrease in Occurrence of Paddy Borers Caused by Practising Late-Seasonal Culture
(Kirakawa-cho, Kochi Prefecture)



first generation larvae will be relieved and the emergence of the second generation moths will be checked.

The occurrence of rice stem borers or paddy borers can be checked by seeding at higher rate in the nursery. Because in the case of seedlings grown from such seeding, due to the lack of soft cellular tissues (parenchyma) between the vascular bundles, the larvae of these borers will die, though they bore into the plant stems. On the contrary, due to the heavy application of nitrogenous fertilizers, plant stems and leaves become so softened that they will become convenient for the larvae to bore into them, thus causing an increase in the breeding rate of borers.

The extent of damage by insect pests, and their breeding rate vary according to the varieties of host crops. And the egg-laying ability of the moths is also influenced in some instances by the varieties of host crops on which the larvae fed. The variety of high resistance to the damage or breeding of insect pests is known as "insect pest resistant variety". Since the resistance of crop varieties varies with the species of insect pests, it is impossible to obtain such crop variety possessing high resistance to every insect pest. Upon this, it is wise to select the varieties of high resistance to the insect pests which inflict the most serious damage in the respective regions, but the selected varieties, needless to say, must be of high yielding ability and superior in every character from the cultural viewpoints. Rice varieties of high or low resistance against insect pests are shown in Table 5–13.

In order to relieve from insect pest damage, fields are sometimes laid in fallow or a crop rotation system is adopted. Both of the two ways are the means to relieve from insect pest damage for a certain period and to make the field inconvenient for insect pests to live, thus checking the insect pest breeding. However, such methods would not be effective unless practised ranging over a fairly wide area at least at a community or sub-community level, because insect pests in general have travelling habits.

(c) Utilization of natural enemies

The insect pest control practice by making use of such predatory insects as may devour insect pests detrimental to crop plants or such insects as may be parasitic on insect pests, or other animals, fungi or bacilli, is known as "biological control", and such organisms as may kill insect pests known as "natural enemies". We can admit that it is a very effective method to control insect pests by breeding the available natural enemies, but it is, in practice, very hard to make use of natural enemies. The fact that any sudden outbreak of certain living things does not happen under the normal conditions can be ascribed to the existence of the natural equi-

Table 5-13. Rice Varieties of High or Low Resistance to Rice Insects

	Stem borers * (*Chilo Suppresalis* WALKER)	*Stem maggot* ** (*Chlorops oryzae* MATSUMURA)	*Crane fly* *** (*Tipula aino* ALEXANDAR)
Low resistant varieties	Shigaasahi No. 27 Wasesekitori Matsuyamaomachi Kinaiomachi Kameji	Norin No. 8 Norin No. 16 Norin No. 48 San-in No. 39 San-in No. 42 Kinki No. 45	Aimasari Tarobeimochi Saitamamochi No. 10 Norin No. 36 Norin No. 10 Muboaikoku
High resistant varieties	Norin No. 1 Taiheimochi Harudaasahi Senbon-asahi Tangonakate	Norin No. 6 Norin No. 22 Norin No. 44 Ou No. 187 Sakatawase Ou No. 188	Etsunan No. 1 Hatsuseki Aichiasahi Norin No. 25 Tonewase Norin No. 1

Note: * Low resistance: Number of the damaged stems of 200 or over per 100 hills at harvesting time.
High resistance: Number of the damaged stems of 100 or less per 100 hills at harvesting time.
(ISHIKURA, 1952)

** *Low or high resistance was distinguished basing upon the degree of damage to panicles.*
(OKAMOTO, 1952)

*** High resistance: 90% or more of the ratio between the number of seedlings grown in the damaged plot and those in the non-damage plot.
Low resistance: 70% or less of the above ratio.
(MASAKI, 1959)

librium among the livnig things. If such equilibrium is disturbed by some measures, some species of insect pests would sometimes break out suddenly or decrease markely in order to attain a new equilibrium. It is very desirable if insect pests may be controlled by using some natural enemies. Out of the natural enemies, insecta are pre-eminent over the rest in controlling the insect pests. The insecta can be grouped into two species: insectivora and parasita. Appreciably great effect of natural enemies is not observed at the beginning, but the insect pest control effect is becoming increasingly marked as time goes on. In order to get early effect, a great number of natural enemies are required to be liberated. THOMPSON states that if natural enemies and insect pests be placed under the same environmental conditions, the equation: $n=ps^t$ could be set up (n: density of insect pests; p: density of natural enemy; s: insect pest control rate in a life cycle of natural enemy; and t: number of generations of insect pests). In selecting and making use of natural enemy, the following points must be taken into consideration.

(i) Natural enemy for a certain insect pests should be selected;

(ii) The natural enemy should attack preferentially on the host insect pests, though it can live on the substitute host when no host insect presents;

(iii) Each female parasite must lay eggs on as many host insects as possible, and each parasite can feed on as many host insect as possible;

(iv) Generation of the selected natural enemy must be more frequent than that of the host insects, and the natural enemy can feed on female host insects before the eggs are laid by the latter.

In importing natural enemies from abroad, as it is impossible to import the required amount, the natural enemies should be multiplied from the imported ones. Natural enemies are multiplied by letting them lay eggs on a large number of the cultured host insects or on the cultured substitute ones. Among the leading natural enemies other than insects are vertebrates, invertebrates, bacteria, fungi, viruses, etc. Even when natural enemies are not used positively to check the insect pest occurrence, the multiplication of insect pests is being controlled to a certain extent by the presence of naturally competiting enemies. Therefore, attention should be paid so as not arrest the activities of these natural enemies. At present, however, the activities of natural enemies are arrested by the insecticide application. In the future, such insecticides as may kill insect pests only (but not kill natural enemies) should be applied. For instance, "Schradan" is a case in point. Schradan is effective in killing aphides, but it gives no ill-effect on *Coccinella bruckii* MULS (natural enemy of aphides). It requires a further study of such valuable insecticides, the time of their application, and the resistance of natural enemies to the insecticides.

Besides the insect pest control methods referred to above, there are mechanical or physical control methods and chemical control methods. Among the former are those control operations such as killing of insect pests by hand, tillage, cleaning up of field, interception, temperature treatment, submergence by water as well as the use of light traps during the night. The chemical control methods indicate the insect pest control

Table 5-14. Changes in Rice Stem Borer Control Practices (MASAKI, 1952)

Traditional control practices before 1952	%	*Recent control practices*	%
Nipping-off of massive eggs	32.3	Dusting or spraying of organic phosphoric insecticides	64.0
Light traps	4.9	Traditional control practices	21.0
Cutting-off of damaged stems	7.1	Unknown	15.0
Fluorescent light traps	12.1		
Application of DDT and BHC	21.1		
Unknown	18.9		
Nothing done	6.1		

by the application of insecticides, i.e., to kill insect pests by means of oral poisoning, contact or gas poisoning, or to bring about an evasional effect. These control methods, however, are effective in minimizing the damage inflicted by the insect pests which have already occurred. These are generally known as "excluding methods".

3. Insect Pest Control Practices

1. Changes in insect pest control practices

In Japan, great changes took place in the study of the control of insect pest against rice plants in about 1952 as the turning-point. In recent years, a rapid progress has been made in the insect pest control practices, as shown above. Insect pest control practices vary according to the level of general farmers' knowledge. Accordingly, the most suitable control methods vary with the areas or countries. In prewar Japan, the control methods by bare hand or primitive control methods had been practised (e.g., nipping-off of massive eggs, collection of larvae or moths, or stabbing of insect pests to death, etc.). In recent years, however, such conventional control practices have almost been replaced by the efficient and time- or labor-saving devices, e.g., dusting or spraying of insecticides by speed sprayers or from airplanes; or mixing of insecticides in irrigation or submergence water or in paddy field soils.

2. Insect pest control practices prevailing now in Japan

Since Japan is a mountainous and hilly island country stretching in a southwest-northeast direction, paddy rice fields are distributed over the areas of different latitudes and altitudes. Accordingly, the environmental conditions of paddy rice fields vary from one to another. The frequency of insect pest occurrence and the insect pest control methods vary according to the areas. In widely opened plains, aerial dusting has become practised, and in the level lands somewhat less in width insecticides are now sprayed by using speed sprayers for low crops, and in areas of further less in width or in hilly land areas, insecticides are sprayed by recently devised methods over the field surface or in the field soils. The main control methods prevailing in Japan are as described below.

Frequency of Occurrence, Symptoms of Damage and Control Methods

(a) Rice Stem Borer (*Chilo Suppresalis* WALKER)

Frequency of occurrence: In general, it emerges twice a year, but in some parts of Japan it will emerge only once a year.

Damaging period: From the end of nursery stage to the ripening period.

Symptoms of damage: Damaged leaves float on the field water surface, growing point of seedling die, leaf sheaths turn yellowish, panicles fail to shoot out, white panicle occur, and rice plants lodge.

Control methods: Heavy application of nitrogenous fertilizers and early transplanting should be avoided because damage will be aggravated in doing so. Insecticides are sprayed 10 days after the peak emergence of moths at the first generation stage, and seven days after at the second generation stage. At the first generation stage, 0.023 per cent Folidol solution is applied at the rate of 72 liters per 10 ares, BHC powder is sprayed on the water surface at the rate of 120 grams (γ-constituents) per 10 ares, and BHC powder of 300 grams per 10 ares is mixed in the shallow soils.

(b) Paddy Borer (*Schoenobius incertellus* WALKER)

Frequency of occurrence: In general, three times a year.

Damaging period: From the beginning of nursery stage to the maturity.

Symptoms: Growing point of seedling or tiller dies. White panicle of from several to several tens in group occurs, particularly markedly after dry windy days. Inner leaves die (the so-called "dead heart"). Due to the damage at the second generation stage, some damaged plants will not come into ears.

Control methods: Serious damage with glutinous rice varieties, and with heavy application of nitrogenous fertilizer. Deep submergence of the nursery causes less attack. The late-seeding is recommended (not to seed until the close of emergence of the first generation moths). In the case of areas, however, where there is a fear that rice plants may not grow fully if seeded so lately, a late-transplanting practice is desired to be adopted (i.e., seedlings are not transplanted until the close of the time of emergence of the first generation moths, and insecticides are applied to the nursery). Folidol of 0.047 per cent solution is applied at two times before and after anthesis at the rate of 144 liters per 10 ares.

(c) Smaller Brown Planthopper (*Delphacodes striatella* FALLÉR)
Green Rice Leafhopper (*Nephotettix bipunctatus cincticeps* UHLER)

Frequency of occurrence: In general, five times a year.

Damaging period: From the beginning of nursery stage to the maturity.

Symptoms: Plant growth becomes poorer because the nutrients in the plant stems and leaves are absorbed by smaller brown planthoppers. As the nutrients are absorbed also by green rice leafhoppers, the plant stems and leaves become discolored and the plant growth is affected. Due to the occurrence of sooty mould from the excretions discharged by leafhoppers, the flag leaves and panicles are stained black.

Control method: As smaller brown planthopper is known as a carrier of stripe-disease virus or black-streaked dwarf virus, the control of the planthoppers is important also in controlling the above-named viruses. Malathion dust at the rate of 60 g (active ingredient) per 10 are and Folidol emulsion of 0.023 per cent at the rate of 72–144 liters per 10 ares are sprayed.

As green rice leafhopper is a carrier of dwarf disease virus or yellow dwarf disease virus, it is particularly important to control the leafhoppers in order to relieve rice plants, from the above-named viruses. BHC is highly effective against smaller brown planthoppers, but not effective against green rice leafhoppers. Folidol emulsion of 0.023 solution is sprayed at the rate of 72–144 liters per 10 ares, Malathion dust of 60 grams (active ingredient) per 10 ares, and Malathion emulsion of 0.033 per cent solution at the rate of 72–144 liters per 10 ares. The insecticide spraying would be of no effectiveness unless it is sprayed over a wide area.

(d) Rice Stem Maggot (*Chlorops oryzae* MATSUMURA)

Frequency of occurrence: Two times a year in the northern part of Honshu, and three times a year in the southern part.

Damaging period: From the nursery stage to the maturity.

Symptoms: Worm-eaten spots appear on young leaves after the maggot larvae bored into the rice plant. Leaves are twisted in severe case. Panicles are damaged and grains are deformed. The damaged panicles stand erect. Heading is deformed.

Control methods: Rice varieties resistant to stem maggot are recommended to be planted. In warm areas, damage can be relieved by early transplanting. EPN emulsion of 0.045 per cent solution is sprayed at the rate of 72–144 liters per 10 ares at the peak occurrence stage of the second generation moths.

(e) Rice Plant Skipper (*Parnara guttata* BREMER et GREY)

Frequency of occurrence: In general, three times in a year, but sometimes four times.

Damaging period: At the plant growth period after transplanting to maturity.

Symptoms: Larvae begin to make nests out of several leaf blades from about the peak tillering stage, hiding therein in the daytime and devouring near-by leaves at night.

Control methods: It is better to avoid heavy application of nitrogenous fertilizers, planting of dark-colored leaf varieties, and late-transplanting. DDT emulsion of 0.02 per cent solution or DDT hydrate of 0.05 per cent solution is sprayed at the rate of 144 litres per 10 ares or DDT dust of 200 grams (active ingredient) per 10 ares is dusted at about the end of the valid tillering stage.

(f) Rice Stink-bug (*Lagynotomus* DISTANT)

Frequency of occurrence: Once a year.

Damaging period: In the plant growth period after trnsplanting to maturity.

Symptoms: Due to the sucking damage, grains become yellowish. The leaves and stems of the damaged rice plants keep green color longer. Due to the damage, husked rice is deformed and becomes less palatable.

Control methods: Control is carried on by spraying insecticides at about one week before or after heading. BHC of 3 per cent dust, and Folidol emulsion of 0.023 per cent are sprayed at the rate of 120 grams (active ingredient) and 144 litres per 10 ares, respectively.

IV. PREVENTION OF LODGING

Lodging of rice plants is caused by the outside action, e.g., wind, rain, etc., effecting on the culm of rice plants which have become weakened under the environmental conditions, e.g., fertile soils, heavy application of nitrogenous fertilizers, deep submergence, sunlight-deficiency, etc. The strength of culms or the load of tops varies according to the plant growth stages. Since the stage at which rice plants are affected by the outside action or the extent to which the culms are affected is not definite, the causes for lodging are much complicated. Lodging may take manifold forms, e.g., lodging in the form of falling down of a whole plant with roots to make a disclosure of a part of the roots on the field soil surface (when seedlings are transplanted shallowly, the hill itself will sometimes fall down. This is observed in the case of a direct-sowing practice); or in the form of breaking or bending of culms at the basal parts. Culms are sometimes broken at the upper internodes instead of at the basal ones. This is sometimes referred to "breaking" in discriminating it from "lodging". However, culms are, in most cases, broken at the basal internodes. With regard to lodging, SEKO reports that lodging has direct bearing upon (1) the breaking resistance of culms and (2) the status of top of plant which is exposed to outside action. Degree of lodging will differ according to the culm length or the weight of panicles or tops, though the breaking resistance of culm is similar. The breaking resistance varies according to the size of culm and thickness of culm-wall and the length of internodes, even though similar in the culm tissue. Strength of culm tissue has direct bearing upon the development of the mechanical tissue or the chemical composition of culms (silicate content, potassium content etc.).

1. Progress of Development of Various Organs of Tops of Rice Plants

The various organs of top are expressed as follows:

Panicle:	B_0
Leaf blades:	B_1, B_2, B_3, B_4, ... (In order of their positions from above.)
Leaf sheaths:	S_1, S_2, S_3, ...
Internodes:	N_0, N_1, N_2, ... (In order of their positions from above, taking the uppermost internode to which a panicle is attached as N_0.)

(See Fig. 5-11.)

The beginning, ending, and peak dates of the principal elongation periods of these organs are represented by the number of days before or after heading (Table 5-15). The term "the principal elongation periods", as used herein, indicates the periods in which the respective organs may reach

10 to 90 per cent of their own full length. As the respective organs reach nearly 50 per cent of their full length and show the maximum increase in length on the central dates of their principal elongation periods, the central dates are assumed as the peak dates. The beginning, ending, and peak dates of the principal periods for the increase in dry matter weight can likewise be indicated by the number of days before or after heading (Table 5-16). When the respective dates fall on the days before heading, they are indicated by the minus numbers, and when the respective dates come after heading, by the plus numbers.

Tables 5-15 and 5-16 show that the respective organs of the tops develop with regularity. The organs which elongate simultaneously are:

B_0 (panicles), S_1 (leaf sheaths), and N_2 (internode)
B_1 (leaf blades), S_2 (〃), and N_3 (〃)
B_2 (〃), S_3 (〃), and N_4 (〃)
. . .
. . .
. . .

Table 5-15. Beginning, Ending, and Peak Dates of the Principal Elongation Periods of Panicles, Leaf Blades, Leaf Sheaths, and Internodes
(SEKO et al., 1957)

Panicle and leaf blade				*Leaf sheath*				*Internode*			
	Beginning	*Peak*	*Ending*		*Beginning*	*Peak*	*Ending*		*Beginning*	*Peak*	*Ending*
B_0	−15	−11	−8	S_1	−16	−12	−8	N_0	−1	+1	+3
B_1	−22	−19	−16	S_2	−22	−20	−17	N_1	−6	−1	+3
B_2	−28	−25	−21	S_3	−29	−26	−23	N_2	−16	−10	−4
B_3	−34	−31	−28	S_4	−35	−32	−30	N_3	−23	−18	−13
B_4	−43	−39	−34	S_5	−43	−41	−38	N_4	−29	−26	−20
								N_5	−44	−36	−28

Table 5-16. Beginning, Ending, and Peak Dates of the Principal Periods of Dry Weight Increases of Panicles, Leaf Blades, Leaf Sheaths, and Internodes

(SEKO et al., 1957)

Panicle and leaf blade				*Leaf sheath*				*Internode*			
	Beginning	*Peak*	*Ending*		*Beginning*	*Peak*	*Ending*		*Beginning*	*Peak*	*Ending*
B_0	−2	+15	+30	S_1	−13	−9	−5	N_0	0	+2	+3
B_1	−19	−14	−8	S_2	−20	−16	−10	N_1	−5	0	+3
B_2	−25	−21	−16	S_3	−26	−22	−17	N_2	−13	−6	+1
B_3	−31	−28	−22	S_4	−34	−29	−21	N_3	−20	−15	−7
B_4	−39	−35	−29	S_5	−41	−36	−28	N_4	−27	−21	−12
								N_5	−33	−24	−12

Namely, the organs that elongate most lately are N_0 and N_1. N_2, B_0 and S_1 elongate and reach the peak dates earlier, and N_3, S_2 and B_1 reach the peak elongation dates further earlier. Namely, when a certain leaf blade elongates, the sheath of the second leaf (from above) and the internode from which the third leaf develops (supposing that a leaf develops from the tip of that internode) elongate almost at the same time. The same trend can be found also in the progress of the dry weight increase of the respective organs, though not so clear as is the case with the elongation (Fig. 5-11).

The time for the elongation of the internodes which relate to lodging can be found out from the above tables and Fig. 5-11.

2. Various Factors Affecting Lodging

1. Amount of nitrogenous fertilizer application

In comparison of rice plants grown by the application of generally-accepted amount of fertilizer with those grown by the application of heavy fertilizer amounting to three times as much, the following results were obtained (Fig. 5-12).

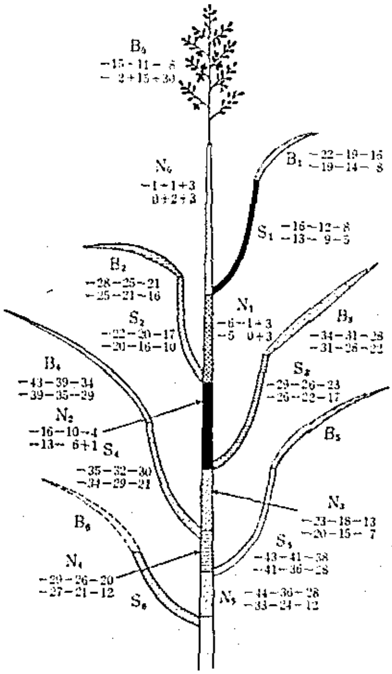
	Standard plot	*Three-time plot*
Length of each leaf blade	100	110–140
Fresh weight of leaf blade	100	120–210
Culm length	100	120
Length of internodes		
Upper internodes	100	104–120
Lower (N_3-N_5)	100	120–340
Weight of internodes		
(including sheath)	100	110–130
Internode weight per centimeter		
Upper internodes	100	100–119
Lower (N_3-N_5)	100	44– 88

On the normal plot, the lower internode, N_4, is buried partly in the ground, while on the three-time plot the N_4 internode appears on the ground because the elongation of the N_5 internode is greater. In the case of rice plants on the heavy fertilizer plot, the wall of a culm is thin, poor in the development of sclerenchyma, low in lignification. Thus the culm becomes weakened. As a result, the internodes, N_3–N_5 are particularly low in breaking resistance. The load charged to the base of a given internode can be expressed by the weight of top above that point. It is natural that the lower the position of internodes, the greater the weight of the tops above that part. However, on the heavy fertilizer plot, the load is always great. The moment (i.e., the product of "load on a given internode"×"the length of top above that internode") is always greater on the heavy fertilizer plot. "Moment for each internode"÷"breaking resistance of each internode" is known as the lodging index. The susceptibility to loding is determined by the lodging index. The lodging index is greater on the heavy fertilizer plot, particularly great in the cases of N_3 and N_4 internodes. As a matter of fact, on the heavy fertilizer plot, lodging due to breaking occurred at N_3 and N_4 internodes.

2. Time of split application of ammonium sulphate

For the purpose of testing the effects of the time for split application of ammonium sulphate on lodging, nine plots were set up to each of which the same amount of ammonium sulphate was applied 47, 41, 34, 27, 20, 13 and 5 days before

***Fig. 5-11.* Model Diagram Illustrating the Progress of Elongation and Dry Weight Increases of Panicles, Leaf Blades, Leaf Sheaths and Internodes, According to Their Positions**

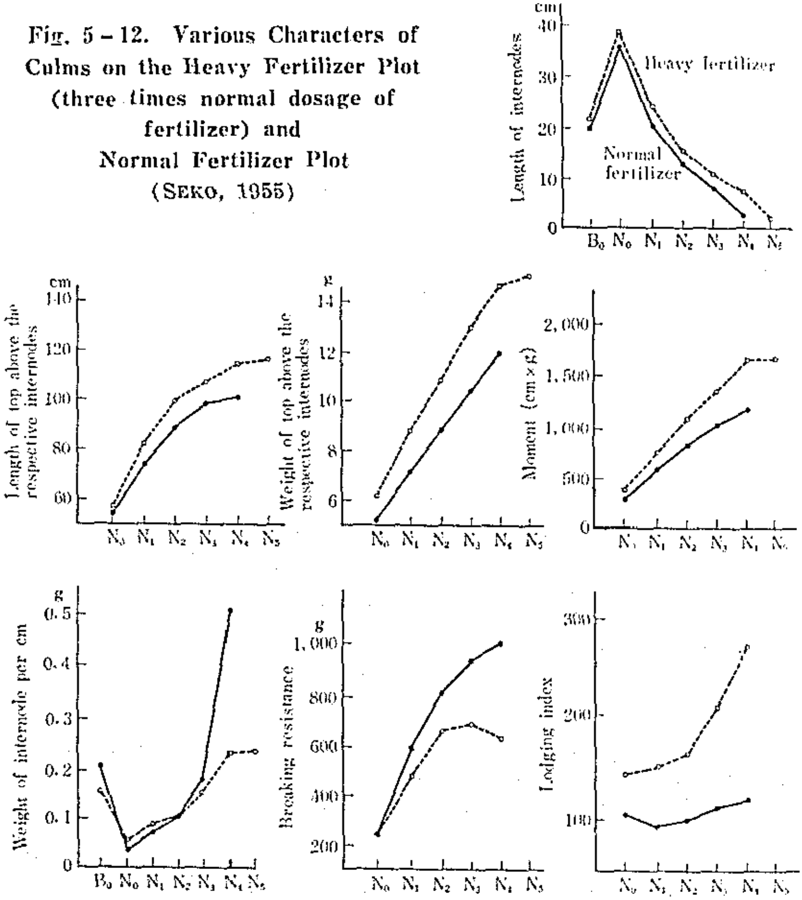


Notes: (1) Numerals indicate the number of days before and after heading, as expressed with minus and plus signs, respectively.

(2) Upper figures, see Table 5-15.
From left to right: beginning, peak, and ending date of principal period of elongation.

(3) Lower figures, see Table 5-16.
From left to right: beginning, peak, and ending date of principal period of dry weight increase.

Fig. 5-12. Various Characters of Culms on the Heavy Fertilizer Plot (three times normal dosage of fertilizer) and Normal Fertilizer Plot (SEKO, 1955)



heading, and 2 and 11 days after heading, respectively. In case where ammonium sulphate was applied 47 and 41 days before heading, rice plants became susceptible to lodging to the most considerable extent. The rice plants on the plots to which ammonium sulphate was applied 34, 27, and 20 days before heading bent to some extent. As indicated in Fig. 5-13, rice plants on 41-day plot were very low in the breaking resistance of N_3 and N_4 internodes, as low as one-half the breaking resistance of standard plot, followed by the breaking resistance of 47-day plot. The cause for frequent lodging of rice plants to which ammonium sulphate is applied about 40 days before heading is found in the fact that the lower internodes are forced to elongate and the breaking resistance of the internodes is lowered by the nitrogen application on those dates.

3. Effect of sunlight-deficiency

Fig. 5–14 indicates the result of shading treatment given for the period of "July 22–August 1", "August 1–11", and "August 11–21". On every shading plot, the breaking resistance of N_3 and N_4 internodes becomes low, particularly in the case of "late-July shading" plot. The lodging index of each shading plot is great, particularly on "late-July plot" and "early-August plot". Early August falls on 24–34 days before heading, i.e., the period from the beginning date to the peak date of the elongation of N_4 internode. As the increase in dry-matter weight of N_4 internode begins to proceed 5 or 6 days after that period, N_3 internode already begins to elongate when the increase of dry matter weight of N_4 comes to be active. Accordingly, the substantial growth of N_4 internode is checked by the shading (sunlight-deficiency) at this period. Though N_4 internode elongates well, the breaking resistance will become lower, and as the weight of the tops which may grow after shading is scarcely affected by the shading, the moment will not become low, thus resulting in the increase in the lodging index. Shading treatment given after that period causes a decrease not only in the breaking resistance of the internode but also in the weight of the tops, and the moment becomes lowered. As a result, the lodging index is not so high as that of the former. In the case of the shading prior to late July, although the breaking resistance of the internode becomes lower, the culms length and weight of the tops will be reduced. As a result, the lodging index is small. Accordingly, rice plants are most susceptible to lodging in the case of sunlight-deficiency on the

Fig. 5 – 13. Characters of Culms as Affected by the Time of Top Dressing of Nitrogen
(SEKO, 1955)

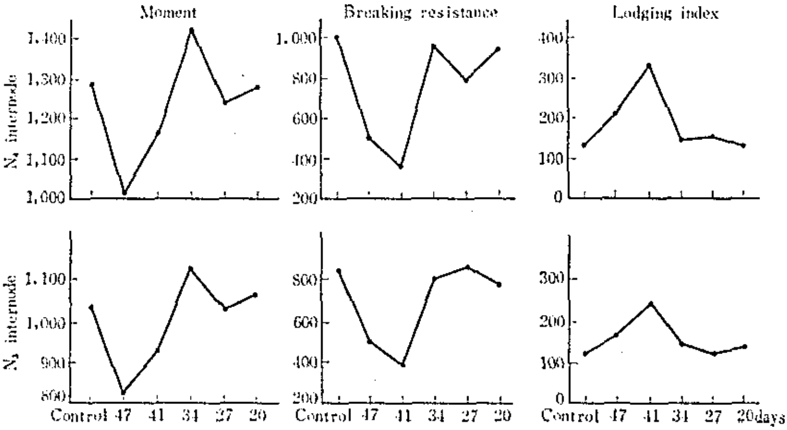
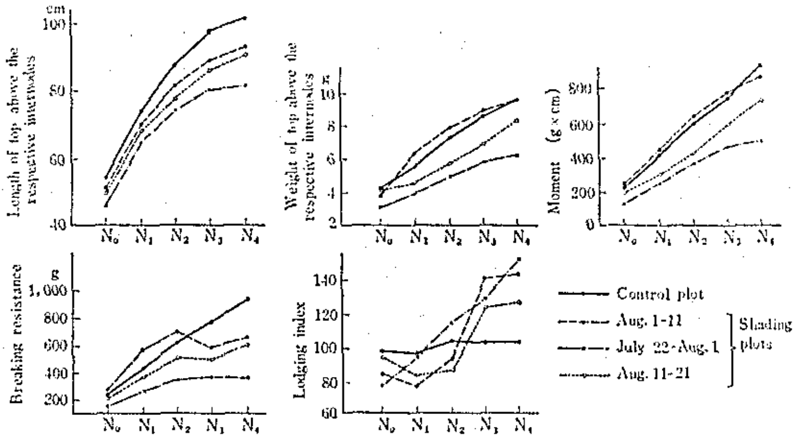


Fig. 5 – 14. Changes in Characters of Culms by Shading Treatment
(SEKO, 1955)



period 25–35 days before heading.

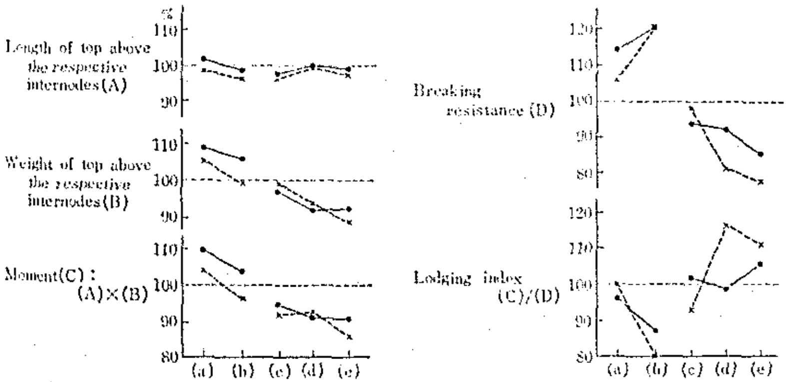
4. Midsummer drainage and deep submergence

Fig. 5-15 indicates the lodging indexes in case where the midsummer drainage and deep submergence was done during the period from July 26 to August 4 (early period) and during the period from August 5 to 14 (late period) and where the deep submergence was done during the period from July 26 to August 14 (whole period). In the case of the standard plot, water was irrigated moderately during the plant growth period. No irrigation was practised during the midsummer drainage period, and the submergence at the depth of about three inches was held during the deep submergence periods prescribed above. September 1 fell on the heading date.

During the period from July 26 to August 4, the elonga-

Fig. 5-15. Effects of Midsummer Drainage and Deep Submergence on Lodging

(SEKO, 1956)



Note: a. early period } midsummer drainage
b. late period }

c. early period }
d. late period } deep submergence
e. whole period }

Standard plot = 100

tion of N_4 internode was in full swing, while during the period from August 5 to 14, the elongation of N_3 internode was in full swing. Although the length of top above these internodes was no more affected greatly by the treatments, the weight of top above these internodes was increased owing to the mid-summer drainage, particularly to the early period drainage, but it was decreased owing to the deep submergence. The moment, as is the case with the above, showed an increase owing to the early period drainage, no appreciable increase in the case of late-period drainage, and showed a decrease due to the deep submergence. On the other hand, the breaking resistance of culms was higher on the drainage plot either of early or late period, particularly remarkable on that in the late period, while the breaking resistance of clums was lowered on the deep submergence plot either of early or late period, particularly noticeable on the deep submergence plots of whole period and late periods. Thus, the effect of the drainage on the breaking resistance is contrasted with that of the deep submergence. The lodging index of late-period drainage plot is clearly lower, while that of the deep submergence plots both of late and whole periods shows a marked increase. Such changes in the lodging indexes are ascribed chiefly to the changes in breaking resistance of culms caused by the treatments. It is needless to say that the actual occurrence of lodging observed on the field coincides well with the lodging indexes.

The effect of the treatment is also found in the tissue of culms. On the midsummer drainage plot, the lysigenous aerenchyma is smaller in number and size, while on the deep submergence plot, it is larger in number and size. And the development of mechanical tissue of culms on the deep submergence plot is poorer than that of culms on the drainage plot and control plot.

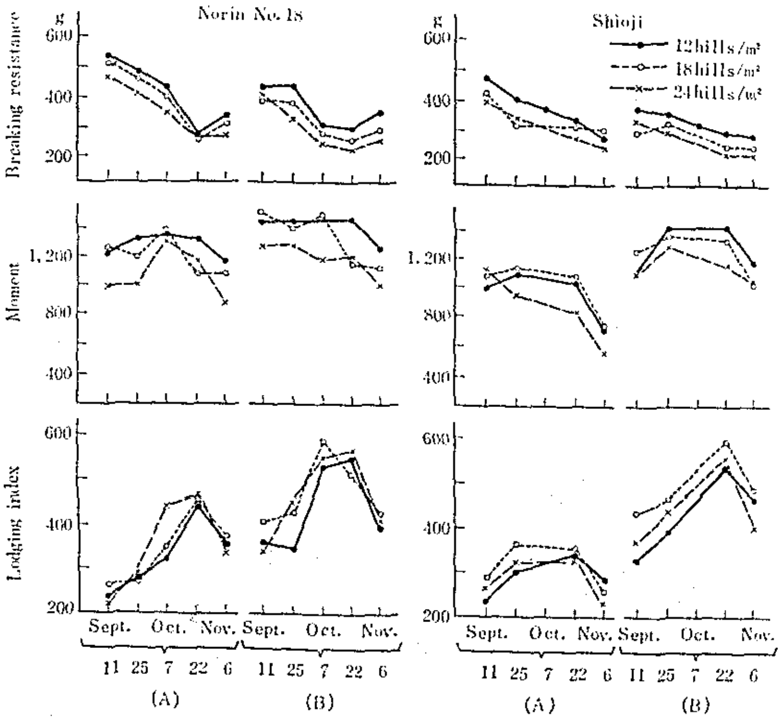
5. *Spacing (density of planting)*

Close planting is a vital factor affecting lodging, as is the case with heavy fertilizer application. The results of tests on Norin No. 18 and Shioji, planted at the rate of 12, 18, and 24 hills per sq. meter, on the normal and heavy fertilizer plots, are as follows: Lodging occurred first on the "heavy fertilizer and dense planting" plot, followed by the "heavy fertilizer and thin planting" plot. The rice plants on the "normal fertilizer and dense planting" plot merely bent to the wind. The internodes close to the surface of the ground on the dense planting or heavy fertilizer plot were longer, but were thinner in size than these of thin planting and normal fertilizer plot, thus becoming more susceptible to lodging. The same trend is found also in the weight per centimeter of the internodes close to the surface of the ground.

The breaking resistance of the internodes close to the surface of the ground is as shown in Fig. 5-16, namely, the closer in spacing and the heavier in fertilizer application, the lower in the breaking resistance. The moment of the internode close to the surface of the ground is larger in heavy fertilizer application, while becomes smaller in the case of the dense planting plot, where the plant height is small and the panicles are smaller in size. However, the lodging index on the heavy fertilizer or dense planting plot becomes greater. Its order coincides with the occurrence of lodging on the field.

As described above, lodging is aggravated markedly by the closer planting, heavy application of nitrogen, nitrogen application at about 40 days before heading, sunlight-deficiency at about 35-25 days before heading, and the deep submergence during the period of elongation of the internode close to the surface of the ground. In view of this, in order to forestall the lodging, it is required to eliminate the above causative factors. The midsummer drainage is effective in making the culms strong to prevent their lodging. Nor is this all. By the midsummer drainage invalid tillering is checked, percentage of valid tillering is raised, and the physiological activity of roots is maintained to be high, thus making the fertility good. With this end in view, the midsummer drainage is practised widely.

Fig. 5-16. Lodging Indexes as Affected by Close Planting and Heavy Fertilizer Application
(SEKO, 1958)



Note: A. Normal fertilizer plot.
B. Heavy fertilizer plot.

3. Prevention of Lodging by the Use of Agricultural Chemicals

Timely spraying of 2,4-D is effective against lodging. The results of the tests conducted at the Kyushu Agricultural Experiment Station (Table 5-17) indicate that it is most effective to spray 2,4-D at the rate of 60-80 grams (in acid) per 0.1 hectare during the period from the peak tillering stage to the young-panicle differentiation stage (i.e., about 45-40 days before heading). When 2,4-D is applied, the elongation of the internode elongating at that time is generally promoted, while the elongation of the internode which may elongate subsequently is checked as a reaction. As a result, when 2,4-D is applied about 40 days before heading, the lower internodes (N_4 or N_5) elongate. However, as the succeeding internodes are shortened, the culm length as a whole becomes shortened, and the diameters and walls of culms of the elongated lower internodes grow larger and the lignification is forced. Consequently, the culms become more resistant to breaking. The results of the study on the cell contents of culm conducted at the Tohoku Agricultural Experiment Station are as shown in Table 5-18. In the lower parts (lower one-thirds) of the culms, both total carbohydrate and starch contents are increased by 2,4-D spraying, and a close relation is found between the starch content in the culm tissue at heading stage and the breaking resistance of the culms (Fig. 5-17).

Table 5-17. Effect of 2,4-D Application in Preventing Lodging (SEKO et al., 1960)

Time of 2, 4-D spraying	*Distance between panicles and ground surface*	*Rate of broken culms*	*Thickness of culm wall*	*Thickness of lignificated part*	*Starch content in culms (Relative value)*
	cm	%	μ	μ	
Control plot	36	52	62	3.0	0
Aug. 1	60	6	67	3.7	5
Aug. 6	60	—	67	3.7	9
Aug. 11	42	35	60	3.7	5
Aug. 17	41	54	55	3.2	0
Aug. 22	37	63	57	2.7	0

Notes: Material: Norin No. 18 on the heavy fertilizer plot.

2,4-D: Amin salt, applied at the rate of 80 grams per 0.1 hectare.

Testing: Culms (central parts of N_3 internode) were examined on Sept. 25. Lodging was recorded at the harvesting time.

Distance between panicles and ground surface: This indicates the degree of lodging. The severe the lodging, the smaller is the distance between panicles and ground.

Fig. 5-17. Relationship between Starch Content in Culm and Breaking Resistance of Culms

(YATSUYANAGI, 1961)

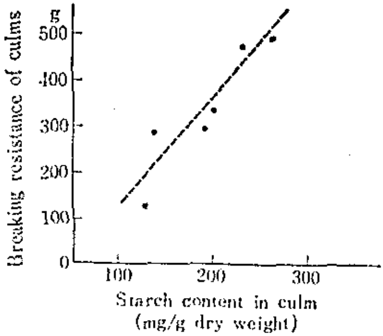


Table 5-18. Effect of 2,4-D Application on the Carbohydrate Content at the Lower Part of a Culm (Lower one-third part)

(Tohoku Agr. Exp. Sta., 1961)

(*mg/g dry weight*)

Nitrogen application kg/10a	*Control plant*			*2, 4-D sprayed*		
	Total carbo-hydrate	*Starch*	*Acid-hydrolyzable polysac-charides*	*Total carbo-hydrate*	*Starch*	*Acid-hydrolyzable polysac-charides*
0	392	267.8	118.4	—	—	—
1.5	364	138.2	131.2	432	262.8	121.6
4.5	424	198.7	121.6	448	233.3	121.6
7.5	312	134.4	124.8	376	190.1	131.2

As described above, 2,4-D application is effective against lodging. When lodging has occurred on non-2,4-D plot, rice yield on 2,4-D plot would always be higher than that on the former. However, when lodging has not occurred on non-2,4-D plot, it would show some decreases in rice yield on 2,4-D plot because of 2,4-D application. Namely, in case where lodging would occur if left undone, lodging would be relieved by 2,4-D application, and the decrease in rice yield due to lodging could be prevented, while in case where rice plants could be freed from lodging even if left undone, it would show about 5-10 per cent decrease in rice yield due to 2,4-D application. Such decrease is caused by the decrease in the number of panicles per hill, spikelets, kernels, and fertilized kernels. When 2,4-D is applied at earlier time, it will show a marked decrease in the number of panicles per hill. When applied lately, the fertility rate or 1,000 grain-weight, and the effect for lodging prevention will be reduced, though the number of panicles and kernels will be affected little. In warm part of the country, the application of 2,4-D about 40–45 days before heading is regarded as a timely practice, while in cold areas (northeastern part of Japan) the application about 30 days before heading is a timely practice because if applied earlier the desired number of panicles per hill could not be secured.

When 2,4-D is applied, the respiration of a rice plant will show about 30 per cent increase within 5 or 6 hours and 40 per cent increase on the day following, and the increase of 10–15 per cent will continue for six days after that. The true photosynthesis will show a slight increase for a few days after 2,4-D application (this can be ascribed to the fact that rice plants are exposed more fully to the sunlight owing to the opening of a hill), but thereafter it will show a 5 or 6 per cent decrease. As a result, the apparent photosynthesis will

Table 5 – 19. Changes in Photosynthesis and Respiration by 2,4–D Application
(SEKO et al., 1960)

(CO_2 g/hr/4 hills)

	Number of days after 2, 4-D application				
	0	*1*	*3*	*6*	*13*
	%	%	%	%	%
Apparent photosynthesis	89	96	100	86	94
True photosynthesis	101	102	106	95	95
Respiration	128	138	115	114	101

Note: Figures indicate the percentage ratio of 2,4–D plot, taking the value of control plot as 100.

show about 10 per cent decrease, thus resulting in the decrease of dry-matter production (Table 5–19).

As described above, 2,4-D is effective against lodging, but it has an yield-decreasing effect. Therefore, in order to form a judgment whether 2,4-D should be applied or not, the early forecasting of lodging is required to be made.

Besides 2,4-D, α-Naphthalene acetic-acid (α-NAA) is also effective against lodging. By the application of α-NAA, the elongation of the internodes which are elongating at the time of the application or after that time is checked. In this respect, the action of α-NAA differs from that of 2,4-D. α-NAA is also effective against lodging because culms become bigger and stronger owing to its application. The application of 2,4-D is practised widely among farmers, but α-NAA application is not as yet.

V. DISASTER DAMAGE CONTROL

1. Wind Damage

A great part of wind damage to paddy rice crop in Japan is caused by typhoons. Annual typhoon damage, including flood and high tidal damages, amounts to 320,000 tons (about 3 per cent of the total rice production in Japan) or 21,000 million *yen* in value. In some years, it reached as much as 700,000 tons (e.g., 1959).

Many a study and survey on the typhoon damage to paddy rice crop has been carried out in the past comparatively long years. As a result, typhoon damage has been made clear to a considerable extent, but little or no experimental study on wind damage having been carried out. The affecting factors and the mechanism of wind damage had not been clarified for a long time. In recent years, however, Dr. Y. Tsuboi of the National Institute of Agricultural Sciences has made clear the outline of the affecting factors and the mechanism of wind damage through a series of experiments conducted by using a wind tunnel.

1. Changes in rice plants damaged by wind

Lodging (falling down) is a visible wind damage to rice plants. When rice plants have lodged, the reaping and harvesting operations become more troublesome, and the amount of carbon assimilation as a whole decreases due to the change for the worse in the light receiving system of the rice plants. Furthermore, the translocation of nutrients is checked by breaking-down of culms and leaf sheaths, the ripening itself is interrupted, and the grains will sometimes germinate on the panicles. Shattering of grains is also a visible wind damage. Shattering is practically a serious problem.

However, the wind damage is not always accompanied by visible damage like lodging or shattering. Even when no such visible damage is recognized, spikelets, leaves, or culms of rice plants will sometimes be injured seriously by wind, thus resulting in decreased rice yield. Sometimes white head may occur and inflict a complete crop failure. Storm damage, in many cases, becomes evident after harvesting, namely, it will show abnormally great increases in empty, abortive or imperfect grains. Most of them grow brownish and change into the so-called "brown colored grains". Thus it will show a decrease in the percentage of ripened grains and in the weight of perfectly ripened grains.

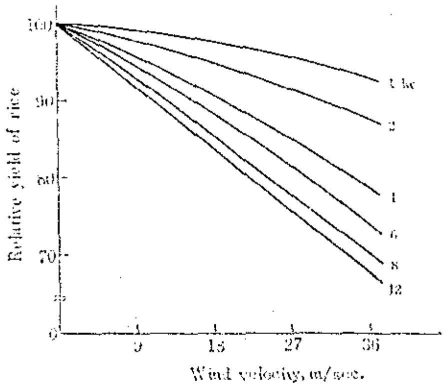
2. Factors affecting wind damage

The extent of wind damage varies with various factors. The affecting factors can be divided into two categories: (i) factors related to the characteristics of wind itself and (ii) factors in the crop plants themselves. The major items in the former are wind velocity, wind duration, humidity and temperature of wind, etc. In the case of the latter, the growth stage of crop plants, rice varieties, and cultural conditions are the important factors.

(i) Characteristics of wind and wind damage

Of course, the higher the wind velocity, the greater the wind damage. It is reported that the rate of rice yield decrease caused by the wind damage at the heading stage is proportional to a value obtained by raising to the square root of wind velocity to third power (Fig. 5-18).

Fig. 5-18. Relationship between "Wind Velocity and Wind Duration" and Rice Yields (TSUBOI)



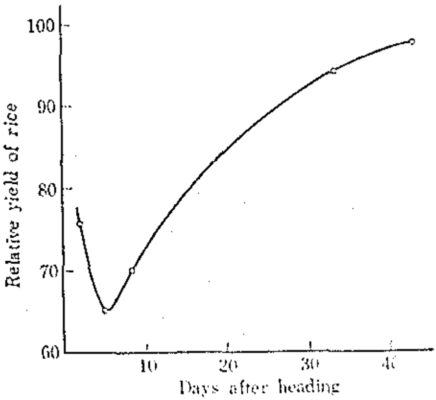
Wind duration gives a serious effect on rice yields next to the wind velocity. Fig. 5-18 is a model graph indicating the effects of wind velocity and wind duration combined on the rice yields.

Even in case where it is same in velocity and duration of wind, the higher the dryness of the wind, the greater the wind damage. White head is believed to occur when rice plants at the heading stage are exposed to a strong and dry night-wind, and if exposed to the intense sunlight on the day following, the damage would be aggravated further.

(ii) Plant growth stages and wind damage

Extent of wind damage varies considerably with the plant growth stages. Paddy rice plants are affected most seriously by the wind at the time of about the heading stage. Particularly, the rate of rice yield decrease reaches a peak when rice plants are exposed to the wind within the several days centering around the fifth day after heading (Fig. 5-19). Thereafter wind damage is becoming decreased generally according as the plants approach to the maturity, but the shattering damage becomes greater according as the ripening proceeds.

Fig. 5 – 19. Relationship between Rice Plant Growth Stages and Storm Damage (TSUBOI)



Not only the extent of wind damage but also the quality of wind damage varies considerably according to the plant growth stages. Wind damage before heading will result in the decrease in the number of spikelets, while the wind damage on the heading date will result in the increase in empty grains or brown colored grains due to non-fertilization. The wind damage within the several days after heading causes to increase empty grains due to the abortion of endosperms, and the subsequent wind damage will result in the increase in abortive grains, brown colored grains, and imperfectly ripened grains.

(iii) Rice varieties and wind damage

Many a report indicates that the wind damage to rice plants varies remarkably according to the rice varieties, but, in most cases, it is merely due to the difference in the heading time among the rice varieties. It is clearly recognized that the extent of lodging or shattering differs with different varieties. It is reported that the extent of occurrence of white head is also different with varieties. However, it is not yet clear that, besides these, is there any varietal difference in the extent of wind damage or in wind resistance.

(iv) Cultural conditions and wind damage

The liberal application of nitrogenous fertilizers makes the culms weak, and as a result rice plants become liable to lodge. Even when rice plants do not lodge, if nitrogenous fertilizer is applied before typhoon, the wind damage will become aggravated (Table 5–20). It is also reported that the occurrence of white head is accelerated by the liberal application of fertilizers.

Table 5 – 20. Nitrogenous Fertilizer Application (Top-Dressing) at the Growth Stage and Wind Damage
(Tsuboi)

Plot	*Percentage of fully ripened grains*	*Weight of 1,000 ripened grains*	*Rice yield index*
	%	gr	
Non-top-dressed plots			
Non-wind control	93.6	21.7	100.0
Exposed to wind	82.0	20.5	76.5
Top-dressed plots			
Non-wind control	94.7	21.9	103.5
Exposed to wind	76.6	19.8	63.9

Note: Ammonium sulfate is applied at the rate of 2 g/pot 3 days before wind treatment. The wind is controlled at 12 m/s for 5 hours.

3. *Mechanism of wind damage*

Due to a storm damage, as stated before, it shows a sharp increase in empty grains or abortive grains, and further shows a decrease in the weight of fully ripened grains. Tuboi explained these matters as follows:

(i) Development of empty grains

Causes for the acceleration of development of empty grains by storm can be divided into two classes: non-pollination and early abortion of endosperms after pollination. Most of the grains damaged by storm at the heading stage are empty grains due to the former, while those damaged by storm after heading stage are empty grains mostly due to the latter. Taken the empty grains as a whole, those caused by the latter are overwhelmingly greater in number.

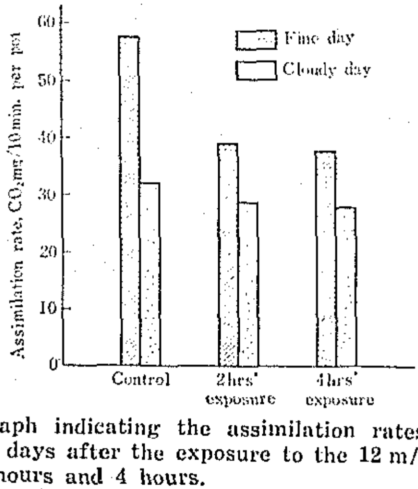
Non-pollination occurs mostly due to the drying of flower organs caused by storm, followed by the failure in opening, by blowing-off of anthers or by shutting out of anthers outside the spikelets. Some inferior spikelets fail to flower, and some panicles become sterile without shooting out from leaf sheaths. And due to the damage to anthers or pollens caused by the wind before heading, fertilization, in some cases, will not take place.

Abortion of endosperms due to the storm after pollination will develop most readily on about the fourth day after anthesis (when the growth rate of endosperm is at a peak). As indicated in Fig. 5-19, rice yield is affected most seriously by wind on about the fifth day after heading. This can be ascribed to the abortion of endosperms stated above.

(ii) Development of abortive grains

Both development of abortive grains and decrease in the weight of perfectly ripened grains originate from the underdeveloped endosperms. This is believed to be due to the shortage in the supply of carbohydrates, the chief nutrient for the healthy development of endosperm. As a matter of fact, the photosynthetic activity of rice plants exposed to a strong wind shows a fairly great decrease even 10 days after the exposure to the strong wind (Fig. 5-20). On the other hand, however, due to the increase in non-fertilized spikelets for the reason prescribed above, it shows a fairly great decrease in the total number of spikelets which develop into grains. As a result, even though the photosynthetic activity shows some decrease, the amount of carbohydrates per spikelet can not always show decrease. Therefore, the abnormally great increase in abortive grains can not be ascribed merely to the decrease in the photosynthetic activity of the damaged rice plants. It has been evidenced that the contributing cause for the development of abortive grains is found in the spikelets themselves. In the case of normal rice plants, the inner and outer glumes usually close tightly after anthesis, while when exposed to a strong wind, it will show marked increase in glumes which may not be closed normally (Table 5-21). The development of endosperms is checked by the dehydration in the inner part of non-closed spikelets or by the invasion of various fungi therein, thus developing abortive grains, brown colored grains or decreasing the weight of perfectly ripened grains. Another factor regarded as the cause for the development of abortive grains or the decrease in the weight of perfectly ripened grains is found in the fact that the translocation of assimilation products or nutrients into the grains is interrupted by the injury inflicted by a strong wind upon the plant stems, rachises, or rachis branches.

Fig. 5-20. Decrease in Assimilation Rate of Rice Plants Damaged by a Strong Wind (TSUBOI)



Note: Graph indicating the assimilation rates surveyed 10 days after the exposure to the 12 m/s wind for 2 hours and 4 hours.

Table 5-21. Increase in the Rate of Non-closed Spikelets by the Exposure to a Strong Wind
(TSUBOI)

Plot	Percentage of non-closed spikelets	
	Early-flowered panicles	Late-flowered panicles
Check plot	6.1 %	12.8 %
Exposed plot*	12.4	23.9

Note: * Exposed to the 12 m/s wind for 5 hours.

4. Countermeasures for wind damage

The basic measures for the wind-damage-free are to set up shelter belts or fences. From the cultural viewpoint, it is the best way to escape from typhoon damage at heading stage either by shifting the cultural season or by the selection of rice varieties. The selection of rice varieties resistant to lodging or shattering, and the restriction of nitrogenous fertilizer applications (to grow healthy rice plants) are also important measures.

Deep submergence is effective as a temporary measure. Deep submergence is effective in minimizing the wind damage by supplementing the loss of moisture in stems and leaves, and by avoiding the violent waving of stems and leaves.

Binding several hills together or stretching of ropes or nets over the rice stands is also effective against the lodging or waving of rice plants. When a typhoon has occurred in the near at the ripening stage, in order to avoid the losses of grains by shattering, it is better to reap rice plants a little earlier, or it is also an expedient measure to lay down the rice plants artificially before being attacked by a strong wind.

2. Drought Damage

1. Foreword

Paddy rice plants are the specific crop plants that are grown generally under the submerged condition. This is ascribed to the fact that paddy rice plants are suited well for the submerged soil condition and grown well even in the oxygen-deficient soils, and water requirement of this plant is generally greater than that of other crop plants. Consequently, the surface of the paddy rice field soils is always kept level so that the fields can be submerged in even depth. Paddy fields are, in most cases, equipped with irrigation facilities in order that water can be irrigated at any time, if need be.

In some years, an abnormally severe dry spell may often be prolonged in the rice cultural season. As a result, even in the cases of paddy rice fields equipped with irrigation facilities, it may often give rise to a serious shortage in the supply of irrigation water, thus causing drought damage to rice plants. In some cases, it may cause a sharp decrease in the rice yield. In order to avoid the decreased rice yield caused by the drought damage, it is important to take effective measures particularly for those areas lacking in well-equipped irrigation facilities or for those areas depending chiefly upon rain-water irrigation.

2. *Occurrence of Drought Damage*

The total quantity of irrigation water required throughout the rice cultural season is computed by using the following equation:

$$\begin{pmatrix}\text{Total quantity}\\ \text{of irrigation}\\ \text{water}\end{pmatrix} = \begin{pmatrix}\text{Transpiration}\\ \text{from}\\ \text{leaf surface}\end{pmatrix} + \begin{pmatrix}\text{Evaporation}\\ \text{from}\\ \text{field surface}\end{pmatrix} + \begin{pmatrix}\text{Water loss}\\ \text{by}\\ \text{percolation}\end{pmatrix} - \begin{pmatrix}\text{Available}\\ \text{precipita-}\\ \text{tion}\end{pmatrix}$$

Water duty varies widely according to the rice varieties (early or late maturing), soil texture and cultural practices. The generally-accepted water duty (with fluctuation of ±50%) is as follows:

Table 5 – 22. Water Duty to the Rice Varieties

Variety	*Precipitation*	*Standard water duty*
	mm	kl (per 0.1 ha.)
Early maturing	1,000	1,000
Medium maturing	1,200	1,200
Late maturing	1,400	1,400

As low as 30 per cent of the total is the quantity of water transpired from the leaf surface, i.e., the quantity of water actually absorbed by rice plants. In other words, for the paddy rice culture it will require water as much as three times the quantity directly available for rice plants. *In Japan*, since the average precipitation during the rice cultural season (April-October) reaches around 1,000 millimeters (though it varies according to the region), almost all the requirement of water can, when taken the season as a whole, be met by the precipitation. However, the availability of precipitation in the case of paddy field is about 70-90 per cent. Moreover, the rain-water distribution is not always coincident with the timely supply of irrigation water at the respective plant growth stages. Upon this, it will become necessary to supply water by the use of irrigation facilities. However, the precipitation is, needless to say, the most important source of water supply, directly or indirectly. If the precipitation during the months from May to August should decrease to 50 per cent or less of the average year's precipitation, drought damage would be caused and the rice yield would show a decrease.

Next, let's observe the requirement of water for the paddy rice from the viewpoint of soil moisture. Supposing the soil moisture be 70-80 per cent level of the maximum water holding capacity of soils, it will show somewhat slight decrease in the rice yield from that in the submerged paddy field, but *when the soil moisture is as low as 50 per cent of* the maximum water holding capacity, it will show a decrease in the rice yield to the extent of ½ or ⅓ of the normal yield. When soil moisture is sufficient, water will be guttated vigorously from leaf apexes during the time from evening to early morning, but when the soil moisture is as low as 40 per cent or less, the guttation would fall into abeyance. When decreased to 30 per cent, the plant leaves will begin to wilt, and decreased further to 20 per cent or less, the plant leaves will roll all the day long in the needle-shaped form and will begin to die from the leaf apexes.

3. Plant growth stages and drought damage

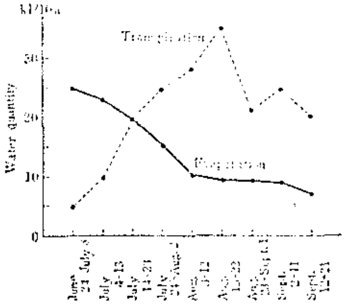
Requirement for water of all crop plants vary according to the plant growth stages. In this respect, rice plants are no exception. In paddy rice plants, the considerably great quantity of water is required immediately before and after transplanting. Water of around 100 millimeter is required at least at the time only for the paddy field preparation and puddling operations. After the transplanting, a great quantity of water is required during the time from booting stage to heading stage when the transpiration reaches a peak. The time at which a great quantity of water is required falls on the time when rice plants are most susceptible to drought damage (Fig. 5–21).

It is very often observed that due to the lack of irrigation water the rooting of the transplanted seedlings is retarded. BABA reports that even when the soil moisture reaches 60 per cent of the maximum water holding capacity of soils, new roots will develop and the rice plants will root firmly on the fourth day from the day of transplanting, but when the soil moisture has decreased to the level of 40–45 per cent, it will take 10 days for the transplanted seedlings to develop new roots, and if the soil moisture has reached 35 per cent or less, the transplanted seedlings would die. Therefore, when a dry spell at the transplanting season continues so long that the field soil surface becomes whitish, the transplanting will be delayed until the rainfall. When the dry spell is prolonged further, the transplanting will become impossible.

Differences in the degrees of drought damage according to the plant growth stages after the rooting of the transplanted seedlings can be clearly indicated by the results of the drought experiment in which the plants grown under submergence are exposed to a definite drought at respective plant growth stages (Fig. 5–22 and Table 5–23). The test results show the facts as described below.

By the drought at tillering stage, some plant leaves died, but new leaves developed and the plant growth has been re-

Fig. 5 – 21. Seasonal Changes in Transpiration and Evaporation in Paddy Fields
(K. SATO, 1942)



stored to the normal condition. It showed a decrease in the number of tillers and panicles per hill, but owing to the larger size of each panicle, no appreciably great decrease in the rice yield resulted in. However, young panicles were by far susceptible to the drought damage than stems and leaves. During the period from young-panicle formation stage to heading and flowering, rice plants in the early-booting stage and in the heading and flowering stages are liable to be affected readily in particular. As the early-booting stage is an important stage which falls on the stage of reduction division of reproductive cells (about 11 days before heading), number of spikelets per panicle as well as ripening is affected seriously by the drought at that time. Due to the drought at the time of heading and flowering, heading is slowed down or flowering or fertilization is affected adversely, thus showing an increase in sterile spikelets. Next to this stage, young panicle formation stage and spikelet primordium differentiation stage (21 days before heading) are also important stages falling on the time for palea and lemma differentiation as well as for pistil and stamen differentiation. If a dry spell should continue ranging over such stages, rice plants would also be damaged seriously.

Table 5 – 23. Differences in Drought Damage to Paddy Rice Plants according to the Plant Growth Stages (1942)

Plot No.	*Non-irrigated period*	*Drought* period*	*Average heading date*	*Total kernel weight per pot*	*Perfect kernel weight per pot*	*Number of grains per panicle*	*Number of fertile grains per panicle*	*Number of panicles per hill*	*Perfect kernel weight per 1,000 grains*
				g	g				g
1	June 25–July 21	July 16–21	Aug. 29	30. 91	29. 51	87. 9	77. 5	7. 4	18. 72
2	July 11–24	July 19–24	Aug. 28	29. 14	28. 23	68. 7	62. 5	8. 5	18. 52
3	July 21–29	July 25–29	Aug. 29	28. 05	27. 30	60. 4	54. 8	10. 0	18. 01
4	July 29–Aug. 5	Aug. 1–5	Aug. 30	28. 30	27. 69	63. 3	57. 9	10. 9	17. 64
5	Aug. 2–11	Aug. 7–11	Aug. 31	30. 36	30. 15	68. 8	58. 3	10. 4	17. 62
6	Aug. 6–15	Aug. 11–15	Aug. 30	27. 12	26. 83	69. 3	53. 9	11. 0	16. 95
7	Aug. 12–22	Aug. 16–22	Aug. 31	7. 90	7. 69	50. 8	17. 0	10. 3	16. 73
8	Aug. 16–26	Aug. 22–26	Aug. 30	23. 12	22. 64	63. 7	53. 2	10. 8	16. 61
9	Aug. 22–Sept. 1	Aug. 26–Sept. 1	Aug. 31	11. 18	10. 34	71. 7	24. 2	11. 2	17. 96
10	Aug. 24–Sept. 3	Aug. 31–Sept. 3	Aug. 28	28. 79	25. 27	70. 6	59. 2	10. 9	17. 62
11	Aug. 26–Sept. 6	Sept. 2–6	Aug. 27	30. 02	23. 29	70. 3	62. 3	10. 6	17. 10
12	Aug. 30–Sept. 10	Sept. 6–10	Aug. 27	26. 94	13. 49	75. 9	66. 9	11. 3	13. 61
Control plot (continuously submerged)			Aug. 27	34. 71	33. 75	71. 7	65. 4	10. 7	18. 28

Note: * Period from the day on which the daytime leaf-wilting began to the day on which soil moisture reached 19 per cent of the maximum water holding capacity of soils.

According to the field observations on the occurrence of drought, it is evidenced that drying of field soils at the tillering stage is not so quick and no appreciably great decrease occurs in the number of tillers, however soil drying becomes severer from about young panicle formation stage and the plant leaves wilt during the daytime. Rice plants are affected fatally during the period ranging from the reduction division stage to the heading and flowering stages, thus delaying the heading, and the fertilization is affected adversely.

4. *Drought damage control*

(1) Drought damage control in the transplanting season

As described before, a great quantity of irrigation water is required at a time for the preparation and puddling of paddy rice field immediately before transplanting. As a result, due to the shortage in the supply of irrigation water, the preparation and puddling operations will become impossible and the transplanting will be delayed, thus resulting in the decreased rice yield. The following steps can be taken to meet the situation.

(i) Seedling preservation

The reason for the decreased rice yield owing to the delayed transplanting is ascribed to the fact that owing to the undue longer nursery stages not only the duration of plant growth after transplanting is shortened, but also the quality of seedlings becomes inferior and disqualified for transplanting. Accordingly, some appropriate steps are required to be taken to prevent the seedlings from being deteriorated.

(a) Seedling preservation in nurseries

When there is a fear that the transplanting may be delayed, it is better to drain water from nurseries in order to prevent the lanky elongation of seedlings. When seedlings have grown abnormally large, parts of about $\frac{1}{3}$–$\frac{1}{4}$ of the leaves must be cut off. In case where nurseries have run out of nitrogen, ammonium sulphate must be supplied at the rate of 20–40 grams per *tsubo* (3.3 sq. meters). In the case of dry nurseries, well-ripened composts or well-fertile soil must be admixed to the soil among seedlings (mulching), instead of ammonium sulphate application. In order to check the evaporation, the nursery bed surface must be covered with paddy husks, wood ash or half-burnt-husks about 6–9 millimeters in depth. For the purpose of avoiding the lanky elongation and the deterioration of seedlings, the densely grown seedling must be thinned or the seedlings are removed in strips of 5–15 centimeters in width so that the width of the strip may become equal to that of the seedling band. The seedlings removed from the nursery are transplanted provisionally in order to meet the shortage of seedlings. The significance of these seedling preservation methods is shown in Table 5–24.

(b) Temporary transplanting and transplanting on dry fields

The seedling preservation methods in nurseries as prescribed above produce no striking effect because even though any of the above methods be practised, the qualification of the seedlings suitable for transplanting could be prolonged only by 5–10 days at most. In order to prevent securely the seedlings from being deteriorated, it is required to take appropriate measures such as temporary transplanting or transplanting on dry fields.

If there is a small extent of paddy fields that can be brought under irrigation, the temporary transplanting of seedlings in such fields is effective in preventing the seedlings from being deteriorated. By such practices the transplanting can be put off by 10–20 days after the ordinary transplanting date, and the decrease of rice yield in case where the seedlings are left standing in the nursery can be saved by 20–30 per cent. Two types of the temporary transplanting are practised: (a) transplanting of seedlings on the paddy rice field near the nursery field, maintaining a close space of 10 centimeters between rows and between hills, by planting clumps of three to four seedlings in each hill; and (b) transplanting of seedlings between the hills which have already been trans-

Table 5 – 24. Significance of Various Seedling Preservation Methods

(BABA, 1953)

Effect of preservation	*Water supply saving*	*Thinning of seedlings*	*Top dressing of ammonium sulfate*	*Mulching*	*Covering of nursery soil surface*	*Cutting-off of leaf tips of abnormally elongated seedlings*	*Cutting-off of leaf tips immediately before transplanting*	*Most effective time*
Control of lanky elongation of seedlings	High effect	Some effect	Reverse effect	Reverse effect	No effect	Some effect	Some effect	When transplanting was delayed by 5-10 days
Promotion of growth of seedlings (increase of dry-matter and nitrogen content)	Reverse effect	Some effect	Some effect	High effect	No effect	Reverse effect	No effect	When transplanting was delayed by 5-15 days
Control of aging of seedlings (avoiding of abnormal elongation of internodes)	Some effect	High effect	Some effect	No effect	No effect	High effect	No effect	When transplanting was delayed by 10-15 days
Prevention from drought damage	Some effect	Some effect	Reverse effect	Some effect	Some effect	No effect	No effect	—

planted normally on the irrigated paddy field available by maintaining a closer space of two to four times the generally-accepted spacing.

Even in the case of dry fields, rice plants could take roots firmly if the paddy field is moistened for seven to ten days after transplanting. As a result, even when the ordinary transplanting practice is not permissible, an unexpectedly great effect can sometimes be brought about by the furrow planting on the paddy field of high water retaining capacity or of high groundwater level. Such transplanting is required to be practised before the quality of seedlings has been deteriorated.

(ii) Resowing

When the transplanting is expected to be delayed as long as 20 days or more, and when temporary transplanting fields are not available or the transplanting on dry fields is not permissible, it is preferable to prepare the rice nursery and to seed again in order to obtain new seedlings suitable for the delayed transplanting.

(iii) Using of upland seedlings

Even though the transplanting is delayed, seedlings grown in non-irrigated nursery beds (upland seedlings) or grown in irrigated nurseries but with low seeding rate will not show so much decrease in rice yield, as compared with the usual seedlings grown in irrigated nurseries. In those areas suffering every year from the shortage in the supply of irrigation water, it is better to produce the seedlings in non-irrigated nurseries at the low seeding rate (180-360 milliliters per 3.3 sq. meters) for the purpose of meeting the late-transplanting.

(2) Drought damage control in the period after transplanting

(i) Irrigation water saving device

In the case of drought, watering at a certain intervals has been practised, but it will be more effective to bring into practice the planned water distribution system (Table 5-25). Under this system, irrigation water is saved at the tillering

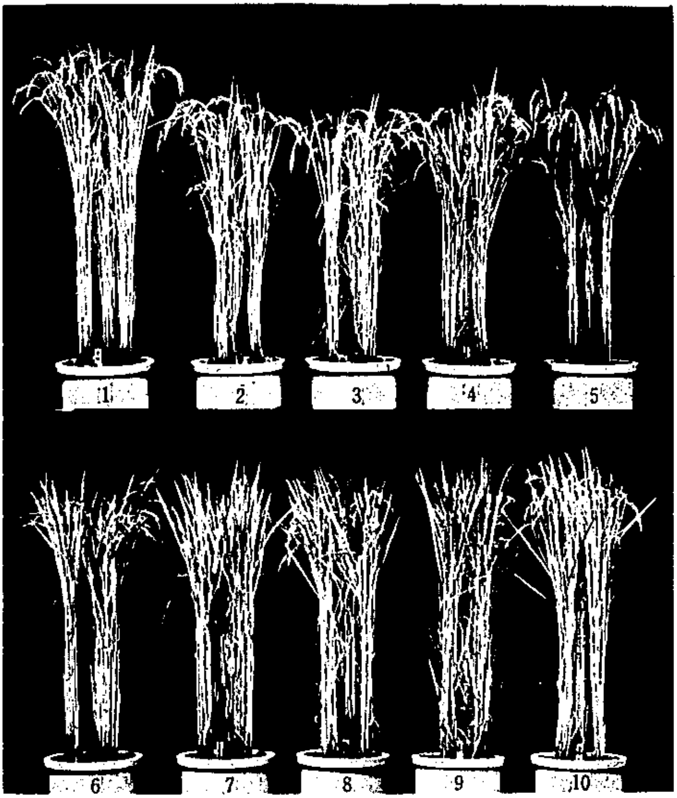


Photo. 5-1. Views of Rice Plants Damaged by Drought at Different Growth Stages

Note:

1. Control (continuously submerged)
2. Early tillering stage
3. Peak tillering stage
4. Late tillering stage
5. Young-panicle formation stage
6. Spikelet differentiation stage
7. Early booting stage (reduction division stage)
8. Booting stage
9. Heading and flowering stage
10. Immediately after anthesis

stage at which drought damage is comparatively slight, the irrigation is started from the young-panicle formation stage (2 millimeters in length of a young panicle), and the water is irrigated sufficiently from the time immediately prior to the reduction division stage (1–2 centimeters in length of a young panicle). Irrigation at random will result not only in the waste of irrigation water but also in the decreased rice yield or may sometimes aggravate the drought damage. In case where the irrigation system is practised by using tanks or reservoirs, it is important to plant such rice varieties with similar heading time.

(ii) Utilization of drought resistant rice varieties and cultural technique improvement

In rain-fed areas or in irriagtion water-deficient areas where suffer frequently from drought damage, it is required to change the rice varieties or to improve the cultural methods in order to avoid drought damage.

(a) Utilization of drought resistant varieties

It is recommended to breed or select rice varieties resistant to drought in order to plant them in habitual drought-damaged areas.

(b) Rice cultural technique improvement

In the rain-fed areas, the early seasonal culture of early-maturing varieties is now practised in order to avoid drought damage during the plant growth period after transplanting. In some areas, the system of direct-sowing on submerged fields has been practised from olden times with a view to avoiding drought damage. Besides these, there are some areas where the paddy rice field acreage has been decreased by converting them into upland fields in order to save the irrigation water.

3. Flood Damage

1. Flood damage in the past

Japan had experienced great floods as frequently as 15 times during the 55 years from 1893 to 1947, or one great flood at intervals of 3–4 years on an average. The flood dam-

Table 5-25. Irrigation Water Distribution Plan as Drought Preventive Measures
(Bofu Branch, Yamaguchi Pref. Agr. Exp. Sta.)

Plant growth stage	*Irrigation water requirements*	*Irrigation water supply device*	
		In case of some shortage in the water supply	*In case of dire shortage in the water supply*
1. Rooting stage after transplanting	Most in need	Submergence	Submergence or moistening
2. Early tillering stage	In need	Moistening	Cutting-off of water supply
3. Peak tillering stage	Ditto	Ditto	Ditto
4. Maximum tillering stage	Very little in need	Cutting-off of water supply	Ditto
5. Young-panicle formation stage	Most in need	Irrigated at several times	Irrigated at a few times
6. Booting stage	Ditto	Ditto	Ditto
7. Heading and flowering stage	In need	Irrigated a few times or moistening	Moistening
8. Dough ripe stage	Some or little in need	Moistening or cutting-off of water supply	Cutting-off of water supply
9. Yellow ripe stage	Little in need	Cutting-off of water supply	Ditto
10. Full ripe stage	Very little in need	Ditto	Ditto

age is most serious among the natural disasters to agriculture in Japan. There is a very strong possibility that great floods may prevail in Japan with high frequency.

Flood damage is confined to specific areas, namely, such areas where are subject to heavy precipitations and where are visited by frequent typhoons are generally exposed to constant danger of flood damage, particularly, water-logged lands lying in river basins are habitual flood stricken areas.

The topography in Japan is very steep and river basins are extremely small. As a result, rivers are apt to run dry during the winter months and in dry spells. When visited by heavy rains, rivers will rise rapidly. Floods occur due to the spring thaw, rainfall in June–July months (known as *Bai-u*), or heavy rains brought about by typhoons in August–September months. Flood damage varies with the areas according to the topography, geology, river conditions, or land utilization. Flood stricken areas can be grouped into the following six types:

(i) Area suffering from floods due to spring thaw (Hokkaido).

(ii) Area suffering from floods during both the spring thaw and *Bai-u* seasons (Japan Sea side of Tohoku).

(iii) Area suffering from floods during the rainy season (*Bai-u*), while less damage during the typhoon season (North Kyushu).

(iv) Area suffering from floods in the typhoon season (Kanto).

(v) Area suffering from floods both in the rainy and typhoon seasons.

(vi) Other type areas.

The most serious damage to rice crop is caused by the floods brought about by typhoons. Due to the great floods, a large extent of arable lands would often be devastated and farm crops would result in total failure.

2. *Changes in rice plants caused by flood damage*

(i) Morphological changes

When the rice plants are submerged under water in a flooding condition, the morphological and physiological changes of various descriptions will take place and it will give rise to the decrease in rice yield or rice plants will die. The abnormal elongation of stems and leaves of the flooded rice plants is the most salient feature of the morphological changes. This phenomenon is particularly noticeable at the vegetative growth stage including the nursery stage. When the cusp of a plant leaf can attain the water surface and is exposed to the air even a little, oxygen being supplied, the plant is kept alive long even under the submerged condition. Next, in the case of the flooding at the tillering stage, it is recognized that the tillering is arrested. Even after the water has subsided, the increase in plant height and in tillers will be stopped, and new sprouts or roots will sometimes develop in order to make up for the perished stems and roots, or the delay in heading will sometimes be caused.

In the case of the flooding in the later growth period beginning with the young-panicle formation stage, the panicles will be injured. Namely, in case of flooding at the young panicle formation or heading stage, a part or all of panicles will die, spikelets will become deformed, the anthesis will be delayed, the uniform heading will be disturbed, sterile grains will become increased, or grains will be tainted.

Flooding at the ripening stage causes a retarded ripening of grains. The physicochemical properties of kernels will become poor. The grains will sometimes begin to germinate under water.

(ii) Physiological changes

(a) Gas-exchange of rice plant under flooding

Rice plants exposed to overhead flooding condition are kept under the state of dire shortage in the supply of oxygen, without having a contact with air. Although rice plants, unlike upland crop plants, possess an air-storing system, the oxygen concentration in the internal atmosphere will show a rapid decrease, while the carbon dioxide concentration will show an increase (Table 5-26). With the decrease in the oxygen concentration in the internal atmosphere, the normal aerobic respiration is reduced greatly, while the anaerobic respiration becomes active. The anaerobic respiration is by far inferior to the aerobic respiration in the efficiency in energy evolution, but the former consumes much more respiratory substrates than the latter. Thus, under reduced oxygen tension, aerobic respiration is reduced in proportion to the oxygen tension and anaerobic respiration is promoted, both resulting in an increased consumption of respiratory substrates with a decreased evolution of energy. Therefore it becomes necessary for the plants to consume a relatively large quantity of respiratory substrates in order to secure energy to keep their life. Consequently, the respiratory substrates in the plants are exhausted rapidly (Figs. 5–22 and 5–23).

Table 5 – 26. Composition of Internal Atmosphere in the Flooded Rice Plants

Parts of rice plant	*After two days of submergence*				*After five days of submergence*				*After two days of submergence nitrogen top-dressed*	
	O_2		CO_2		O_2		CO_2		O_2	CO_2
	1	*2*	*1*	*2*	*1*	*2*	*1*	*2*		
	%	%	%	%	%	%	%	%	%	%
Root (7 cm long)	0.79	0.55	3.57	5.52	0.07	0.05	7.36	5.30	0. 15	6. 01
Leaf sheath	3.29	2.75	2.20	1.50	2.13	2.39	5.68	5.12	1. 52	3. 33
Leaf blade	9.86	10.01	1.80	0.58	6.99	5.49	2.33	6.46	8. 62	2. 37

Notes: Pot tests in 1951 (Pot = 1/50,000 *tan*)
Sample variety: Norin No. 8.
Transplanting of seedlings to the pots: June 28.
Submergence treatment: Beginning with July 1.
Fertilizer application per pot:
Ammonium sulfate, 2 g
Superphosfate, 5 g
Potassium sulfate, 3 g
Nitrogen top-dressing:
Two grams of ammonium sulfate were applied 5 days before the submergence treatment in the top-dressed plot.

Fig. 5 – 22. Gas Exchange, Glucose Consumption and Energy Evolution under Different Oxygen Level
(YAMADA, OTA and OSADA, 1955)

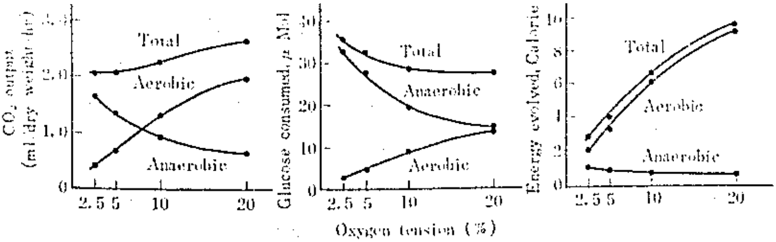
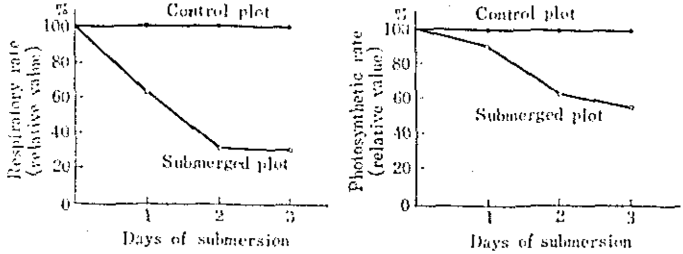


Fig. 5 – 23. Respiratory Rate and Photosynthetic Rate of Leaves under Over-head Submersion
(YAMADA and OTA, 1951)

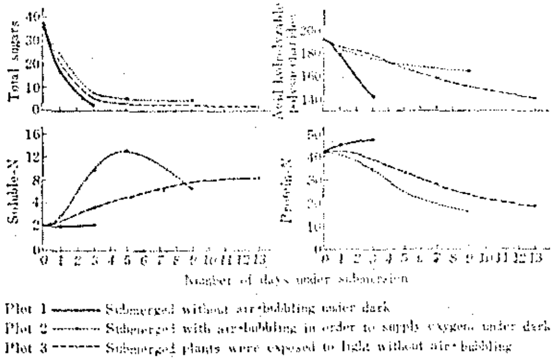


(b) Changes in the chemical composition of the flooded rice plants

Such components as starch, reducing sugar, and non-reducing sugar are exhausted at first, and then a part of acid-hydrolyzable polysaccharides is mobilized and consumed. The rapidity of consumption of such components by the respiration varies with the state of rice plants under the submerged condition. The more the oxygen-deficiency, the more rapid the consumption. The components in the part of a plant where the respiratory activity is high run out with rapidity. Even under the submerged condition, when the water is relatively clear and accordingly the plant is supplied with light in water, the respiratory substrates and oxygen can be produced owing to the photosynthetic activity. As a result, the decrease in carbohydrates is greatly relieved.

With the decrease in carbohydrates, changes take place in the composition of nitrogen. Namely, due to the decomposition of protein-nitrogen, protein-nitrogen is decreased but soluble nitrogen is increased, though it will show a decrease shortly. Such change is observed markedly in leaf blades or leaf sheaths, but it can be observed also in roots. However, when oxygen-deficiency is more marked, the hydrolysis of protein is inhibited. Namely, protein hydrolysis is inhibited and therefore the soluble nitrogen shows a decrease. Thus the rice plants will die, retaining a great quantity of protein and accordingly without changing their green color. (This is known as "*Aogare*," green-death). In contrast with this, in case where there is a considerable supply of oxygen to the rice plants under the submerged condition, e.g., in case where water is clear (it makes possible the supply of light to plant and production of oxygen by photosynthesis), or where water is flowing (flowing water can supply more oxygen than stagnant water does), a great quantity of protein is hydrolysed into soluble nitrogen which may serve as respiratory substrate. As a result, not only a greater quantity of substrates becomes available for the respiratory activity of the flooded plants but also the rate of consumption of the respiratory substrates is lower due to the oxygen supply. Thus the plants can continue to live for longer even under the submerged condition. However, when the duration of the flooded condition is prolonged, the flooded plants will after all die as the result of the decomposition of the protoplasm due to the carbohydrate exhaustion and protein hydrolysis. (This is known as "*Akagare*," red-death.) Effect of supply of oxygen

Fig. 5 – 24. Changes in Nitrogen and Carbohydrate Content of Rice Plants under Submersion
(N. YAMADA et al., 1955)
(mg N. and mg glucose per g dry weight)

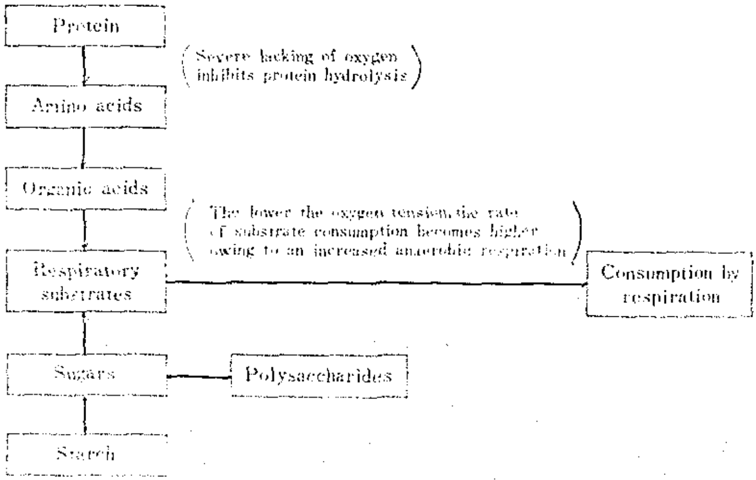


Note: Variety, Norin 8, was subjected to overhead submersion treatment on July 23.

or light to the submerged plant on the extent of protein hydrolysis and carbohydrate consumption is shown in Fig. 5-24.

3. *Physiological basis of the resistance of rice plants against overhead flooding*

The metabolic pathway of respiratory substrates under the submerged condition is illustrated as below.



The rapidity of consumption of respiratory substrates under the submerged condition depends upon the respiratory intensity under the submerged condition. Consequently, the resistance of rice plants to submergence is determined by two factors: (i) the amount of available respiratory substrates contained in rice plants before submergence; and (ii) the rapidity of consumption of them under the submerged condition. Sugars and starch are mostly used as respiratory substrates, and a part of acid-hydrolyzable polysaccharides is used as well. In case protein hydrolysis takes place, the hydrolyzed products of protein are also utilized in respiration. The rapidity of consumption under the submerged condition varies according to such factors as (a) the intensity of respiration of rice plants themselves; (b) water temperatures; and (c) the oxygen tension of water as effected by the degree of clearness and the movements of water (dead or running).

4. *Varietal difference in resistance of rice plants to submergence*

(i) Resistance to submergence according to the growth stages

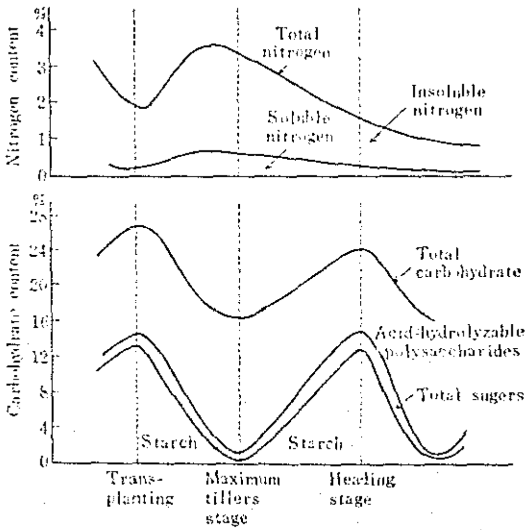
Flood damage varies widely according to the plant growth stages. Rice plants immediately after transplanting suffer *relatively slight damage from flood. Rice plants at the most* active tillering stage (during 10–20 days after transplanting) and in the flowering stage suffer the most serious damage from flood. The serious damage at the flowering stage is caused by the injury to panicles. The submergence resistance of rice plants can be accounted for by the intensity of respiration and the amount of carbohydrate content. The intensity of respiration of rice plants immediately after transplanting is low, and thereafter it becomes increasingly higher as time goes on, reaching a peak about 10–20 days after transplanting. Thereafter, it becomes lower little by little, but the intensity of respiration of young panicles is far higher than that of vegetative organs. Namely, the intensity of respiratory *activity is the exact reverse of the resistance to submergence.* The higher the respiratory rate, the less the resistance of the plant against flooding. The quantity of starch and sugars contained in rice plants immediately after transplanting is large. With the progress in the plant growth, it shows a decrease in quantity, reaching a minimum at the maximum tillering stage, but thereafter it begins to increase. Thus the quantity of starch and sugars forms a positive relationship with the resistance to submergence (Fig. 5–25).

When nitrogen is applied (as split application) to the paddy field before rice plants are submerged, it will show a decrease in carbohydrate content, while the respiratory activity will become vigorous. As a result, the exhaustion of *respiratory substrates is promoted* and the flood damage will be aggravated.

(ii) Resistance to submergence according to the prop-

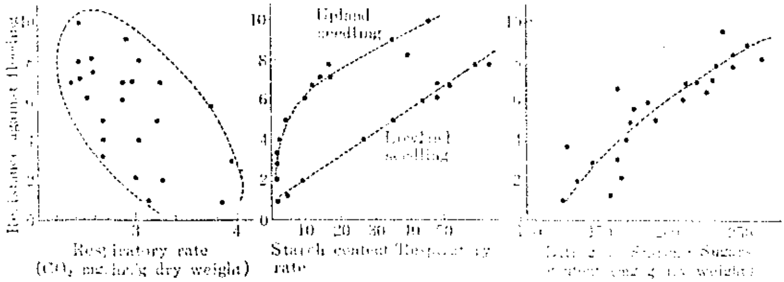
erties of seedlings grown under different conditions
The results of experiment on the resistance to submer-

Fig. 5-25. Changes in Nitrogen and Carbohydrate Content according to Plant Growth
(YAMADA, 1956)
(Content expressed by percentage on dry weight basis)



gence according to the properties of seedlings grown under different conditions show that the resistance to submergence is determined principally by (a) the quantity of starch and total sugars contained in the seedlings, and (b) the rate of respiration of the seedlings. Namely, the seedlings low in the respiratory rate and rich in the carbohydrate content are high in the resistance to submergence, i.e., substantial and stout seedlings are regarded as high resistant ones to submergence. In addition to this, in the case of upland seedlings the greater amount of protein contained in them is mobilized and utilized as an additional source of respiratory substrate. For this reason the upland seedlings can exhibit a higher

Fig. 5 – 26. **Resistance of Seedlings against Flooding and Its Relation to Respiratory Rate and Respiratory Substrates**
(YAMADA and OTA, 1957)



Note: Each dot indicates seedlings grown under different condition.

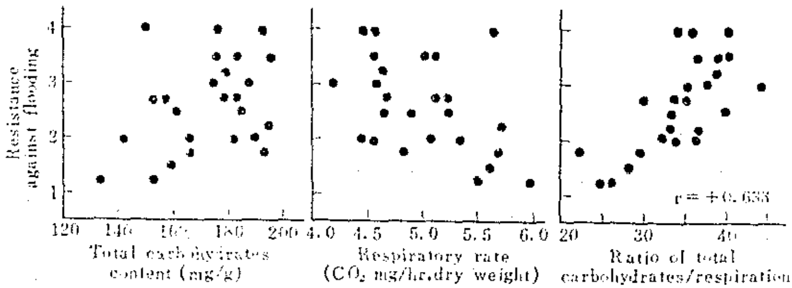
resistance than that expected from the carbohydrate content and respiratory rate (Fig. 5–26).

(iii) Resistance to submergence according to the rice varieties

For the purpose of clarifying the difference in the resistance to submergence among various rice varieties and the relationship to the chemical composition and the respiratory rate, the flood damage experiment for various rice varieties was made at five times ranging over the period from the end of the nursery stage to the booting stage. The results show that the resistance to submergence bears a close relationship with carbohydrate content, i.e., carbohydrate-rich varieties are higher in resistance to submergence than those low in carbohydrate content. Needless to say, however, carbohydrate content shows an increase or decrease according to the plant growth stages, and the changes in carbohydrate content vary with the varieties (early-maturing or late-maturing). Therefore, even a rice variety containing more starch than other ones at a certain time will sometimes show a lower starch content than other varieties at another time. In response to the decrease in starch content, the order of resistance to submergence will be reversed. The resistance to submergence has a negative relationship with the respiratory rate of rice plants, particularly, in case where carbohydrate content is low, the respiration rate, i.e., the rapidity of consumption of substrates, gives great effect on the resistance to submergence. Therefore, the resistance to submergence can be related more clearly to the ratio of "carbohydrate content" to "respiratory rate" than to the carbohydrate content alone (Fig. 5–27).

Fig. 5 – 27. Correlation between Resistance to Flooding of Rice Varieties and Respiratory Rate and Content of Respiratory Substrate

(YAMADA and OTA, 1957)



Note: Each dot indicates a variety.

The difference in resistance to submergence among various rice varieties will sometimes vary according to the plant growth stages, as stated above, and the resistance must be judged by the complicated factors including the recovery rate of plants after the water has subsided or the grain germination of panicles caused by flooding. For this reason, it is difficult to make a clear-cut judge, but the results of experiments on varietal difference conducted by YAMADA and OTA are as given in Table 5–27.

5. Testing methods of resistance to submergence

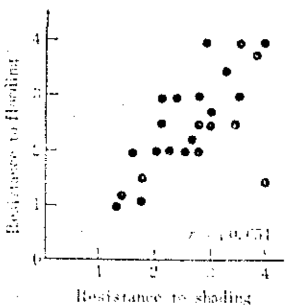
The varietal difference in resistance of rice plants to submergence is determined by the factors prescribed before. As a result, the resistance to submergence could be determined by testing the rate of dissipation of rice plants kept in dark

Table 5-27. Varietal Difference in Resistance to Submergence (Results of the Experiments for Two Years) (YAMADA and OTA, 1956)

Resistance	*Rice varieties*
Highest	Yachikogane, Norin No. 30, Tonewase, Norin No. 29, Tetep.
High	Norin No. 14, Norin No. 48, Norin No. 37, Norin No. 8, Fujisaka No. 5, Kanto No. 9, Norin No. 6, Kameji, Norin No. 7.
Medium	Norin No. 25, Norin No. 32, Norin No. 3, Harutaasahi, Norin No. 10, Ginbozu, Norin No. 21, Norin No. 1, Mubo-aikoku, Waseaikoku No. 30, Tangin, Hatsuminori.
Low	Norin No. 35, Shinriki, Chibaasahi, Senbonasahi, Sen-ichi, Saitamamochi No. 10, Tarobeimochi, Aichiasahi, Murasakiine.
Lowest	Kokuryomiyako, Reishiko, Norin No. 36, Asahi No. 1.

place, instead of a submergence treatment. In the case of rice plants at the late stage of a nursery period, since a fairly close relationship is observed between the resistance to submergence and the resistance to shading, the test for resistance to shading can serve as a simplified method for testing the resistance to submergence. This method is supported by theory and in practice, as it has become evident that the resistance of rice plants to submergence is tested well by using this method (Fig. 5-28).

Fig. 5-28. Correlation between Resistance to Flooding and Resistance to Shading of Rice Varieties



CHAPTER 6

THEORY AND PRACTICE OF RICE CULTURE

I. PRETREATMENT OF SEEDS OF RICE

The pretreatment of seeds of rice is practised in order to secure better germination of seeds and better growth of seedlings. For the pretreatment of seeds, the processes of seed selection, seed disinfection, seed soaking, and presprouting treatment are carried out.

1. Seed Selection

1. Theory of seed selection

Seed selection is the first step to the rice cultural operations. In the case of the rice culture by means of transplanting method, it is very important to produce good seedlings in order to obtain high yields. For this purpose, plumpy and healthy seeds are required to be selected.

Plump seeds germinate well and the seedlings start to grow well, thus resulting in high yields. Seed selection is the operation made for the purpose of selecting the plumpy and healthy seeds. At the early stage of seedlings of rice, the seedlings grow chiefly by taking nourishments stored in the endosperm until nearly the time when the third leaf(on the main culm) develops, but after that time the seedlings grow by absorbing nutrients through their own roots, thus becoming independent for the first time. As a result, it can easily be found that the germination of seeds and the growing of seedlings at early stage have important bearings upon the quantity of the stored nourishments, i.e., upon the size of seeds.

The comparison between large-sized plumpy seeds and small-sized poor seeds shows much difference. For instance, both embryo and endosperm of a heavy weight seed are heavier than those of a light weight seed (ANDO's report), and the correlation coefficient as high as $r=0.61\pm0.0284$ is found between kernel weight and embryo weight (YAMAKAWA). Such facts will show that the heavy embryo means high germination ability and that the heavy endosperm results in good growth of seedlings.

Table 6-1. Relationship between Specific Gravity and Germination of Seeds of Rice

(TAMURA and SHIROISHI)

Specific gravity of saline solution	*Large-sized seeds*			*Small-sized seed*		
	Germination percentage (5 days)	*Germination energy*	*Percentage of healthy seedlings*	*Germination percentage (5 days)*	*Germination energy*	*Percentage of healthy seedlings*
(Floating)	%	%	%	%	%	%
1.055	50	30	46	55	29	40
1.070	79	62	65	72	52	53
1.085	87	67	71	85	67	54
1.100	88	70	71	89	76	60
1.115	88	76	70	90	79	61
1.130	89	77	73	91	81	67
1.145	92	86	81	96	83	79
1.160	94	87	82	96	85	80
1.175	94	89	83	97	87	83
(Sinking) 1.175	98	91	90	98	88	86

Notes: 1. Sample variety: Norin No. 25.

2. Large-sized seed: Larger than 3 mm and over in diameter of a sieve mesh.
Small-sized seed: Smaller than 3 mm in diameter of a sieve mesh.

TAMURA et al. conducted the experiments on the relationship between seed specific gravity and germination and obtained the results given in Table 6–1. It is recognized that a seed of greater specific gravity is superior in germination and subsequent growth of seedling to a seed of smaller specific gravity, and that in the case of seeds of the same specific gravity, a larger seed is superior to a smaller one.

KIDO conducted the experiments as to the relationship between the size of rice seeds and the growth of seedlings. The results are as given in Table 6–2. Under his experiments, the effect of the quantity of the nourishments stored in seeds on the growth of seedlings was examined, using the seeds of different size (large, medium, and small) and the seeds from which a portion of endosperm had been removed (e.g., whole-kernel, 2/3-kernel, 1/2-kernel, and 1/3-kernel). The results show that the larger in the size of seeds and endosperm, the better the growth of seedlings. Thus, it is clear that there is a close relationship between the size of seeds and the growth of seedlings, but it will be very hard to observe the effects of the size of seeds on the yields of rice. Since the difference in growth of seedlings of rice is apt to become negligible due to the environmental conditions after the transplanting of seedlings in paddy fields, the size of seeds has no "direct"

Table 6–2. Relationship between Size of Rice Seeds and Growth of Rice Seedlings
(41 days after sowing)
(KIDO)

Plot	*Weight of 100 soaked seed*	*Plant height*	*Number of leaves*	*Number of roots*	*Fresh weight of a seedling*
	g	cm			g
Large-sized seed	3.61	13.8	5.1	11.0	0.117
Medium-sized seed	3.50	11.4	4.8	8.8	0.089
Small-sized seed	3.25	10.8	4.8	8.0	0.083
2/3-sized seed	2.63	9.2	4.2	7.0	0.055
Whole kernel	2.82	9.4	4.5	11.2	0.063
2/3-kernel	2.20	7.9	4.2	10.8	0.051
1/2-kernel	1.53	7.0	4.0	9.0	0.035
1/3-kernel	0.81	5.8	4.1	6.5	0.023

Table 6-3. Relationship between Specific Gravity of Seeds and Yields of Rice

(Yamaguchi Prefectural Agr. Exp. Sta.)

Specific gravity of seeds	*Weight of brown rice per hectare*	*Percentage ratio*
	kg	%
Winnower selection	4,071	100.0
Specific gravity selection		
1.00 (floating) (water)	4,002	98.3
1.00 (sinking) (water)	4,350	106.9
1.05 〃 〃	4,441	109.1
1.10 〃 〃	4,509	110.8
1.15 〃 〃	4,516	110.9
1.20 〃 〃	4,911	120.0

bearings on the yields of rice. As to the problem, however, many experimental results are available, indicating that the greater seeds with greater specific gravity show the higher productivity.

According to the results of the experiments conducted at the Yamaguchi Prefectural Agricultural Experiment Station, as shown in Table 6-3, there is a very high correlationship between the specific gravity of seeds and the rice yields. If the seeds of specific gravity of 1.10 and over are selected by means of specific gravity selection, it would show a 10 per cent increase in yields over that of the seeds selected by means of winnower.

TAMURA et al. conducted the similar experiment and obtained the results as given in Table 6-4. Table 6-4 indicates that the larger in the specific gravity of seeds (both large and small in size), the higher in rice yields, particularly marked in the case cultured with the light application of fertilizer than in the case with heavy application.

To sum up, the size of seeds has a close bearing on the growth of seedlings and brings about a great effect on the rice yields. Though the difference in seedling growth is apt to become negligible due to the environmental conditions after the transplanting of seedlings in paddy fields, as stated before, it is generally accepted that 5-10 per cent increase in

Table 6–4. Relationship between Specific Gravity of Seeds and Rice Yields

(TAMURA and SHIROISHI)

Specific gravity of saline water	*Heavy application of fertilizer*		*Light application of fertilizer*	
	Large grains	*Small grains*	*Large grains*	*Small grains*
(Floating)	kg	kg	kg	kg
1.100	279.4	3,233	2,678	2,903
1.115	3,001	3,281	2,940	2,516
1.130	3,326	3,266	2,546	2,595
1.145	3,244	2,891	3,086	2,411
1.160	3,503	3,439	2,803	2,783
1.175	3,615	3,293	2,891	2,704
(Sinking) 1.175	3,239	3,293	2,879	2,854

Notes: 1. Figures indicate the weight of kernels (brown rice) in kilograms per hectare.
2. Sample variety: Norin No. 25.
3. Size of a sieve mesh: 3 mm in diameter.
4. Heavy application of fertilizer:
   Ammonium sulfate, 450 kg per hectare
   Superphosfate, 225 kg per hectare
   Ammonium chloride, 113 kg per hectare
5. Light application of fertilizer:
   Ammonium sulfate, 188 kg per hectare
   Superphosfate, 113 kg per hectare
   Ammonium chloride, 75 kg per hectare

rice yields is expected when the seed selection is made, and the effect of the seed selection is thought to become further marked under the unfavorable environmental conditions. Special seed collecting methods (e.g., picking-up of seeds only from the upper part of a panicle, or collecting young seeds before full-ripe, etc.) are sometimes practised, but such methods would be of no use, because if the specific gravity selection method is adopted instead of such methods, good seeds can be obtained.

2. *Practice of seed selection*

Among the seed selection practices are sieve selection, wind selection, and specific gravity selection. Above all, the practice in combination of wind selection and specific gravity selection is most effective and in wide use.

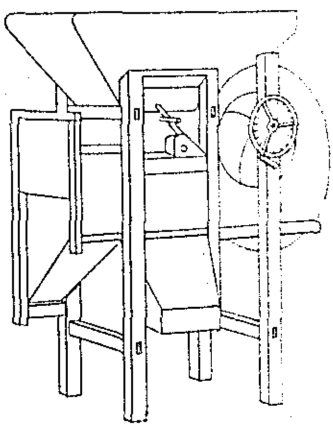
(i) Sieve selection

A sieve is a shallow wooden cylinder with cross wires stretched across bottom. Stalks, leaves, sand or earth mixed in the seeds are removed through a sieve, but mixtures similar to seeds in size cannot be romved. In order to remove larger-sized mixtures, a wind selection is required.

(ii) Wind selection

In Southeast Asian countries, a wind selection is practised widely. In order to select seeds by means of wind, seeds together with mixtures are thrown down from the height of two or three meters. In Japan, *Mi* (hand-winnower) or *Tomi* (winnower) (see Fig. 6–1) is used. This is the selection made by means of wind which is produced by the use of implements. At present, however, owing to the popularization of power threshers, both sieve selection and wind selection have gone out of use.

Fig. 6 – 1. Winnower



Note:	Height:	100–150 cm
	Width:	36– 54 cm
	Length:	100–150 cm
	Weight:	17– 30 kg

3. Specific gravity selection

Seeds are immersed in the solution of a certain specific gravity and stirred well. The seeds of greater specific gravity go to the bottom, while the seeds of smaller specific gravity float up to the surface. When the seeds which have floated on the surface are removed, the seeds of greater specific gravity can be picked up. This is called the specific gravity selection. In order to obtain the solution used for the specific gravity selection, sodium chloride (salt) or ammonium sulfate is dissolved into fresh water. Special attention is required to be attached to the value of specific gravity of the solution. TAMURA et al. made the specific gravity selection of seeds of various varieties of paddy rice by using the solutions with different specific gravities of from 1.055 to 1.175. The results are as given in Table 6–5. The percentage distribution varies with glutinous, non-glutinous rice and varieties. The specific gravity for the use of seed selection ought to be specified for each variety, if possible. In Japan, basing upon the

Table 6–5. Percentage Distribution of Rice Seeds in Specific Gravity Selection
(TAMURA and SHIROISHI)

Specific gravity of saline water	*Chiba-asahi*	*Norin No. 29*	*Norin No. 25*	*Norin No. 36*	*Saitama-mochi*	*Kahi-mochi*
	%	%	%	%	%	%
(Floating) 1.055	—	7.77	11.77	5.71	16.46	16.91
1.070	—	4.21	3.28	2.64	14.93	12.08
1.085	—	6.87	4.37	4.49	14.76	22.43
1.100	15.9	8.51	5.15	4.23	29.27	32.19
1.115	5.5	7.89	9.88	5.20	15.59	12.58
1.130	11.2	14.89	10.60	9.11	8.96	3.77
1.145	11.9	12.54	11.44	9.59	—	—
1.160	27.2	15.39	15.32	16.18	—	—
1.175	15.5	17.12	16.54	16.31	—	—
(Sinking) 1.175	12.8	4.73	9.59	26.49	—	—

Notes: 1. Chibaasahi, and Norin Nos. 29, 25, and 36 are awnless non-glutinous varieties.
2. Saitamamochi and Kahimochi are awnless glutinous varieties.

above results, the standards of specific gravities of solutions to be used for the seed selection have been established, as given in Table 6-6.

Table 6-6. Specific Gravity Standards for Rice Seed Selection

Species and variety of rice	*Specific gravity*	*Sodium chloride per 18 l-water*	*Ammonium sulfate per 18 l-water*
		kg	kg
Awnless and non-glutinous	1.13	4.8	5.1
Awned and non-glutinous	1.10	3.8	4.1
Glutinous	1.08	3.0	3.1

When the specific gravity selection is intended to be applied to *indica* type rice seeds, the preliminary tests are required to be attempted in order to find the optimum specific gravities.

When a hydrometer is not available, a fresh egg can be used. When the egg thrown into the solution rises a little from the bottom, the specific gravity of the solution is proved to have reached 1.08-1.10.

When the seed selection is repeated several times, the specific gravity of the solution become lowered. As a result, the specific gravity of the solution is required to be measured at intervals of three or four times of seed selection, and if lowered, it must be compensated. After completion of the specific gravity selection, the selected seeds must be rinsed well with fresh water to remove the salinity completely. If not rinsed fully, the germination of seeds would sometimes be injured by chlorine. After the rinse, the seeds are dried in the shade and then stored or subjected to disinfection.

2. Seed Disinfection

When the seeds bearing fungi of such diseases as rice seedling rot (*Achlya Prolifera*), *Bakanae* disease (*Gibberella*

Fujikuroi), rice blast (*Piricularia Oryzae*), Brown spot (*Ophiobolus Miyabeanus*), etc. are sown, there are many instances where the above diseases will occur. In order to prevent the occurrence of such diseases, the seed disinfection is carried out. It can be practised most easily and effectively at lower cost than any other practices.

1. Disinfection by mercury compounds

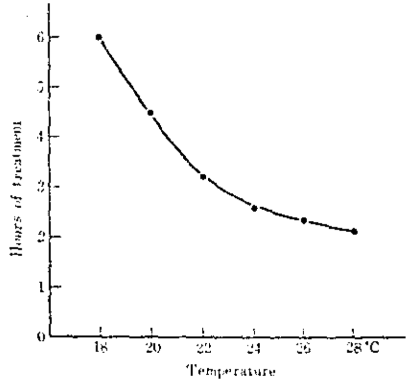
The disinfection by mercury compounds can be carried out with great ease, and is effective in the control of the above-named four diseases. For this reason, this disinfection method is practised most widely. There are various commercial mercury compounds including Usplun, Mercuron, etc. After the soaking of seeds in a 1/1,000 mercury compound solution for a definite time, seeds are rinsed and then soaked in fresh water to supply ample moisture for germination. Six hours are the generally-accepted optimum time for the seed disinfection at temperature of 18°C (Fig. 6-2). It is required to shorten the time for soaking in the solution in inverse proportion to the rise in temperatures. The same solution can be used for three times of seed disinfection repeatedly. After that, the concentration of the solution decreases to an ineffective level. If the decrease in volume of the solution is supplemented with a solution of doubled concentration, the same solution can be used repeatedly for up to five times of seed disinfection.

In carrying out the seed disinfection, attention must be paid not to use the germinated seeds because they may be injured by the disinfection. Particularly, in the case of Southeast Asian countries, special attention must be attached to this point, because the seeds will sometimes germinate in the course of the seed disinfection owing to the higher temperature. By the way, as the seeds disinfected by mercury compounds are noxious, these must not be destined for food or feed purpose.

2. Disinfection by formalin

Seeds are soaked in a 1/100 formalin solution for three

Fig. 6-2. Relationship between Seed Disinfecting Time and Temperature
(Disinfection by means of mercury compound solution)



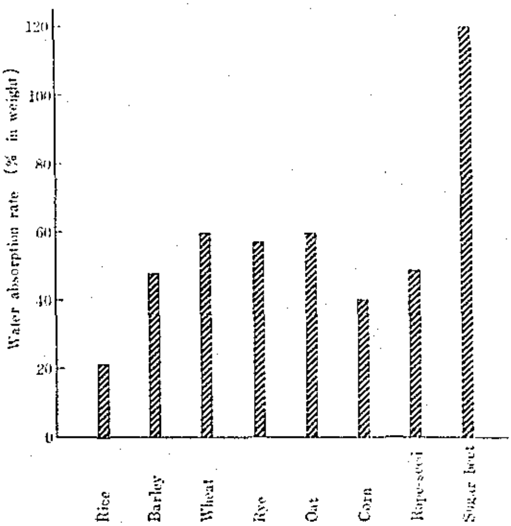
hours and rinsed well. During the soaking in the solution, the container must be covered with a lid in order to prevent the volatilization of formalin. When a great quantity of seeds are required to be disinfected, seeds are soaked in a 1/100 formalin solution for 30 minutes and scooped up out of the solution. After the solution is drained from seeds, the seeds are wrapped in wet straw-mats for three hours and rinsed well, and then the seeds are soaked in water. During the three hours, water must be sprayed from time to time so as to prevent them from being dried because if the seeds are dried the germination of seeds would be jeopardized. The formalin solution is available up to three times. After that the reduced volume of the solution must be supplemented by a formalin solution of doubled concentration. Through the disinfection by formalin solution, *Bakanae* disease, rice blast, and brown spot are controlled.

3. Seed Soaking (in Water)

An adequate temperature and ample supply of oxygen and moisture are indispensable for germination of seeds. Seed soaking is a process for supplying the required moisture to the seeds. When the seeds are sown without soaking in water, it will take a number of days for germination. If taken a long time for germination, the seeds are liable to be affected adversely and seedlings lack in uniformity.

According to the results of experiments conducted by NOGUCHI, the saturated water absorption of rice seeds is 22.6 per cent of the weight of seeds as given in Fig 6–3. Rice seeds germinate with the least moisture absorption amongst the seeds of various cereal crops. Water absorption speed of rice seeds will, as given in Fig. 6–4, become greater with the rise in temperatures. Accordingly, the number of days necessary for seed soaking varies according to the temperatures (Table 6–7). When the seeds have reached to the saturated absorption, it is better to remove the seeds from the water as soon as possible to sow or to promote presprouting. When the seeds are soaked in water for unduly longer period, the nourishments stored in seeds would exude and the

Fig. 6 – 3. Maximum Water Absorbing Degree at the Time of Germination of Various Crop Seeds
(NOGUCHI)



seeds would be depleted, thus lowering the rate of seed germination. Seeds are contained in bags and soaked in water in a tub, pond, or brook. In this case, attention must be paid to the oxygen deficiency. When seeds are soaked in water in a tub in high temperature areas, water must be replaced by fresh water at least two or three times every day, and seeds must be stirred well up and down.

Fig. 6-4. Relationship between Water Absorption Speed and Temperature
(KONDO)

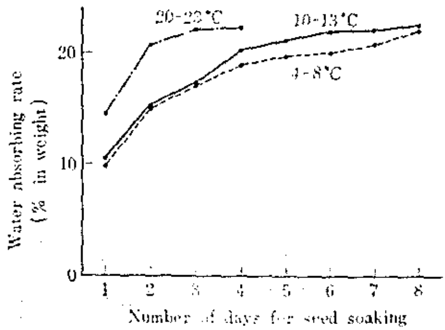


Table 6-7. Relationship between Number of Days for Soaking and Temperature
(KONDO)

Mean water temperature	*Number of days for seed soaking*
	days
10°C	10
15	6
22	3
25	2
27	1

4. Presprouting of Seed

In case where seeds are liable to sink into nursery beds due to the inferior soils, or in case where seeds are liable to become rotten owing to the severe reduction of soils due to high temperature, if seeds are sown after presprouting, seeds would be prevented from being rotten and the uniformity in seed germination could be secured. The sprouted seed sowing practices are prevailing widely in the various parts of Southeast Asian countries. When the soaked seeds are wrapped in wet straw-mats so as to hold ample supply of moisture and kept at temperature of 25–32°C, seeds will germinate to the extent of one or two millimeters long within one or two days. From Table 6–8, it can be concluded that sprouting to the extent of one or two millimeters in length is optimum. When seeds germinate even a little, it may safely be said that the object of the promotion of seed germination has been attained. If sprouted too long, seeds could not be sown uniformly because the sprouts or rootlets are entangled with one another, and the germination rate would become lowered because the plumules (young sprouts) and radicles (young roots) are injured. When the sprouted seeds are not allowed to be sown due to the climatic conditions and there is a fear that the sprouts grow too long, the seeds are dried in order to arrest the elongation. Even if the seeds are dried, when the sprouts are not broken, the seeds can be sown after soaking them again in water.

5. Processes for Seed Pretreatment

Wind selection
↓
Specific gravity selection
↓
Rinsing
↓
Seed disinfection
↓
Rinsing
↓
Soaking in water
↓
Sowing, or sowing after the presprouting treatment

Table 6-8. Relationship between Extent of Presprouting and Growth of Rice Seedlings

(KIDO)

Test plot	*Plant height*	*Number of tillers*	*Number of leaves*
	cm		
Check plot	30.4	1.9	7.5
5 mm sprout	32.1	2.4	7.6
1.5 mm sprout	35.0	2.6	7.7
3 mm sprout	35.3	2.6	8.0

Notes: Sample variety: Norin No. 1.
Seeding date: May 2.
Sampled: June 13.

II. PERFORMANCE OF PADDY RICE SEEDLINGS

The production of healthy and superior-quality seedlings is the first step to the successful rice culture. The requirements for the superior-quality seedlings are:

(i) Seedlings are large enough to be pulled out and readily transplanted in paddy fields;

(ii) Favorably grown seedlings with uniformity in growth;

(iii) Free from diseases and insect pests, and bearing no eggs of insect pests;

(iv) Greater rooting activity after transplanting, i.e., high in rooting ability, and firm enough to be free from injury by transplanting. For this purpose, seedlings are required to be hard, and to have substantial basal parts and such morphological characteristics as erect type leaves (not drooping), or shortness in leaf sheath, etc.;

(v) Seedlings with physiological qualifications for growing healthy and steadily, adapting well for the paddy field soil fertility and the amount of fertilizer application as well as for the climatic conditions (temperature, sunlight intensity, etc.).

Items (i), (ii), and (iii) are the requirements for the superior-quality seedlings, and items (iv) and (v) indicate the physiological performance for the superior-quality seedlings. Particularly, item (v) is an important qualification because the qualifications for the superior-quality seedlings vary according to the paddy field soil fertility, rice cultural practices, or climatic conditions. The qualifications can not be determined independently of the conditions during the plant growth period in the paddy field. For instance, the seedlings regarded as superior-quality ones in cold regions can not be superior-quality ones in warm regions, but may be rather inferior-quality ones. In view of this, there are many cases where the qualifications of seedlings must be judged from the standpoint of the fitness for a given condition.

1. Seeding Rate and the Duration of Nursery

Effects of "age of seedlings" (days after seeding in the nursery) and "seeding rates" on the rice yield are given in Table 6–9. In conducting this experiment, several plots with different amount of fertilizer application to the paddy field and different spacing have been designed. However, Table 6–9 indicates the results obtained under such conditions as might be regarded that the indivdual plants have grown relatively freely and the performance of seedlings have been displayed fully. Table 6–9 shows that "panicle weight per hill" both on the early-transplanting plot and the late-transplanting plot showed an increasing trend proportionately with bigger seedlings grown in the thinly seeded nursery, and showed a decreasing trend proportionately with smaller seedlings grown in the densely seeded nursery. This decrease in the "panicle weight per hill" is observed remarkable in the case of late-transplanting plot. In case where it is equal in the seeding rate but different in the number of days after seeding, the optimum number of days after seeding can be observed, respectively with different seeding rates. In either case of younger seedlings and older ones than the optimum age, it showed a decrease in the "panicle weight per hill."

Table 6 – 9. Relation of Size and Age of Seedlings to Rice Yield

(KONDO, 1944)

Trans-planting date	*Seedlings used*			*Panicle weight per hill*	*Panicle number per hill*	*Average weight per panicle*
	Seeding date	*Seeding rate **	*Days after seeding*			
Early trans-planting (June 20)	May 1	1 go	50days	50.2 g	22.8	2.20g
	May 11	1	40	47.6	23.0	2.07
	May 1	2	50	46.8	21.3	2.19
	May 11	2	40	45.6	22.2	2.06
	May 21	2	30	45.3	24.7	1.84
	May 11	3	40	42.9	21.6	1.99
	May 21	3	30	46.2	25.0	1.85
	May 21	5	30	44.2	23.7	1.87
Late trans-planting (July 10)	May 1	0.5	70	33.7	17.2	1.96
	May 11	0.5	60	36.6	18.3	2.00
	May 21	0.5	50	35.4	19.7	1.80
	May 1	1	70	29.7	16.1	1.85
	May 11	1	60	33.5	17.2	1.95
	May 21	1	50	33.5	17.3	1.93
	May 31	1	40	29.7	18.7	1.61
	May 11	2	60	24.5	17.5	1.40
	May 21	2	50	28.2	18.8	1.50
	May 31	2	40	28.4	19.0	1.49
	June 10	2	30	26.7	19.2	1.39
	May 21	3	50	19.5	17.8	1.09
	May 31	3	40	24.8	20.8	1.19
	June 10	3	30	23.1	20.0	1.15

Notes: Variety: Sen-ichi.
* *go* per *tsubo* = 0.18 liter per 3.3m^2.

It is quite natural that "panicle number per hill" on the late-transplanting plot is less than that on the early-transplanting plot, but roughly speaking, "panicle number per hill" in the case of seedlings grown in the thinly seeded nursery is less than that in the case of those grown in the densely seeded nursery. This is ascribed to the fact that in the case of this experiment it shows a lower nitrogen content in the seedlings at lighter seeding rate than in those at heavier seeding rate, and a fairly higher C/N ratio. In general, as might be described later, seedlings grown in the densely-seeded nursery become poorer: i.e., lower both in nitrogen content and carbohydrate content than in the seedlings grown in the thinly-seeded nursery. As to the age of seedlings, in the case of younger seedlings the number of panicles and tillers is larger than those in the case of older ones. "An average weight per panicle" reaches a maximum when the number of days after seeding is optimum, showing decreases in either case of younger and older ones. An average weight per panicle of the thinly-seeded seedlings is larger than that of the other.

As prescribed above, seedlings grown in the thinly-seeded nursery are higher in productivity, and the higher productivity is due to the greater average weight per panicle rather than due to the greater number of panicles. Such superior performance of seedlings grown in the thinly-seeded nursery can be ascribed to the increased productivity owing to the full absorption of nitrogen present in the paddy field. Younger seedlings are great in the tillering ability and bear many panicles with a less average weight per panicle. This is ascribed to the fact that younger seedlings absorb much nitrogen in the paddy field and develop more tillers, thus the vegetative growth becoming excessive and the grain-straw ratio becoming lower. In case of an early-transplanting practice, the plant growth period after transplanting is longer. Therefore, even though different in size and age of seedlings, almost the same quantity of rice yield can be obtained by a closer spacing for transplanting. However, in case of a late-transplanting practice, the plant growth period after transplanting is shorter, the rice yield from the seedlings grown in the densely-seeded nursery will decrease even if seedlings be transplanted more closely, because though the number of panicles per unit area could be increased even if the seedlings were smaller, the panicles would fail to grow larger and the percentage of fertile grains decreases.

As prescribed above, the seedlings grown in the densely-seeded nursery are low in the productivity, and the productivity will be lowered rapidly according to the longer duration of nursery stage. On the contrary, the productivity of the seedlings grown in the thinly-seeded nursery is high and no appreciably great decrease in productivity would be observed even though the duration of nursery stage be prolonged. In either case of seedlings grown in the densely-seeded nursery and those grown in the thinly-seeded nursery, little or no difference in the plant growth could be observed for some days after the seed germination, but with the lapse of days, the leaves of densely-seeded seedlings are becoming increasingly discolored and the plant growth is becoming poorer day by day. This is ascribed to the fact that the nursery soil fertility is depleted more by the dense seeding rate, and the leaves become overlapped with one another with a result of decreased sunlight intensity received by each seedling, showing a decrease in photosynthetic production of individual plants. (Fig. 6-5). As a result, the seedlings become lankly and the lower leaves become dead. Such seedlings are low in nitrogen content and carbohydrate content, and substantially poor. Accordingly, the seedlings lack in rooting ability and are injured seriously by transplanting. The lower tillers tend to die, so that no excellent lower tiller is produced. The results of experiment on rooting ability of seedlings grown in the plots seeded at different rates are given in Table 6-10 and Fig. 6-6. The rooting ability (represented by the number and weight of newly produced roots) of seedlings at lighter seeding rate is great. The heavier the seeding rate, the lower the rooting ability of seedlings. From Table 6-10, it can be observed that in the case of seedlings at lighter seeding rate a slight decrease in the rooting ability would be found though the duration of nursery stage be prolonged, while in the case of seedlings at heavier seeding rate, with the prolonged duration of nursery stage, a marked decrease in the rooting ability will be observed. The above results indicate that there is the following relationship between the rate of seeding and the rooting ability of seedlings.

$$Y = aX^{-b},$$

where

Y: Weight of newly produced roots,

X: Seed rate,

a and b: Constants.

Table 6-10. Rooting Ability of Seedlings at Different Seeding Rates and Different Duration of Nursery Stage

(SATO, 1946)

Seeding rate go per tsubo	*0.5* go	*1* go	*2* go	*3* go	*4* go	*6* go	*8* go	*10* go
Root weight (mg)								
38-day old seedlings	23.33	21.99	18.09	12.19	12.08	9.76	5.20	4.53
68-day old seedlings	37.20	24.20	20.05	15.17	11.72	8.41	4.92	4.76
Rooting rate (%)								
38-day old seedlings	4.45	6.19	6.93	7.64	8.58	7.38	4.80	6.58
68-day old seedlings	3.25	4.45	4.24	5.09	4.32	3.75	3.52	3.25

Notes: (1) Variety: Zuiko.

(2) In order to test the rooting ability, seedlings (from which old roots were cut off) have been transplanted into culture media of solution culture.

Fig. 6-5. Dry-matter Production of Seedlings at Different Seeding Rates

(TAKEDA and MARUTA, 1955)

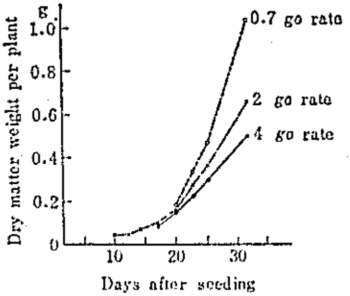
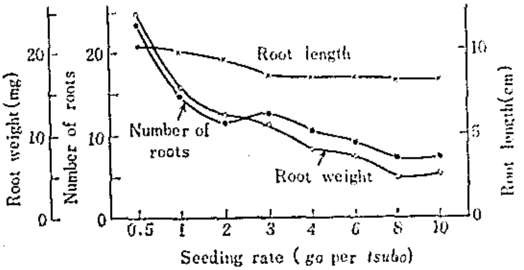


Fig. 6-6. Relationship between Rate of Seeding and Rooting Ability of Seedlings (SATO, 1946)



2. *Growth* of Seedlings and Changes in Chemical Components

Changes in the components of a seedling take place with the growth of seedling, as indicated in Table 6–11 and Fig. 6–7. Content of nitrogen, phosphorus, and potassium in a seedling increases after seeding, and reaches the maximum about the third week after seeding, and then decreases with the aging of the seedling. On the contrary, crude starch content is lowest in younger seedlings, but increases with the growth of seedlings. As a result, C/N ratio is becoming higher with the growth of seedlings, showing 10–13 at the optimum transplanting time (when a seedling has developed 6 or 7 leaves in the case of medium-maturing rice variety). What will signify such changes in the components of a seedling? After seeding, the embryo in a seed absorbs nutrient stored in the endosperm, the seed germinates, the plant develops roots, and the plant grows larger. However, by the time when the seedling has developed the fourth leaf, the nutrient in the endosperm will have been depleted. At that time, the seedling will have 4 or 5 crown roots. Until that time, the seedling has fed on the nutrient stored in the endosperm, but thereafter the seedling begins to grow by absorbing inorganic nutrients from the soils and by acting photosynthesis through leaves. Upon this, the seedling reaches the stage to support itself. Nitrogen absorbed by plant roots is synthesized into protein by combining with sugars formed by the leaves. *Protein is the main component* of a plant and forms an important part of protoplasm. Without increased protein, a plant could not grow. Protein forms the essential constituents of a cell. The cell grows larger and increases in number by the cell division. In addition to this, the substances forming the cell wall are required, i.e., such substances as cellulose, pectine and lignine are required. Above all, a great quantity of cellulose is most in need. These substances are originated from the sugar produced by the action of photosynthesis. Accordingly, sugar is produced at first by the photosynthesis. A part of the sugar combines with nitrogen to synthesize protein. The remaining part is used to construct the cell wall substances, and wraps protein. New leaves and roots are formed with the production of protein and cell wall. With the increase in the number of leaves, production of sugar by the photosynthesis will also increase, and with the increase in the number of roots, inorganic nutrients to be absorbed by roots will become increased, thus growing further. When the amount of sugar (photosynthetic product) exceeds the amount of nitrogen absorbed by roots, it will leave a surplus of sugar and *the surplus sugar is converted into starch and stored in a plant* body, while when the absorbed nitrogen is more, all the photosynthetic product (sugar) *is consumed as material for forming* the protein, and no surplus being left, starch is not formed.

During the time when a seedling is younger, the leaf area is small, and on the other hand, young roots with high absorptive ability grow vigorously and absorb a great quantity of nitrogen. As a result, a majority of sugar (photosynthetic product) combines quickly with nitrogen to produce protein. Accordingly, the nitrogen content (protein is represented by "nitrogen content"×6.25) in a plant body is becoming rapidly increased. However, with the lapse of days, the leaf area becomes larger and the photosynthetic product becomes increased, while the fertilizer in the nursery soil becomes decreased due to the absorption by seedlings. Accordingly the relative amount of nitrogen absorbed by roots becomes less than photosynthetic product (sugar). Thus the amount of sugar or starch stored in seedlings is becoming greater. As a result, nitrogen content begins to decrease and the carbohydrate content (starch or sugar) is increasing.

Table 6-11. Changes in the Chemical Composition of Seedlings in the Nursery Stage

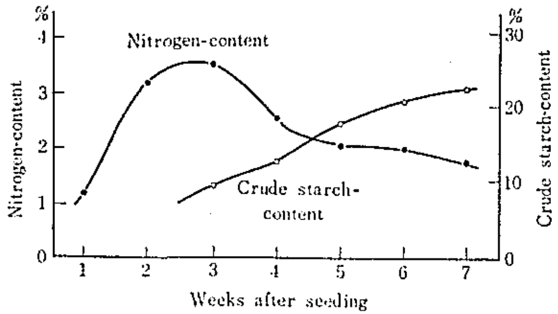
(MATSUKI and HOTTA, 1942)

Item	*Weeks after seeding (May 12)*						
	1	*2*	*3*	*4*	*5*	*6*	*7*
Plant height (cm)	3.4	12.3	25.9	30.8	33.0	37.2	37.3
Seedling age	—	2.8	4.7	6.3	5.6	6.3	9.7
Number of tillers	1.0	1.0	1.3	1.7	2.4	3.0	3.5
Dry weight per plant (mg)	4.4	6.0	24.8	57.2	82.9	111.7	135.4
On dry weight basis							
Nitrogen (%)	1.171	3.200	3.498	2.504	2.014	1.957	1.676
Phosphorus (%)	0.860	1.090	1.200	1.080	0.921	0.808	0.762
Potassium (%)	1.448	2.714	2.955	2.915	2.681	2.317	2.348
Crude starch (%)	—	—	10.220	13.140	18.990	21.490	23.890
C/N ratio	—	—	2.9	5.2	9.4	11.0	14.3

Notes: Sample variety: Nakatchikari
Nursery bed: Irrigated nursery
Seeding rate: 3 *go* (0.54 liters) per *tsubo* ($3.3m^2$)

Thus, the younger seedlings are characterized by high nitrogen content and low starch content, while the older seedling by low nitrogen and high carbohydrate content. However, in the case of seedlings grown in the densely seeded nursery, as prescribed before, photosynthetic product is decreased due to the overlapping of leaves. Thus the starch content is not allowed to increase. As a result, seedlings become poorer, with lower nitrogen and starch content.

Fig. 6 – 7. Growth of Seedlings, and Nitrogen Content and Crude Starch Content
(MATSUKI and HOTTA, 1942)



3. Qualifications for Superior-Quality Seedlings according to the Regions

Comparative characteristics of seedlings grown at the respective regional agricultural experiment stations in the country are given in Table 6–12. Plant height of seedlings at the Hokkaido and Tohoku Agricultural Experiment Stations is low, followed by those at the Hokuriku and Tokai Agricultural Experiment Stations. Plant height of seedlings in warm regions is high. No tillering in the nursery is observed, except for the case of Hokuriku. "Dry weight per plant" of seedlings at the Hokkaido and Tohoku Agricultural Experiment Stations is light, that of seedlings at the Hokuriku and Chugoku Agricultural Experiment Stations is heavy, and that of seedlings at other agricultural experiment stations is almost similar.

Nitrogen content of seedlings shows a regular decrease from north to south with an exception of Hokuriku where an extremely high content is observed. It is clear that nitrogen content in the seedlings in cold regions is high and that in warm regions is low.

Respecting P_2O_5- and K_2O-content, no clear regional dif-

Table 6-12. Size of Seedlings at Eight Regional Agr. Exp. Stas. and their Chemical Compositions

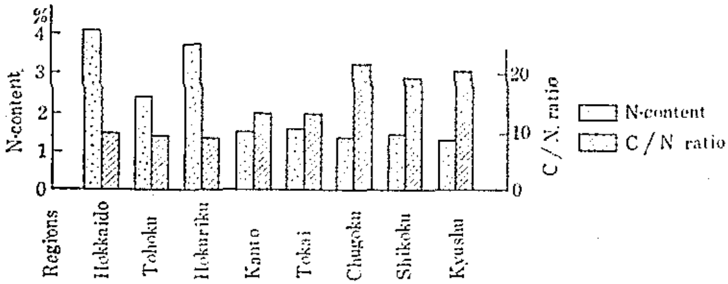
(ISHIZUKA and TANAKA, 1956)

Name and locality of Agr. Exp. Stas.	*Hokkaido* (*Kotoni*)	*Tohoku* (*Omagari*)	*Hokuriku* (*Takada*)	*Kanto* (*Konosu*)	*Tokai* (*Isshinden*)	*Chugoku* (*Himeji*)	*Shikoku* (*Zentsuji*)	*Kyushu* (*Hainutsuka*)
Plant height (cm)	18	18	25	34	24	33	29	33
Dry weight per plant (g)	0.037	0.054	0.205	0.137	0.120	0.255	0.153	0.115
Number of tillers	1	1	3	1	1	1	1	1
Percentage in dry-matter (1952 Survey)								
N-content	2.96	2.44	4.18	1.72	1.48	1.44	1.16	1.12
P_2O_5-content	0.96	0.71	1.09	0.89	0.75	0.63	0.63	0.74
K_2O-content	4.85	4.79	5.00	4.52	4.93	3.09	4.24	4.30
Percentage in dry-matter (1953 Survey)								
N-content	4.10	2.42	3.78	1.56	1.71	1.48	1.52	1.42
Total carbohydrate (C)	40.50	22.50	35.00	20.70	22.70	31.90	29.50	30.10
C/N ratio	9.90	9.30	9.30	13.20	13.20	21.50	19.20	21.10
SiO_2	4.35	8.50	4.50	8.20	6.80	8.50	10.00	10.60

ference is observed, but particularly low in the case of seedlings in the Chugoku and Shikoku Districts. Generally speaking, P_2O_5- and K_2O-contents in the seedlings in cold parts are higher, and those in the seedlings in warm parts in Japan are lower.

With respect to "total carbohydrate content," no definite regional difference is observed, but C/N ratio (carbohydrate-nitrogen-ratio) is evidently greater in the warmer parts of Japan (9-10 in Hokkaido, Tohoku, and Hokuriku; 13 in Kanto and Tokai; and about 20 in Chugoku, Shikoku, and Kyushu) (Fig. 6-8).

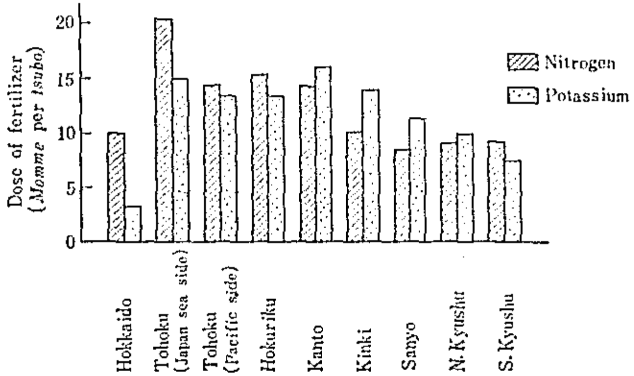
Fig. 6-8. Regional Difference in Nitrogen Content and C/N Ratio of Seedlings (ISHIZUKA and TANAKA)



As to the growing methods of the seedlings referred to above, no definite difference is observed with seeding rate, but the duration of nursery stage after seeding is longer in warm regions and shorter in cold regions. The amount of nitrogen application is doubtlessly great in the Tohoku and Hokuriku Districts. In general, as indicated in Fig. 6-9, the amount of nitrogen application is larger in colder regions, and smaller in warmer regions of Japan.

The same can be said of K_2O. Particularly, it is pointed out that K/N ratio is lower in cold regions and higher in warm regions. When the duration of nursery stage and the temperatures during the nursery stage are taken into con-

Fig. 6-9. Amount of Fertilizer Apllication to Nurseries in Nine Regions
(ARASHI and KONDO, 1955)



sideration, the supply of various fertilizer elements at the later nursery stage seems to be restricted in warmer regions.

Then what will indicate the difference in chemical components of seedlings between cold regions and warm regions? Based upon the Fig. 6-7, it can be said that the seedlings in cold regions are younger ones and those in warm regions are older ones.

The production of new roots of seedlings has a close bearing upon the size of seedlings as well as upon the nitrogen content in a plant body, i.e., the higher the nitrogen content, the larger the rooting ability. On the other hand, the injury to rice plants caused by transplanting has bearing upon the carbohydrate content, particularly upon the starch- and sugar-content. Seedlings of high C/N ratio are tough and not readily injured by transplanting. Accordingly, seedlings in cold regions have great rooting ability and are able to develop many tillers and roots after transplanting. In cold regions, paddy plant growth period being short, the vegetative growth is required to be attained during the short season under comparatively low temperatures. Little or no appreciable difference is observed in the duration from panicle primordia initiation stage to heading stage, as well as in the duration of ripening period after heading between cold and warm regions. Accordingly, the shortness in the plant growth period indicates the shortness in the vegetative growth period. With a view to extending the vegetative growth period even a little by extending toward the earlier days, and for the purpose of accelerating the vegetative growth within the limited period by hastening the growth of the initial period even a little, the improved seedling production systems by the use of "protected semi-irrigated nurseries" (covered with oil paper or vinyl) or "vinyl-covered upland nurseries" have come into practice. After all, younger seedlings with high rooting ability, rapid in growth at the incipient stage, and with high nitrogen content are used. In this sense, seedlings of not only high in nitrogen content but also high in starch content have been grown. A further description of this will be given later.

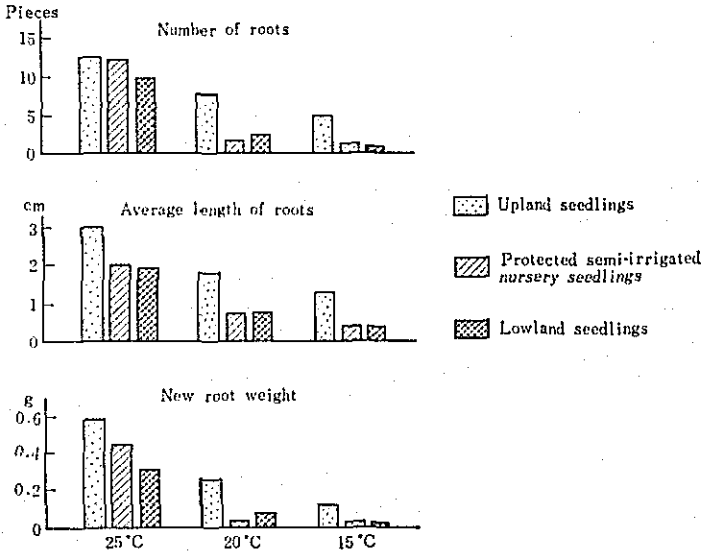
Contrary to the above, in the case of ordinary cultural practice in warm regions, owing to the longer vegetative growth period as well as owing to the higher temperature, rice plants are liable to grow larger readily. Moreover, in the later growth period, soil reduction is accelerated due to the higher temperatures and hydrogen sulfide and other harmful substances occur, which may readily cause harm to roots (like root-rot), thus showing a declining trend in the plant growth in the later growth period. When younger seedlings with greater rooting and tillering abilities are transplanted in the paddy field under such climatic and soil conditions, rice plants will be seriously injured by transplanting and due to the active vegetative growth at the incipient stage after transplanting, culms and leaves will grow excessively, thus *resulting in making straw, but in failure of rice crop.* Such failure is ascribed to the fact that when rice plants grow too large, it will, despite the larger leaf area, show a decrease in photosynthesis (due to the decrease in the light-receiving coefficient) because of heavy mutual shading of plant leaves. On the other hand, the larger the plants grow, the more the carbohydrates are consumed by the respiration. As a result, it will show a decreasing trend in photosynthesis-respiration ratio (P/R ratio) and result in a decrease in the efficiency of dry-matter production, and at the same time, it will become impossible to absorb ample nutrients sufficient for supporting so large plants, thus accelerating a declining trend in the plant growth in the later growth period. Owing to the lack of nitrogen content in the seedlings in warm parts of Japan, it can not be taken that the rooting ability is vigorous, but when the seedlings are grown with much amount of nitrogen, the elongation of plants is promoted and the seedlings will be injured more seriously by transplanting. In view of this, the application of quick-acting nitrogenous fertilizer to nurseries has been saved so as to produce tough seedlings with high starch- or silica-content. Such seedlings are suitable for the paddy fields in warm parts of Japan.

4. Lowland Seedlings and Upland Seedlings

Recent methods of growing seedlings in cold parts of Japan have shifted from the practice of the irrigated-nurseries to the use of protected semi-irrigated nurseries, and thence to the use of vinyl-covered non-irrigated nurseries. The non-heated rice nursery which developed in Hokkaido is also a sort of non-irrigated upland nurseries. The progress in the seedling growing can be ascribed to the shifting from irrigated-nurseries to non-irrigated ones. Many differences can be observed in the characteristics between lowland seedlings (seedlings grown on irrigated-nursery) and upland ones (seedlings grown on non-irrigated-nursery).

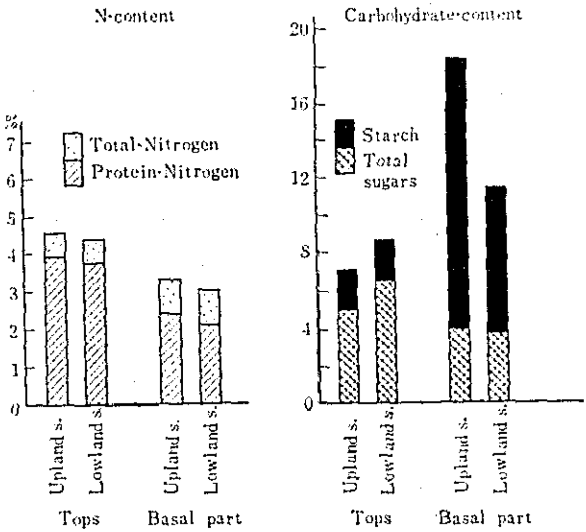
The first characteristics of upland seedlings: Upland seedlings are characterized by the vigorous rooting ability, comparing with the rooting ability of lowland seedlings. Fig. 6-10 indicates the difference in rooting abilities at the different temperatures among lowland seedlings, semi-irrigated seedlings, and upland seedlings. At any temperatures, the upland seedlings are pre-eminent above the rest in the rooting ability, followed by the semi-irrigated seedlings. The lowland seedlings are poorest. The vigorous rooting ability of the upland seedlings is particularly marked at a low temperature. The protected semi-irrigated-nursery seedlings are pre-eminent above the rest in the plant growth at the time of transplanting, followed in the order by the lowland seedlings and the upland seedlings. Accordingly, the difference in rooting abilities among the three types of seedlings is ascribed to the difference in the quality of the seedlings resulted from the difference in nursery types, but not ascribed to the difference in the growth of seedlings before transplanting. Thus, the upland seedlings are more vigorous in rooting ability than the semi-irrigated seedlings and the lowland ones, and furthermore the decrease in rooting ability due to the prolonged duration of nursery period or to the increased seeding rates is relatively small with upland seedlings. Such is

Fig. 6 – 10. Rooting Abilities, by Types of Seedlings (YATSUYANAGI, 1957)



Note: Variety: Norin No. 17 (45-day old seedlings)

Fig. 6-11. Nitrogen Content and Carbohydrate Content in Lowland and Upland Seedlings Immediately before Transplanting
(YATSUYANAGI, 1957)



the feature of the upland seedlings, then to what factors can such features be ascribed?

Fig. 6-11 indicates the comparison of nitrogen, total sugar and starch content in the tops between upland and lowland seedlings immediately before transplanting. Nitrogen content in upland seedlings is higher than that in lowland seedlings, and at the same time the former are higher in starch content (or starch plus total sugar) than the latter. In order to make it clear whether or not the above results can always be obtained, irrespective of the different conditions such as amount of fertilizer application to nurseries, seeding rates, and sunlight intensity, an experiment was conducted in which twelve different conditions were set up by combining three levels of nitrogen application (non-application, normal dose application and three times normal dose application), three levels of sunlight intensity (natural intensity, 50 per cent shading, and 70 per cent shading) and seeding rate. Lowland and upland seedlings were grown under the respective conditions, and nitrogen content and starch content in the respective seedlings immediately before transplanting were examined. The results are shown in Fig. 6-12. It is evident that nitrogen content in upland seedlings is higher than that in lowland seedlings, showing nitrogen content as high as about two times that of lowland seedlings, i.e., upland seedlings are characterized by the high nitrogen content. Next, in either case of lowland and upland seedlings, when nitrogen content is higher, the starch content becomes lower, showing a reverse relation between nitrogen and starch contents, but when it is equal in nitrogen content the starch content in upland seedlings is always higher than that in lowland seedlings. Namely, in the case of lowland seedlings when nitrogen content exceeds 20 milligrams per gram in dry weight, little or no starch is present, while in the case of upland seedlings even when the nitrogen content exceeds 20 milligrams per gram in dry weight, starch content is still high. As a result, upland seedlings are not only higher in nitrogen content than lowland seedlings but also higher in starch content, irrespective of high nitrogen content.

Fig. 6-12. Nitrogen Content and Starch Content in Lowland and Upland Seedlings
(YAMADA and OTA, 1957)

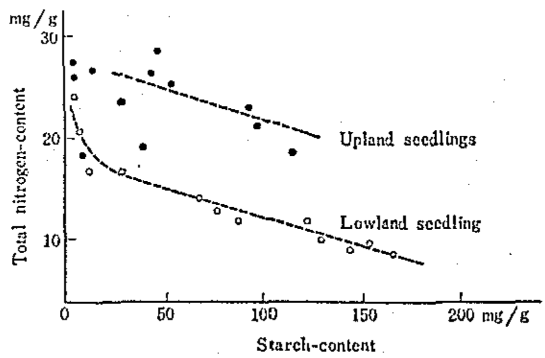


Fig. 6-13. Relationship between "Rooting of Seedlings" and "Top Weight and Total Nitrogen Content in Tops"
(YAMADA and OTA, 1957)

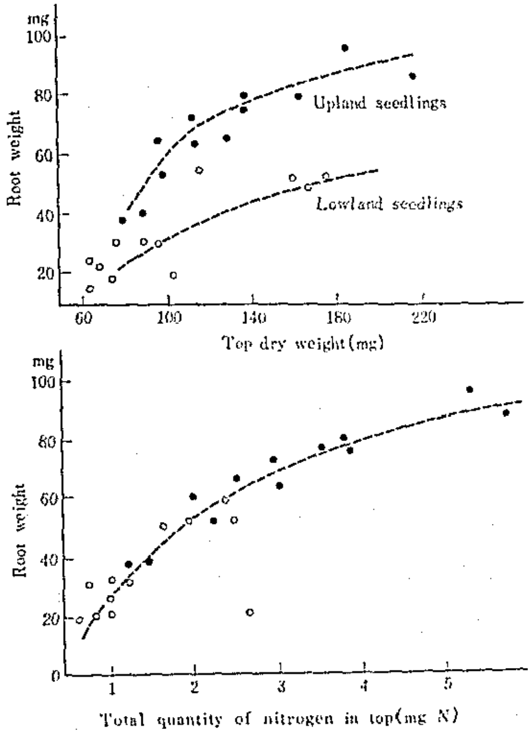
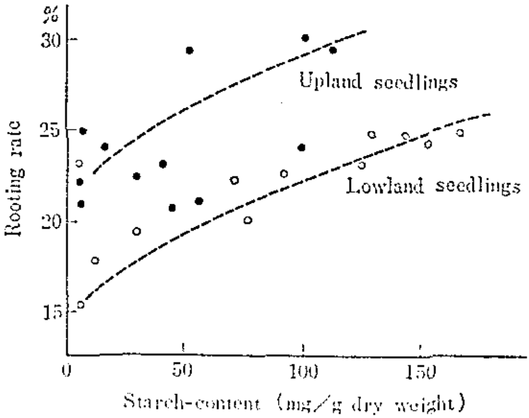


Fig. 6-13 and Fig. 6-14 indicate the comparison of rooting abilities between upland seedlings and lowland ones. The larger the growth of seedlings, the more the weight of new roots. Difference is distinctly observed between upland seedlings and lowland ones. When the seedlings are equal in the growth, the rooting ability of upland seedlings is always higher than that of lowland ones. This is due to the high nitrogen content in upland seedlings. Including both of upland seedlings and lowland ones, a certain relationship is observed between the "total nitrogen quantity in tops of

Fig. 6-14. Relationship between Seedlings' Rooting Rate and Starch Content in Seedlings
(YAMADA and OTA, 1957)



seedlings" (combination of seedlings' growth and nitrogen content) and the "rooting ability". It is evident, therefore, that the superiority in rooting ability of upland seedlings, equal in top dry weight to lowland seedlings is ascribed to the higher nitrogen content. The rooting rate has a close bearing upon the starch content, but the rooting rate of upland seedlings is always higher than that of lowland ones, even when the starch content is equal between the two.

To sum up, the fact that the rooting ability of upland seedlings is high can after all be attributed to the characteristics that upland seedlings are high both in nitrogen content and in starch content.

The second feature of upland seedlings: It is found in the lower contents of silica and manganese. The reason for low silica content in upland seedlings lies in the fact that the water absorption (transpiration) by upland seedlings is less than that by lowland seedlings and that the low water absorption remains unchanged even after transplanting (Table 6-13). A warning has been taken that because of this feature upland seedlings are more liable to be affected by blast disease than lowland ones. However, when seedlings are grown slowly at lower temperature through earlier seeding and earlier transplanting, silica will be accumulated and nitrogen absorption will be limited. Thus the decrease in silica-nitrogen ratio can be avoided and can be free from the uneasiness.

Table 6-13. Effect of Soil-Moisture during the Seedling Stage on the Transpiration of Adult Plant

(BABA, 1955)

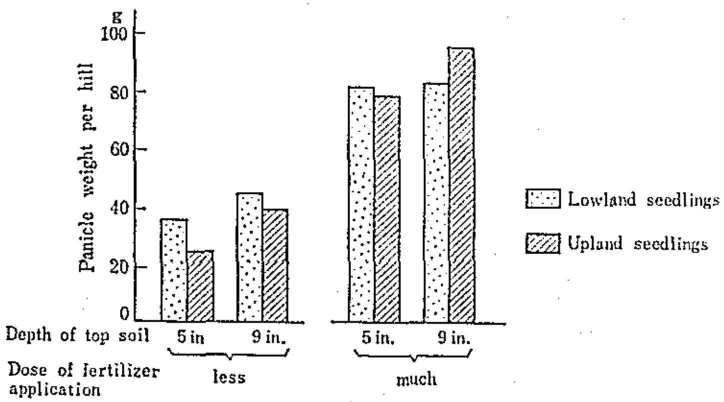
Rice variety	*Plot*	*Leaf transpiration (c/x)*		
		13th leaf (next to flag leaf) 3 p.m, Aug. 5.	*16th leaf (flag) 3 p.m, Sept. 5.*	*16th leaf (flag) 11 a.m. Sept. 29.*
Norin No. 6	Lowland seedling plot	0.89	0.92	0.86
	Upland seedling plot	0.77	0.85	0.78
Murasaki-ine	Lowland seedling plot	0.88	0.90	0.86
	Upland seedling plot	0.80	0.84	0.79

Note: Transpiration is measured by a cobalt paper method.

The third feature of upland seedlings: The incipient growth of upland seedlings after transplanting being more vigorous than that of lowland seedlings, upland seedlings are suitable for fertile lands or paddy fields of deep top soils with liberal application of fertilizers, but the characteristics of upland seedlings can not be displayed fully when transplanted in paddy fields of poor fertility or when grown with less fertilizer application. In such case, rice plants show an *Akiochi*-like growth (a decline in growth at later growth stage) with decreased yield (Fig. 6-15). However, this is the phenomenon which arises from the discord between the characteristics of upland seedlings and the cultural practices after transplanting. In view of this, even when cultivated in poor fertile lands or with less fertilizer application, if the supply of more organic manures, split application, or entire top soil placement of nitrogenous fertilizers are practised, the rice yield comparable to that from lowland seedlings can be obtained with the use of upland seedlings.

Fig. 6 – 15. Depth of Top Soils and Yield of Rice Plants Growth from Lowland and Upland Seedlings

(BABA, 1955)



In the case of a late-transplanting practice in the warm parts of Japan, when lowland seedlings are grown, seedlings are liable to grow tall and slender and become poorer, while if upland seedlings are grown, firm and substantial seedlings can be obtained, and seedlings grow vigorously after transplanting. Namely, the vegetative growth can be attained within the shorter duration. In this sense, upland seedlings are suitable for the late-transplanting practice in warm areas.

Upland seedlings have many features superior to lowland seedlings. Such superior characteristics of upland seedlings have been utilized widely in producing superior-quality seedlings suitable for cold areas, for fertile lands in warm areas, for late-transplanting purpose, or for drought areas.

III. PRACTICES OF GROWING SEEDLINGS

1. Irrigated Rice Nursery

Nursery beds are brought under submerged irrigation. In cold area, beds are kept warm by the irrigated water. In general, the damage by sparrows or rice crane flies can be relieved by the irrigated water, and the growth of seedlings can be regulated by irrigation or drainage, and the emergence of weeds can be controlled.

As a rice nursery, it is desirable to select such place where is sunny, free from strong wind, convenient for irrigation and drainage, not flooded by any heavy rain, and so near to farmer's home that he can take good care of it. The rice nursery is plowed in winter or early spring and harrowed two or three times. Immediately before seeding, it is irrigated and its levees are recoated with mud and the soil surface is puddled. The surface of a bed must be smoothed out. Puddling must be done so lightly that the inner part of a seedbed is kept to be porous. The seedbed is generally partitioned into a strip of 1.20 meters (4 feet) in width, and elevated about 2 or 3 inches above the ground level and surrounded with foot ditches (one foot in width) so that good care can be taken.

About 10–15 *tsubo* (one *tsubo*=3.3 sq. meters) is the appropriate rice nursery area required for 10 ares of paddy field, though it varies according to the number of seedlings ("number of hills"×"number of seedlings per hill") transplanted to the paddy field, size of grains (number of paddy per *sho*, 1.8 liters), percentage of germination, and seeding rate per *tsubo*. The optimum seeding rate is 0.36–0.54 liter per *tsubo*. and the required quantity of seeds (dried seeds) 5.4–7.2 liters per 10 ares. The effects of heavy or light seeding rate on the quality of seedlings are as explained in II. In early spring of cold area, it may safely be seeded at the rate of 0.72–0.90 liter per *tsubo*, while in warm area the seeding at the rate of 0.72–0.90 liter per *tsubo* is too heavy; it must be less than 0.54 liter. About 0.45 liter is the optimum rate.

In the case of cold area, fertilizers to the rice nursery must be applied more than in the case of warm area. The generally accepted criteria for fertilizer application according to the districts are shown in Table 6–14.

Table 6 – 14. Standard Amounts of Fertilizers Applied to Rice Nurseries in the Respective Parts of Japan

District	*Fertilizer constituents per 3.3m² tsubo*		
	N	P_2O_5	K_2O
Northern part of Tohoku	52.5–60 g	60–90 g	45–64 g
Southern part of Hokkaido	〃	〃	〃
Southern part of Tohoku (level area)	45 –56	56–75	37–56
Hokuriku	〃	〃	〃
Warm area (level)	30	34	41
Warm area (coastal)	26	26	34
Warm area (intermountain cold part)	37	49	56

After seeding, the sown seeds are pressed with wire-net roller or wooden trowel to the extent that more than half of the body of any seeds may sink into the nursery bed soils. (Attention must be paid so that the whole body of any seeds may not sink into the soils.) Instead of pressing, the sown seeds are sometimes covered with burnt-chaff mixed with upland soil (at the ratio: 3:1) to the extent just the seeds may disappear. After seeding, the rice nursery is irrigated slowly and submerged somewhat deeply. When seeds have germinated and leaves have emerged on the surface of soils, the rice nursery is drained. When primary leaf (incomplete leaf) starts to emerge, the nursery bed is drained at daytime on the warm windless day (cloudy weather is preferable, if possible) and the sprouts are exposed to the air for several hours. Afterward such nursery bed drainage is repeated on the warm windless days in order to expose the tiny seedlings to the air for longer hours little by little. Through the exposure of seedlings to the air, they will become healthy and firm and the development of roots is hastened. If the seedlings are placed in the submerged beds, due to the oxygen-deficiency the rooting and root growth would be checked, while when seedlings are exposed to the air through the drainage, oxygen is translocated from leaves to roots, thus hastening the rooting and root growth to a considerable extent.

After drainage, the nursery beds are irrigated up to some 1 centimeter in depth. The nursery beds are occasionally drained at daytime or at night in order to produce firm seedlings, but in case where temperature is low or where there is a fear of occurrence of frost, the nursery bed is submerged deeply.

At the nursery stage, attention must be paid to disease and insect pest control. When ammonium sulfate is applied at the rate of 5–10 grams per sq. meter about 4 or 5 days before pulling out of seedlings to transplant to the paddy fields, the root development will become vigorous and the rice plants will be less injured by transplanting.

2. Non-Irrigated Rice Nursery

The rice nursery is not brought under irrigation. Seeds are sown and seedlings are grown in the non-irrigated nursery. The non-irrigated rice nursery has been used chiefly in the water-deficient areas or in the areas where paddy fields suffer frequently from long dry spell. The non-irrigated rice nursery has the following characteristics.

(i) In the case of seedlings grown in the non-irrigated nursery, the root development after transplanting and the plant growth at the incipient stage are more vigorous than those grown in the irrigated rice nursery. As a result, when the seedlings are transplanted to the fertile paddy field of deep furrow slice it will show an increase in rice yield, while, when transplanted to the poor rice field of shallow furrow slice, the rice yield is liable to decrease.

(ii) Even though the number of days at the nursery stage be prolonged, the seedling quality would not be degraded so much. Accordingly, it is recommended in case where the transplanting is delayed due to the shortage in the irrigation water supply or due to the delay in the harvest of winter crops in the paddy field.

(iii) In case where seedlings are grown in the non-irrigated nursery, the transpiration is dull. As a result, they are resistant to drought. On the other hand, due to the dull transpiration the absorption of silicate becomes dull, and the rice plants become susceptible to blast.

(iv) In the case of the non-irrigated nursery, due to the difficulty in holding a definite soil moisture content, there is lack of uniformity in germination, and seedlings will suffer damage from birds and rice stem borers.

(v) As the ground temperature can not be raised by irrigated water, the use of non-irrigated rice nurseries is not permissible in the cold areas. However, when protected with vinyl-cover, the non-irrigated rice nurseries will display the excellent function even in the cold areas (a further description will be given under the caption "Vinyl-covered non-irrigated rice nursery").

Seeds are required to be sown at lighter rate under non-irrigated nurseries than under irrigated condition in order to produce stronger seedlings high in blast resistance. Therefore, it is necessary to provide wider area than under irrigated condition, namely 15 *tsubo* (50 sq. meters) per 10 ares is desired and seeds are sown at a rate of 0.27 liter per *tsubo* (3.3 sq. meters). Under non-irrigated condition, slow-acting fertilizers (e.g., cotton seed cake, fish cake, composts, etc.) are mainly applied, but the application amount is almost similar to that under irrigated condition. Under non-irrigated condition unlike the case with irrigated nursery, the sown seeds are covered with fine soils in the depth of 0.3 inch and covered further with burnt-chaff in the depth of 0.2–0.3 inch for the purpose of preventing from being dried and from the emergence of weeds, or from bird damage. Furthermore, in order to prevent from being dried reaped grass or Chinese milk vetch are mulched over the nursery bed in the depth of 2–3 inches.

Care must be taken to drain rain water from the nursery bed so that it may not stay longer. Irrigation is not needed, except in a long dry spell. As a result, labor for the water control is saved.

3. Semi-Irrigated Rice Nursery

This is an ecletic rice nursery combining irrigated and non-irrigated rice nurseries. Under this method, having the advantages of both of these two nurseries, excellent seedlings can be produced. It is prevalent generally in warm parts of Japan. For preparing the semi-irrigated rice nursery, the elevated nursery bed in the strip form is made. For this purpose, plowing and harrowing are done carefully. After irrigation, the nursery is puddled lightly in order to smooth out the bed surface. After seeding, seeds are pressed lightly and covered with burnt-chaff mixed with fertile soil (at the ratio: 3:1) in such a depth that the seeds may disappear. The water in the surrounding foot ditches is levelled up slowly so that the moisture may be absorbed fully by the bed surface soil, but with the progress in germination within one or two days, the water in the foot ditches is levelled down so that the bed surface may be exposed to the air, thus providing oxygen essential to the elongation of young roots. Such drainage treatment must be done thoroughly for a long time (e.g., 10–15 days). After the drainage period, the nursery is kept always under irrigated condition, but the irrigated water is required to be refreshed from time to time.

4. Protected Rice Nurseries

Among the typical protected rice nurseries are: (i) protected semi-irrigated rice nursery (covered with oil paper); (ii) vinyl-covered non-irrigated rice nursery; (iii) non-heated rice nursery; and (iv) vinyl-house rice nursery.

1. *Protected semi-irrigated rice nursery covered with oil paper.*

Seeds are sown in the nursery bed containing optimum moisture under non-irrigated condition and oil paper is spread over the bed in order to keep it warm.

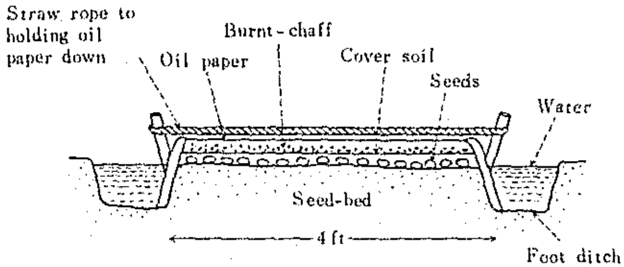
By the practice of an ordinary irrigated nursery the date of transplanting falls on the time of average air temperature of 15–16°C, while by using the protected rice nursery the growing of seedlings and transplanting can be made earlier by one month or more. Even in cold areas, the transplanting can be hastened by 7–10 days as compared with the production of seedlings in an ordinary rice nursery.

Seeds are sown in the elevated nursery bed, as is the case with the semi-irrigated rice nursery referred to above. In the protected semi-irrigated rice nursery beds, the presprouted seeds with plumules and radicles of about 0.1–0.2 inch in length are sown at lighter rate than in irrigated nursery. Less than 0.18 liter per *tsubo* (3.3 sq. meters) is the optimum seeding rate in warm areas and less than 0.54 liter per *tsubo* in cold areas. After seeding, seeds are covered with upland soil and burnt-chaff is scattered over the bed surface, and then the bed is covered with oil paper pervious to light. Foot ditches are flooded, but the bed must be exposed to the air. Two weeks after, seedlings will grow so large (1.5 inches in height) that they push up the oil paper cover. Then the cover is removed (Fig. 6–16).

2. *Vinyl-covered non-irrigated rice nursery*

The use of a vinyl-covered non-irrigated rice nursery makes possible the earlier seeding and transplanting than the

Fig. 6 – 16. Protected Semi-Irrigated Rice Nursery Covered Oil Paper

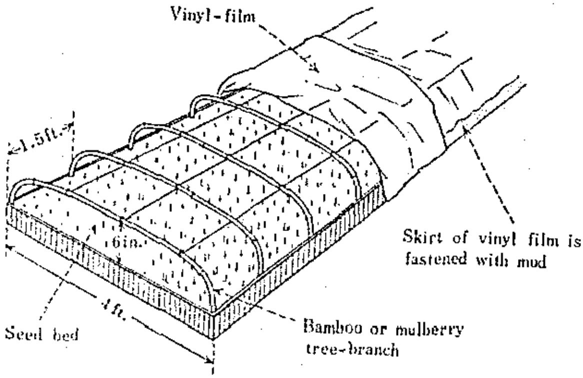


use of a protected semi-irrigated rice nursery. In the case of this nursery, the tunnel-shaped house is made by using vinyl film which is by far greater than oil paper in durability, transmission of light, and heat insulation. The seedlings at the nursery stage are protected fully from the cold. As a result, the seeds can be sown at early season at the average air temperature of as low as 4–5°C, and the seedlings can be transplanted at the temperature of 12–13°C. Therefore, the seeding is hastened by 15–20 days earlier than the case of protected semi-irrigated nursery.

In constructing the vinyl-covered upland nursery, if the bed soil is not suitable, the seedlings would suffer from damping-off and the like. Therefore, the porous and soft soils high in water holding capacity, rich in organic matter, and high in acidity (pH 5) are selected and used. If such soil is not available, effort should be given to produce the soil by improving the usual soil. Fertilizers are applied two times as much as the standard amount for irrigated nurseries. Slightly sprouted seeds are sown and covered with fine soils mixed with burnt-chaff in the depth of about 1 centimeter. The frame is made of stake and bamboo and covered with vinyl film, which is fastened with rope (Fig. 6–17).

Important hints: (a) attention must be paid to the properties of nursery bed soils; (b) the nursery must be irrigated before seeding so sufficiently that it may not be irrigated during the period when the nursery bed is covered

Fig. 6 – 17. Vinyl-Covered Non-Irrigated Rice Nursery



with vinyl film (for this purpose, the soils of high water holding capacity are selected), and (c) after germination, ventilation is practised by rolling up the skirt of the vinyl-film in order to avoid the rise in the daytime temperature exceeding 25°C (in fine weather) and 30°C (in cloudy weather).

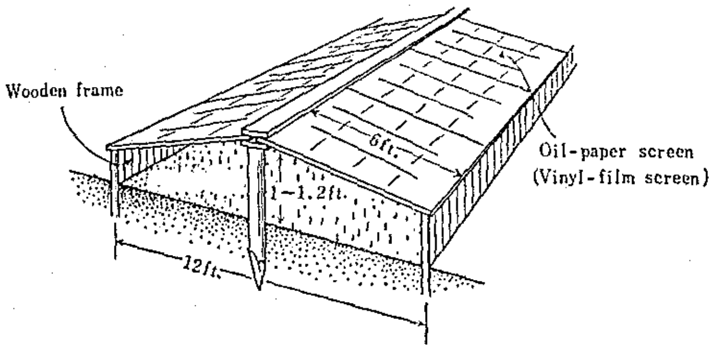
3. Non-heated rice nursery

This nursery is the protected nursery prevalent in Hokkaido from 20 years ago. This is, in principle, similar to the vinyl-covered upland rice nursery. In this case, wooden frame is used instead of tunnel-shaped room, and covered with oil-paper screen, but in recent years the oil-paper screens have come to be replaced by vinyl-film screen (Fig. 6–18).

4. Vinyl-house rice nursery

This has been devised quite recently. During the germinating period and younger seedling stage (up to the second leaf stage), a vinyl-house (for an example 3.6 m× 4.5 m×12 m) is heated with electricity. After that the seedlings are transplanted provisionally in an ordinary semi-irrigated nursery, an upland nursery or a tunnel-shaped vinyl-covered nursery. In the case of a large vinyl-house (3.6 m×4.5 m×12 m), seedlings can be produced at a time

Fig. 6–18. Non-Heated Rice Nursery



sufficiently for 4.5 hectare paddy fields. It is reported that by the repeated use of this vinyl-house, seedlings sufficient for 55 hectare paddy fields were produced. This device will contribute much toward the cooperative mass production of seedlings.

IV. PLOWING, PUDDLING, AND TRANSPLANTING

1. Plowing

1. Effect of plowing

Plowing may invert, stir and break up the top soil. As a result, the following effects can be cited: (i) weed control, (ii) incorporation of fertilizers with field soils, (iii) increase in the soil porosity, (iv) mixture of soils of upper and lower layer, and (v) making the soils finer.

(i) Effect of plowing on weed control

As the furrow slice is turned over by plowing, weeds grown on the field are plowed under, and most of the seeds of weeds contained in the upper layer soils are plowed under the deeper layer where the seeds can not readily germinate. Accordingly, a great effect on weed control can be brought about by the careful inverting of soil.

(ii) Effect of plowing on the incorporation of fertilizers with soils

Fertilizers or green manures scattered on the field can be plowed under the soil and incorporated with the soils. Fertilizers or green manures can be plowed under the deeper soil layer by the careful inverting by plowing. Nitrogen loss by the action of denitrification can be checked when nitrogenous fertilizers are deeply plowed under by plowing. Accordingly, in the case of the field less in percolation, nitrogenous fertilizers plowed under the intermediate or lower layer will be kept longer in the soil than in case where these are applied to the upper layer soils (Table 6-15).

Table 6 – 15. Fertilizer Distributions in Soil according to the Time of Fertilizer Application (Ammonium Sulfate)

Time of fertilizer application	*Plowing and puddling operations done with*	*Percentage of NH_3-N content in the lower layer to that in the upper layer*
		%
Before plowing	Rotary power tiller	74
	Plow and harrow	148
At the time of puddling	Rotary power tiller	50
	Plow and harrow	71

Note: Upper layer of furrow slice: 0– 6 cm in depth.
Lower layer of furrow slice: 6–12 cm in depth.

(iii) Effect of plowing on the increase in soil porosity

Soil may be broken up by plowing into clods of varied size in the state of loosened texture. When plowed, the porosity of the soil can be increased. The more increase in soil porosity, the larger becomes the soil surface area, and the aeration and the percolation of soils will become greater. Owing to the increase in the soil surface area and the aeration, the evaporation from the soil surface will become increased, and owing to the increased percolation, the water held in the soil will become decreased. On the other hand, as the capillary system between the top soil and the subsoil layers will be cut off by plowing, the supply of water by capillarity to the top soil from the lower soil layer will be impeded.

For the above reason, the top soil will become increasingly drier according as the soil porosity is increased as the result of plowing. When the soil becomes dry, the mineralization of organic nitrogen in soils (i.e., effect of soil drying) will be accelerated (Table 6–16).

Table 6–16. Soil Dryness according to the Tillage Methods

Method of tillage	*Soil moisture*	
	May 10	*May 23*
No tillage	% 41.8	% 42.7
Rotary power tiller	38.5	36.7
Animal-drawn plow	34.8	31.2

Note: *Tillage and harrowing operations are repeated twice.*

Through the increased aeration and percolation of the soil owing to the increased soil porosity, the soil weathering will also be promoted.

(iv) Effect of plowing in mixing soils

With the inverting of soils between the upper and lower layers, the fertile soils in the upper layer will be mixed with the unweathered soils of the lower layer, and the latter will become easily weathered. Accordingly, the entire layer of top soil will become increasingly fertile. In the case of degraded paddy field soils in which the active iron or manganese leached from the top soil are deposited in the subsoil, this iron or manganese can be returned to the top soil by plowing to the depth of subsoil.

(v) Effect of tillage to make the soils finer

Adsorption of fertilizers by soils will become increasingly greater according as the soil becomes finer and the soil surface area is increased. According as the top soil becomes finer, the mineralization of organic nitrogen in soils after the submergence will be accelerated and the ammoniacal nitrogen content in the top soil will increase. At the same time the top soil will be brought into reductive state.

2. Characteristics of plowing implements

In Japan, the plowing operation is done chiefly with Japanese plows or power tillers. Japanese plows have the following advantages and disadvantages as compared with power tillers: (i) superior in a soil inverting capacity, particularly double moldboard plows are superior; (ii) lower in a soil breaking-up capacity, with larger clods remaining unbroken, and larger in amount of soil porosity; and (iii) in-

Table 6 – 17. Soil Turning-Over Capacity of Various Types of Tillage Implements

Types of implements	*Stubbles exposed to the field surface **
	%
Plow	9
Japanese plow	18
Crank type power tiller	23
Rotary type power tiller	42

Note: * $\frac{\text{(Stubbles exposed after tillage)}}{\text{(Stubbles exposed before tillage)}} \times 100$

Table 6 – 18. Distributions of Clods on Furrow Slice after Tillage and Puddling Operations

Testing time	*Types of machinery* \ *Diameter of clod*	*8 cm and over*	*4–8 cm*	*2–4 cm*	*1–2 cm*	*0.5–1 cm*	*Under 0.5 cm*
		%	%	%	%	%	%
After tillage	Japanese plow	22.4	29.4	18.1	18.4	9.5	5.8
	Rotary power tiller	1.3	18.3	33.1	24.2	15.4	7.6
After puddling	Animal-drawn harrow	—	31.2	8.9	9.2	7.3	43.5
	Rotary power tiller	—	18.2	10.7	12.4	7.9	50.2

ferior in the working efficiency (Tables 6–17, 6–18 and 6–19).

By the way, the operation done with power tillers may be said as "plowing and harrowing" operations combined rather than mere plowing operation.

Table. 6 – 19. Working Efficiency, by Tillage Machines

Type of machine	*Operating time required per 10 ares*
Cattle-drawn Japanese plow	2.7–4 hours
Horse-drawn Japanese plow	2.2–2.7
Rotary power tiller	1.5–2.0

3. Practices of plowing

(i) Time of plowing

When the plowing is done in the previous autumn, it will bring about a great "effect of soil drying" because the top soil has been left long in the state of coarse clods. However, in the areas with much rain in winter the full effect of soil drying cannot be expected from the autumn plowing. In the cases of fields planted to winter crops, the effect of soil dryness is little, because the soils are broken into fine state in preparing for cropping. Therefore, in general, the plowing is practised after early spring.

Owing to the autumn plowing, the top soil will be kept in the loosened state during the winter months, and accordingly the spring plowing can be done easily, but so great effect cannot be expected, if there is much rain after the autumn plowing because the top soil will become hard.

(ii) Methods of plowing

In winter-fallow area (e.g., mainly in the Tohoku and Hokuriku Districts), plowing is done two or three times or more with a view to increasing the effect of soil drying and to incorporating fertilizers thoroughly with soils. In double-cropping paddy field areas (wheat, barley or rape-seeds are planted as winter crops after the rice has been harvested), plowing is done one or two times only, i.e., less in the times of plowing. This is due to the fact that the top soil is kept swell owing to the plowing done immediately before the planting of winter crops and to the intertillage during the winter months, and due to the short duration from the harvesting of the winter crops to the date of transplanting.

In most cases, composts or green manures are applied to paddy fields before plowing. In order to incorporate fertilizers to the whole layer of top soil thoroughly, chemical fertilizers are sometimes applied at the time of plowing. However, such method is not adopted when the duration from the time of plowing to the time of irrigation is long, because there is a fear for losing the fertilizers applied.

Plowing done with Japanese plows: By using a fixed type plow, the operation is done to make rides by mounding the turned-over furrow slices from both sides (ridging plowing) as shown in Fig. 6–19. After plowing, stripes of ridges made of the turned-over furrow slices (with many pore spaces inside the ridge) will align all over the field. As a result, the drying and weathering of soils are accelerated by this method of plowing. However, in order to level the field surface, the ridges must be broken down by using the plow (deridging plowing), and the levelling operation must be intensively repeated. When wheat or barley was planted on the ridges, the levelling operation is also required to prepare for rice planting.

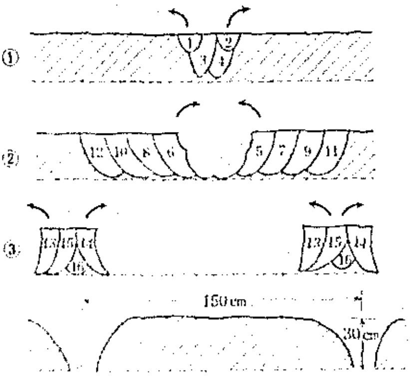
When the plowing is done with a reversible type plow, furrow slices are turned to the same side of the field in plowing either direction. (This is known as "plane tillage") (Fig. 6–20). After plowing, the turned-over furrow slices will align flatly overlapping each other (with fairly high porosity between clods). Afterward, careful harrowing and levelling operations must be done.

Plowing done with power tiller: paddy field soils are plowed almost flatly and the clods are broken into fairly fine pieces. As a result, harrowing or levelling operation is saved, though a defect is pointed out that the plowed soils are not readily dried or weathered.

The intensity of operation done with a power tiller is somewhat lower than that done with an animal-drawn plow. However, as a power tiller is far higher in efficiency than an animal-drawn plow, the energy consumption is by far smaller than that of the latter.

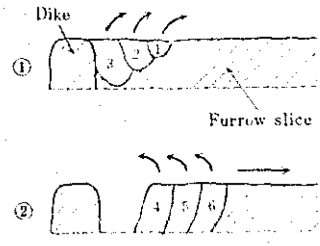
With the plowing methods as described above, the depth of plowing is generally 10~15 centimeters, but in recent years, with a view to plowing as deep as 20 centimeters or more, four-wheeled-tractor-drawn plows have also come into use.

Fig. 6-19. Order of Ridge Forming Operation With Fixed Type Plow



Note: *In forming smaller ridge the number of plowing times is reduced.*

Fig. 6-20. Order of Plane Tillage Operation with Reversible Type Plow



2. Puddling

1. Effects of puddling

Puddling is done after the paddy field has been submerged. The top soil is made finer, stirred and moved. The

Table 6-20. Intensity of Operation and Energy Consumption

Method of tillage	*Intensity of operation* *	*Energy consumption per 10 ares*
Hand tillage	8.0	cal 6,119
Horse tillage	5.0-6.9	1,039
Power tillage	5.0	660 **

Notes: * Indicates energy metabolic ratio.
** Very low due to the shortness in the required operating time.

hard pan is stamped down by working men or animals or by wheels of a puddling machine. As a result, the following effects are brought about: (i) water percolation is prevented; (ii) transplanting operation becomes easier; (iii) paddy soil surface is levelled; (iv) fertilizers are mixed well with soils and distributed evenly all over the field; and (v) other effects similar to those described in the case of plowing.

(i) Water percolation is prevented

When the submerged paddy field soils are broken up and stirred, the top soil will become muddy and the percolation becomes lowered. As the hard pan is stamped down, the leaks in the hard pan are stopped up. As a result, the percolation of water will become increasingly decreased when the paddy field is puddled repeatedly (Table 6-21).

(ii) Transplanting operation is made easier

Paddy field soils will become increasingly softened according as the soils are stirred and the clods are broken up. When the clumps of seedlings are pushed by fingers into the mud, the mud of 5-10 centimeters in depth from the field surface must be soft (viz., so soft that seedlings can readily be pushed by fingers into the mud to the extent of 4-6 centimeters deep, with little or no resistance). However, when the mud is too soft, seedlings will be pushed into too deeply and the plant growth will be affected adversely.

(iii) Paddy soil surface is levelled

Table 6-21. Number of Repetition of Puddling Operations and Percolation Losses of Water

(YAMAZAKI)

Number of repetition of puddling operation	*Daily average percolation loss of water*	
	For 5 days after puddling	*For 10-15 days after puddling*
No puddling	0.9 cm	0.6 cm
2 times	0.4	0.5
10 times	0.2	0.2

Note: Sample paddy field soil is low in percolation.

Undulated paddy field can be levelled by puddling. Accordingly, the water level will become readily adjusted. Thus the uniformity in the rice plant growth can be maintained well and the weed control becomes effective.

(iv) Incorporation of fertilizers with soils, and even distribution of fertilizers all over the field

Owing to the stir in the top soil, the fertilizers applied are mixed well with soils, and owing to the movement of clods the fertilizers become distributed evenly all over the field.

(v) Other effects of puddling

As the clods are broken into fine particles, the mineralization of the organic nitrogen in soils is hastened, and owing to the stir of the top soil the weeds are buried under the bottom of soils. And owing to the stir in the submerged paddy field soils, the reductive gas produced in the soil is discharged and the activities of micro-organisms are stimulated, thus accelerating the decomposition of green manures which were plowed under by the plowing practice.

2. *Features of various types of puddling implements*

In present-day Japan, puddling operation is done chiefly with (a) animal-drawn rotary cutaway disk-harrow, (b) tiller type hand tractor (garden tractor), and (c) power tiller.

Each of these implements is characterized by the following advantages and disadvantages.

Animal-drawn rotary cutaway disk-harrow: By using this harrow the top soil can be broken up and stirred and turned over to a certain extent. The clods are carried and scattered by the rear levelling plate. It has a puddling capacity of 40–50 ares per day.

Tiller type hand tractor (garden tractor): The hand tractor has a higher harrowing capacity than the above disk-harrow, but it is somewhat inferior in a turning capacity. The clods are carried by the spike harrow. This tractor has a puddling capacity of 50–60 ares per day. The puddling-purpose rotor of this hand tractor having some buoyancy, this hand tractor can be used even in the case of a paddy field in which the walking of a draft animal is hardly permissible because of its too mild hard pan.

Power tiller: Power tiller has a far higher harrowing capacity than either of the above two implements, but it cannot carry the clods. As a result, the paddy field surface can not be levelled. The operating efficiency is as high as 80–100 ares per day, but the body weight of this power tiller is greater. As a result, this cannot be used in the paddy field with mild hard pan.

3. *Practices of puddling operation*

(i) Time of puddling

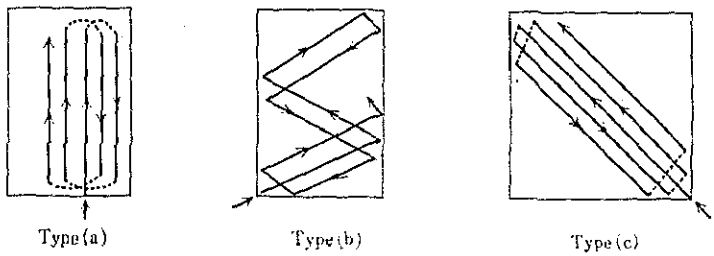
In the past, puddling operation had been done at several times repeatedly during the period from submergence to transplanting, but as the puddling implements of a higher harrowing capacity have recently come into wide use, the puddling operation has generally come to be done immediately before transplanting. Sometimes harrowing operation is done prior to the submergence in the paddy field, but this is considered to be supplemental to the puddling. When fertilizers were not applied at the time of the plowing operation, they are applied at the time of the puddling.

(ii) Method of puddling practices

Method of puddling done by using an animal-drawn rotary cutaway disk-harrow:

A disk-harrow is driven: (a) to the directions both crosswise and lengthwise, (b) in zigzag, and (c) to the diagonal direction (Fig. 6-21).

Fig. 6-21. Directions in which an Animal-Drawn Rotary Cutaway Disk-Harrow Is Driven



When a disk-harrow is driven to the direction (a), puddling is repeated unnecessarily at the field edges because the disk-harrow turns at the field edges, but such shortcoming is remedied by following the direction of (b) or (c). However, it is somewhat more complicated to drive a disk-harrow to the direction of (b) or (c) than to the direction of (a). Type (b) is suitable for the rectangular paddy fields and Type (c) for the square ones. The driving is generally repeated at four to six times. In the case of paddy fields of over-percolation, the driving is repeated more often. In driving a disk-harrow, attention must be paid so as to carry the clods at the beginning, but in the later driving, it is required to pay attention so that fertilizers may be mixed well with soils, and finally the puddling is to be done to level the field surface.

Puddling done with tiller type hand tractor: The puddling operation done by using a tiller type hand tractor is similar to the case with an animal-drawn rotary cutaway disk-harrow, but the driving is repeated at three or four times because of its higher harrowing capacity.

Puddling done with power tiller: The power tiller is driven to the direction both crosswise and lengthwise, but because of its high harrowing capacity, it is driven once or twice. When puddled with power tiller the top soil will sometimes become too soft. As a result, there occurs a fear for transplanting seedlings too deeply. Therefore, it is better to wait until the soils become harder. When the levelling of the field surface is required, a levelling plate is attached to the rear part of the tiller. Because the power tiller has a high harrowing capacity, it can be used to do both plowing and puddling all at once after the field is irrigated.

With respect to working intensity, it is highest in the use of an animal-drawn rotary cutaway disk-harrow and lowest in the use of a tiller type hand tractor. The energy consumption per 10 ares is markedly great for puddling with the disk-harrow. This is due to the high working intensity and to the need for longer working time. The energy consumption for puddling with tiller type hand tractor is almost similar to the case of a power tiller (Table 6-22).

Table 6-22. Working Intensity and Energy Consumption per 10 Ares, according to the Puddling Implements

Types of puddling implements	*Working intensity* *	*Energy consumption per 10 a*	*Remarks (Repetition)*
Animal-drawn rotary cutaway disk-harrow	7	cal 700	4-5 times, repeated
Rotary power tiller	6	400	Driven at one time only, but heavy work is required to change direction
Tiller type hand tracter	4	400	3 times repeated

Note: * Indicates the intensity of energy metabolism.

4. *Effects of different tillage practices on the rice plant growth*

Effects on the rice plant growth vary according to the tillage practices, particularly between (a) tillage practice consisting of plowing with plow and puddling with harrow; and (b) that of plowing and puddling operations done with power tiller.

The clods of soil plowed with a power tiller are finer and the furrow slice is not turned over. As the puddling with power tiller is not repeated much, the top soil does not become *muddy*. Owing to the finer clods, organic nitrogen in the soil becomes readily mineralized. Accordingly, ammoniacal nitro-

Table 6–23. Ammoniacal Nitrogen Content and Eh Value in the Top Soil Tilled by Rotary Power Tiller and Animal-Drawn Plow and Harrow

Plot (by tillage methods)	*NH_4-N mg content in 100 g of dry soil*			*Eh_6 in top soil (m V)*		
	Jun. 25	*Jul. 9*	*Jul. 28*	*Jul. 11*	*Jul. 25*	*Aug. 4*
Small clod plot tilled with rotary tiller	6.7	4.3	0.8	217	151	125
Large clod plot tilled with animal-drawn plow and harrow	4.9	3.7	0.8	243	201	175

Table 6–24. Difference in Rice Yield according to the Tillage Methods

Type of paddy field	*Plots (by tillage methods)*	*Number of panicles per 3.3 m^2*	*Number of spikelets per 3.3 m^2*	*Rate of fertilization**	*Weight of 1,000 grains*	*Weight of brown rice per 3.3 m^2*
				%	g	g
Successive application of inorganic fertilizers	Rotary power tiller	578	68,000	66.0	21.5	966
	Animal-drawn plow and harrow	538	64,000	66.3	21.4	926
Successive application of Chinese milk vetch	Rotary power tiller	493	56,000	78.8	21.9	943
	Animal-drawn plow and harrow	512	54,000	80.8	21.9	958

Note: * (Number of fertile grains) ÷ (Total number of grains).

gen content in the top soil plowed by using a power tiller is greater than that in the top soil plowed and puddled by using a plow and harrow, but the top soil of the former is in the more reductive state (Tables 6–23 and 6–24).

As a result, the former shows increases in the number of panicles and spikelets over that of the latter, but the roots are damaged and the percentage of ripened grains is lowered. Therefore, in the areas where the soils are not readily brought into reductive state (areas of low temperature as the northern part of Japan, or areas consisting of soils containing little organic matter), i.e., in the areas where rice plant roots are not readily affected by soil reduction, it will show an increase in the rice yield when paddy fields are plowed by using a power tiller. In other paddy fields, it would give rise to the increased rice yield when the tillage is done with an animal-drawn plow and harrow. The results of IZUMI's experiments are given in Table 6–24. Namely, the use of a power tiller gave a better yield on the paddy fields to which only inorganic fertilizers had been applied each year and the soils of which were not readily brought into the reductive state, while its use was unfavorabl on the paddy field which was liable to become reductive due to the successive application of green manures.

As the use of a power tiller results in the less turning-over of furrow slice than the use of an animal-drawn plow and harrow, weeds emerge more and the percolation loss of water will sometimes be greater (due to the less muddy soils) in the case of former than in the case of the latter. These two things should not be overlooked in the rice cultivation.

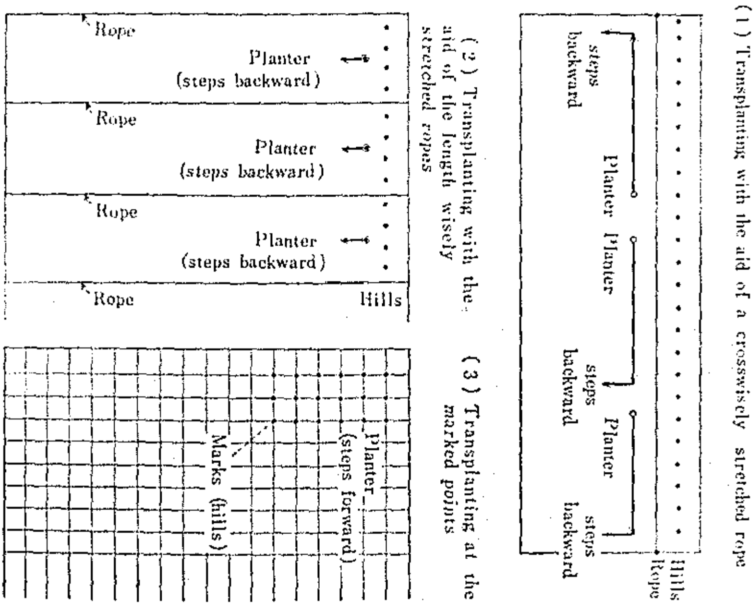
3. Transplanting

The relationship between the spacing or transplanting time and plant growth will be dealt with in some other chapter. In this chapter, the transplanting practices will be dealt with.

Various types of transplanting methods are prevalent in

Japan. The transplanting method can be divided into two: transplanting done with the aid of ropes to maintain uniform space; and transplanting done with the aid of marks on the field surface. In the case of the former, a rope is stretched either crosswise or lengthwise (Fig. 6-22).

Fig. 6-22. Transplanting Methods



1. *Transplanting with the aid of a crosswise stretched rope*

Transplanting operation is done by the following steps in order.

(i) Stretching a rope supported by both side levees The stretched rope serves as a base line of planting rows. The rope has marks at regular intervals so as to make possible the maintenance of uniform space between hills;

(ii) Several planters in team line up along the rope;

(iii) Each planter, while moving crosswise, plants a certain number of seedlings in each hill one after another along the marks on the rope;

(iv) When the transplanting in the first row has been finished, each planter steps backward and begins to transplant again the seedlings along the rope, which was moved to the next row.

The above transplanting method has the following advantages and disadvantages.

Advantages: (a) Even a beginner can transplant seedlings in a regular row with uniform space between hills; (b) spaces between rows and between hills can readily be changed, if need be; and (c) for transplanting, any special consideration for irrigation or drainage is needless to be taken.

Disadvantages: (a) A rope cannot be removed to the new row until the planting in a row has been completed. As a result, when one or two team members are delayed, the remaining ones have to wait idling; (b) too frequent removal of a rope; and (c) seedlings may sometimes be transplanted in footprints made by the feet of planters. (The footprints must be levelled, otherwise the seedlings would be planted too deeply or could not be planted easily.)

2. *Transplanting with the aid of lengthwise stretched ropes*

In this case, the operation is done by the following steps in order.

(i) Ropes are stretched lengthwisely at an adequate intervals (1.5–2.0 meters intervals) in the paddy field (i.e., a field is partitioned into even panels by ropes);

(ii) One planter is in charge of one panel;

(iii) The planter transplants seedlings in one row maintaining the uniform space between hills and between rows by measuring with the eye;

(iv) When seedlings have been transplanted in the hills of the row, a planter steps backward to transplant in the next row;

(v) When a planter has finished the transplanting within one panel, he moves to another panel.

This transplanting method has the following advantages and disadvantages.

Advantages: (a) Each planter can continue the transplanting independently of other planters. Thus each planter can display his full capacity; (b) a planter need not to move crosswise; and (c) any special consideration is needless to be paid to the irrigation or drainage.

Disadvantages: (a) It is very hard for a beginner to transplant seedlings in each hill by maintaining uniform space between rows and between hills; (b) if the spaces between rows and between hills are changed, the working efficiency would be lowered; and (c) seedling may sometimes be transplanted in the footprints, as in the case of above (1).

3. Transplanting with the aid of rules or markers

The order of the operation is as follows:

(i) Marking the points (at which seedlings are to be planted) on the field surface by using a rule, or marker;

(ii) A planter sets out the seedlings at the marked points (5-7 in number) while stepping forward.

Advantages or disadvantages of this method are as follows:

Advantages: (a) Seedlings are transplanted exactly at the pointed places; (b) each planter can continue the transplanting operation independently of other planters, and it is needless to remove a rope. Since each planter can transplant at his own pace, the working efficiency can be displayed to the fullest extent; and (c) seedlings are never transplanted in footprints.

Disadvantages: (a) The paddy field surface must be levelled enough to make possible the clear marking; (b) at the time of transplanting it is necessary to drain water from the field so that planters can see clearly the marks, and on completion of the transplanting the paddy field must be submerged to protect the transplanted seedlings from being withered, viz., water must be drained promptly before transplanting and be irrigated immediately after transplanting; and (c) in order to change the spacing, other rules or markers must be used.

Table 6–25 indicates the working intensity and energy consumption of the transplanting methods described above. As shown in Table 6–25, the working intensity and the energy consumption are greatest in the transplanting method with the aid of a crosswise stretched rope, because the planter must move to left and right.

Table 6 – 25. Working Intensity and Energy Consumption according to the Transplanting Methods (HAYAKAWA)

Method of transplanting	*Working intensity**	*Required time per 10 a*	*Energy consumption per 10 a*	*Spacing*		*Number of hills transplanted by one planter*
				Between rows	*Between hills*	
		min	calories	cm	cm	hills
Crosswise stretched rope	5.5	403	2,697	22.5	22.5	11
Lengthwise stretched rope	3.6	414	1,989	〃	〃	5
Marker or rule	4.1	405	2,149	24.0	21.0	5

Note: * Indicates the intensity of energy metabolism.

V. INTERTILLAGE

In Japan, it has been customary for farmers since several hundred years ago to use a combined term "intertillage and weeding" instead of using two terms "intertillage" and "weeding" separately. A term "intertillage and weeding" has been used because "intertillage" is done for the purpose of tilling, inverting, and stirring the field soils as well as for the purpose of weed control.

"Intertillage and weeding" operation is practised mainly in Japan and China. In recent years, however, the trial use of hand rotary weeders imported from Japan has come into practice in several Southeast Asian countries. In Japan, special importance had been placed on the intertillage operation out of the "intertillage and weeding", regarding that the intertillage implies some significance. Whereas, since the introduction of chemical herbicides immediately after the end of World War II, the weeding operation has come into practice independently of the intertillage operation. Upon this, the question has come to be raised, in addition to the weeding operation, whether a tillage operation is necessary or not. This problem is at present so much to the fore because the problem of labor-saving and mechanization of rice culture is becoming increasingly important. Originally speaking, it is by no means easy to mechanize the operation on submerged paddy field. If the effect of intertillage is not appreciably great, the operation can be thought to be eliminated.

It has hitherto been generally said that the rice yield can be increased reflecting the following effects of intertillage (some of these are scientific and others are traditional).

(1) Stirring and inverting of soils.
- (a) Rising in the soil-temperatures;
- (b) Refreshing and ripening of soils;
- (c) Promoting the development of roots by softening soils;
- (d) To make possible the subsequent hand weeding operation easier;
- (e) Inverting the upper layer soil which has been exposed to the sun, thus supplying the main roots with nutrients;
- (f) Supply of oxygen to soils;
- (g) Prevention of denitrification.

(2) Effects on rice plants
- (a) Improvement in the rice plant growth by root pruning;
- (b) Checking the lowering of rice plant vitality by

removing floating or withered leaves;

(c) Development of the vertical roots by pruning other roots (white roots, lateral roots or floating roots) growing near the field soil surface, thus giving favorable effect on the grain ripening;

(d) Root-pruning after *Doyo* (mid-summer) or *Tanabata* (the seventh of July) is harmful to the rice plant growth;

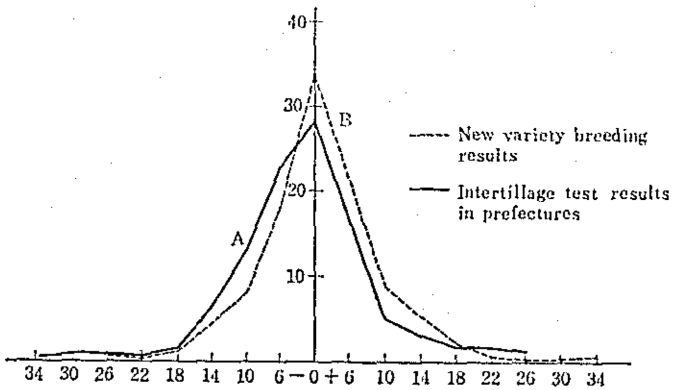
(e) Root-pruning in cool areas or at cool times is harmful to the rice plant gorwth.

(3) Weeding

(a) Weeding is of importance;

(b) Weeds plowed under will serve as nutrients to rice plants.

Fig. 6-23. Effect of Intertillage on Rice Yield
(Distribution percentages, entire country)



By qualitative measurement on these effects of intertillage, it was found out that the effects are too small to affect the rice yield. In view of this, it is considered that the past reports showing that "the increased rice yields resulting from the intertillage" are quite doubtful whether it is reliable or not.

NOZIMA collected a large number of the results of the experiments conducted throughout the country ranging over many years and examined the effects of intertillage (excluding the weeding effects). The result is shown in Fig. 6-23. The effect of intertillage on the rice yield is shown as the curve A of Fig. 6-23. The fluctuations obtained basing upon new variety breeding test results are shown as the curve B in Fig. 6-23. These two curves are very similar. As curve A is considered to show merely the fluctuations to each other, it is judged that the rice yield can not be affected favorably by the intertillage.

Basing upon the above fact, it can be concluded that the effect of a combined practice of "intertillage and weeding" is nothing other than the weeding effect, and the effect of intertillage itself is of a non-entity or quite minor. If weeds can be controlled by the application of herbicides to the extent that the rice plants may not be injured by the weeds, the intertillage practice becomes needless. This is a great advantage from the standpoint of the development of labor-saving and mechanization of rice culture.

VI. IRRIGATION AND DRAINAGE

History of rice culture in every rice producing country reveals clearly that rice culture has developed with the progress in irrigation system. The fact that the irrigation for rice crop has developed to the submerging irrigation method indicates the specific feature of rice culture.

In historical background of the development of a specific type of irrigation in rice culture, many a complicated factor is found. The problems confronting the irrigation in rice culture are practically many-sided and profound. Even taking merely a problem of agronomical phase of irrigation techniques, many factors would be involved therein. Each of those factors is closely connected with the fundamental problems of rice culture as well as with the environmental conditions (climatic conditions, soils, etc.). Accordingly, many a problem still remains unsolved. The descriptions handled in this chapter are nothing but the explanations of some aspects of irrigation techniques and practices prevailing in recent times.

1. Soil Moisture and Growth of Paddy Rice Plants

Under which conditions of soil moisture will the rice plants grow best and can the highest yields of rice be obtained? This is one of the fundamental problems of paddy rice culture. The improved irrigation techniques are required to be approached basing upon the results of researches in relation to these problems.

The relationship between soil moisture and rice plant growth or rice yields has hitherto been studied by many workers, but in this chapter the results of studies carried out chiefly from the cultural viewpoint will be introduced.

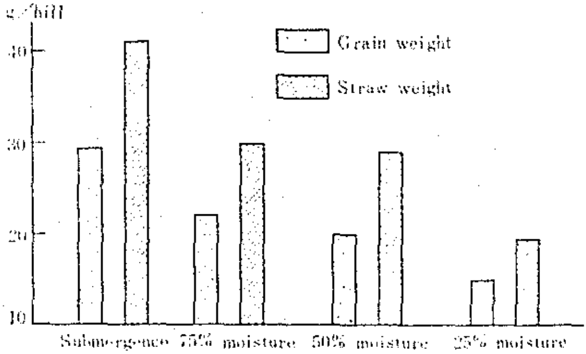
UEDA (1935) made a comparative test between submerged plot (submerged ranging over the period from rooting stage to ripening stage) and upland plot (containing soil moisture at the levels of 75, 50, and 25 per cent). The results are given in Fig. 6–24. According to Fig. 6–24, both grain weight and straw weight per hill in submerged plot are greatest, decreasing according to the decreases in soil moisture-content (75, 50, and 25 per cent in order).

Almost similar test was conducted by KOJIMA (1936). He reported that submerged plot was pre-eminent above the upland state plot in plant growth as well as in rice yield which is decreasing according to the decreases in soil moisture-content.

FUKAGI (1929) reported that, amongst the dry plot, wet plot, water-saturated plot (0 centimeter), shallow water plot (3 centimeters), and deep water plot (6 centimeters), the shallow water plot ranked first in grain weight, top weight, and grain numbers per hill, followed by the deep water plot, saturated plot, wet plot, and dry plot in order.

HANAI (1904) conducted a comparative test for 30 paddy rice varieties in three plots: deep water plot (6 centimeters, June 30–July 24; 9 centimeters, July 25–August 14; and 15 centimeters, August 15–September 20), shallow water plot (3 centimeters), and occasionally irrigated plot (irrigated at intervals so as to prevent paddy-field-surface from cracking). Grain weight and straw weight averaged for the 30 rice varieties in shallow water plot were greatest, followed by those in deep water plot. Those in non-submergence plot were smallest.

Fig. 6 – 24. Relationship between Rice Yield and Soil Moisture Content (UEDA)



According to the experiment conducted at the Bofu Experiment Farm (1947), husked rice (brown rice) weight in submerged plot was greater than that in upland state plot (both in the cases of transplanting and direct-sowing), decreasing in the brown rice weight in order of 80 per cent, 60 per cent and 40 per cent soil moisture-content plots. The brown rice weight in the last plot was as low as 45 or 50 per cent of that in submerged plot.

The experiment of the Tochigi Prefectural Agricultural Experiment Station (1957) showed that amongst the three plots: shallow water plot (3–5 centimeters); deep water plot

(10 centimeters); and wet plot (0 centimeter)—water depth in each plot indicates the depth throughout the plant growth period—the wet plot was lower in rice yields throughout the test years than the deep water or shallow water plot, but difference in yields between shallow and deep water plots varied according to the test year, thus indicating no definite trend.

JONES (1933) tested rice yields in 6 plots and reported that the rice yield in saturated plot (0 centimeter) was by far lower than those in other plots, increasing in rice yields in order of plots of 4 inches, 6 inches, 8 inches, 10 inches, and zero inch in depth.

ARASHI (1950) reported that the greater the irrigated water depth, the less the rice yield. If the rice yield in 3 centimeters-deep plot is represented by 100, that in 15 centimeters-deep plot would be indicated by 82.

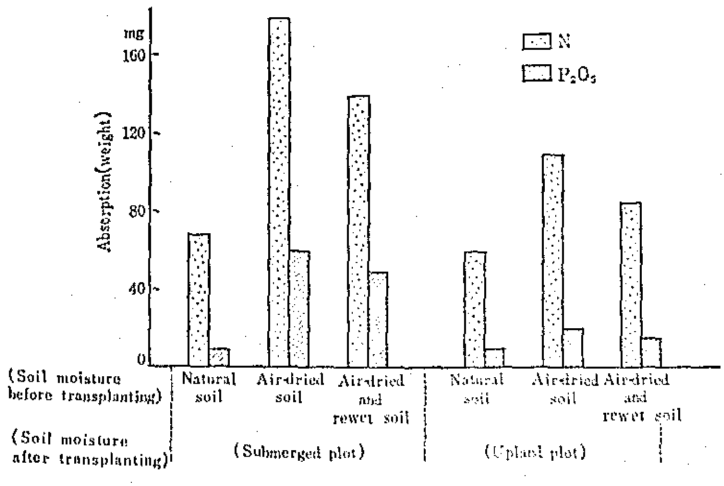
VLAMIS and DAVIS (1944) conducted the comparative tests for upland rice, lowland rice, caloro rice, barley, and tomatoes (each crop was grown both in clay and loam soils) by setting up submerged plot and drained plot. The results revealed that top weight and root weight of barley and tomatoes in drained plot were greater both in clay and loam soils than those in submerged plot, while those of upland rice, lowland rice, and caloro rice in submerged plot were greater than those in drained plot.

SENEWIRATE and MIKHELSON (1961) conducted a comparative test for growth and nutrient absorption of rice plants between submerged plot and upland plot. The results showed that, at the earlier growth stage the rice plants grew larger in upland plot than in submerged plot, but afterward it showed increases in the number of tillers, plant height, and leaf area in submerged plot over those in upland plot, and rice yields in upland plot accounted for 52.6 per cent of those in submerged plot. They reported that with respect to the nutrient absorption, Mn-content in rice plants in upland plot was remarkably greater than that in submerged plot, but no difference was found in the contents of other elements, and that high Mn-content in rice plants in upland plot was ascribed to the fact that the presence of soil nitrogen in upland plot was found in the form of NO_3-N. They reported also that rice plants in upland plot displayed low catalase activity and high peroxidase activity.

SHAPIRO (1958) carried out the comparative test on rice plant growth and absorption of nitrogen and phosphate both in "submerged plots" and "soil moisture at field moisture capacity plots", consisting of 11 types of soils with different rates and forms of nitrogen and phosphate application as well as with and without organic matters. In this test, he recognized that fresh weight and nitrogen and phosphate absorption in submerged plots were greater without exceptions, than those in field moisture capacity plots.

KAWAGUCHI (1952) studied the effects of drying of soils before transplanting and moisture content of soils after transplanting on the nitrogen and phosphate absorption. The re-

Fig. 6–25. Effect of Soil Moisture on Nitrogen and Phosphate Absorption by Rice Plants
(KAWAGUCHI)



Note: *Sampling date:* 46 days after transplanting.

sults are as given in Fig. 6–25, which indicates the following points: (i) the effects of the drying of soils before transplanting on nitrogen and phosphate absorption are remarkable in case where soils after transplanting are kept in the submerged state; (ii) difference in nitrogen and phosphate absorption according to the water content of soils after transplanting is greatest when air-dried soil was used, while extremely minor when wet natural soil was used; and (iii) for the rice plants cultured in submerged state, the effect of soil drying prior to transplanting is brought about not merely by the increase in available nitrogen and phosphate owing to the soil drying itself, but also by the increased quantity of nitrogen and phosphate which may become available under the submergence after transplanting.

Under the sand cultural system, BABA (1958) tested the nutrient absorption in various plots different in soil moisture-content (i.e., submerged plots with 100, 80, 70, 60, 50 and 40 per cent moisture-content). He reported that panicle weight and straw weight decreased in general with the decreases in soil moisture-content; and P_2O_5- and SiO_2-content in the tops showed a sharp decrease; and FeO content showed a slight decreases with the decrease in soil moisture-content; but K_2O, CaO, N, and MnO contents were larger in 70 per cent moisture-content plot than in submerged plot and in 50 per cent moisture-content plot.

From the above results, it can be concluded that from the viewpoints of rice growth, rice yields, and nutrient absorption, it is evidently unprofitable to grow paddy rice plants in the upland state or wet state for a prolonged period, as compared with the culture in the submerged state. However, in the case of rice culture in the submerged state, a definite relation is not always found between water depth and rice yields, and it is generally accepted that the optimum water depth for the rice plant growth varies with the climatic, soil, and cultural conditions.

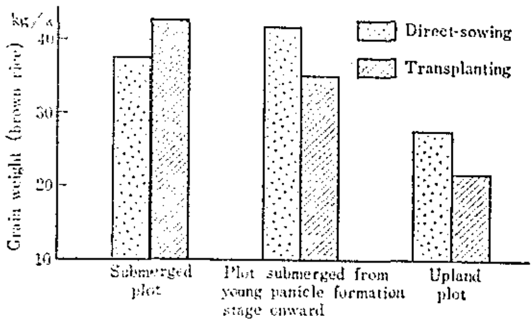
The reason for that rice culture in the past has been practised in the submerged state, in principal, is supported well by such results indicating that the submerged state is most desirable in order to secure better plant growth and higher rice yelds. However, in the case of areas where irrigation water supply is not available so sufficiently to submerge paddy fields during the whole plant growth period, it is necessary to use the limited available water as rationally as possible. Connected with this, KAWAHARA (1944) conducted the experiment in which paddy rice grown under upland state is subjected to submerged irrigation for the days at different growth stages and found out that the submerged irrigation applied for some ten days during the booting stage could give a similar yield as that in continuously submerged plot, even though the paddy field was kept nearly in a drought state at other stages.

YOSHIOKA et al. also reported that, when a paddy field was held at some 70 per cent moisture-content in earlier growth stage and then submerged after the young panicle differentiation stage, it would bring rice yield approximating to that in the paddy field which had been submerged since the beginning of the growth.

BABA (1951) reported that in case where a paddy field at the tillering stage was kept in the upland state and submerged after the young panicle formation stage, it showed only a 6 per cent decrease in panicle weight per hill in 80 per cent moisture-content plot (at tillering stage) from that in continuously submerged plot, while in the case of 60 per cent moisture-content plot it showed a 22 per cent decrease.

YOSHINO et al. (1952) made a comparative test for rice yields both in the transplanting and direct-sowing plots under the irrigation-water-saving cultural system. The results they obtained are given in Fig. 6-26, which indicates the irrigation-water-saving can be attained safely by submerging at the young-panicle formation stage. In this case, little or no decrease in rice yield is found in direct-sowing plot, while a 20 per cent decrease in transplanting plot. For the purpose of irrigation-water-saving, the direct-sowing practice is more adaptable than the transplanting practice. Two reasons can

Fig. 6-26. Effiect of Late-Irrigation on Rice Yield
(YOSHINO and KAWASAKI)



be cited for this: (i) in the direct-sowing practice it is easy to secure the number of panicles from the lower nodes under the lower soil moisture condition, and (ii) the increased resistance of direct-sown plants to drought due to the difference in the form of roots. Under such irrigation practice in which paddy field is submerged only after the young-panicle formation stage, the irrigation water can be saved by 20 to 30 per cent, as compared with that in continuously-submerged plot.

According to the results of experiment conducted at the Chugoku Agricultural Experiment Station (1959), in case of transplanting practice, rice yield in late-irrigating plot (kept in the upland state up to the young panicle formation stage, and then submerged), was similar to that in continuously-submerged plot in the five years out of the seven test years, with about 5 per cent decrease in the remaining two years only.

The experiment conducted at the Bofu Experiment Farm (1947) showed that under direct-sowing practice, rice yields in 40 per cent moisture-content plot (moisture was kept at 40 per cent level during the tillering stage, and submerged only after the young panicle formation stage) were almost similar to those in continuously submerged plot, and those of 80 per cent moisture-content plot showed a 13 per cent increase.

According to the report on the irrigation time (in the case of direct-sowing practice) made by AMATATSU et al. (1954), the submersion at young panicle formation stage gave 10-40 per cent increase of yield over the yield for plot of whole season submersion or submersion at early tillering stage. On the other hand, KIDO et al. (1950) made a report on the irrigation time (in the case of direct-sowing between wheat rows). In this case, the results showed about 30 per cent decrease in yield in the "plot submerged from the young panicle formation stage" from that in the "plot submerged from the early tillering stage". Speaking generally, the later the beginning of irrigation, the less the rice yield.

WATANABE (1950) reported that although the effective submerging time in the case of direct-sowing cultural practice varies to a considerable extent according to the time and quantity of ammonium sulfate application, it showed 10-20 per cent decrease in the rice yield in the "plot submerged from the young-panicle formation stage" from that in the "plot submerged from the early tillering stage".

From the above results, it can be concluded that the rice yield approximating to that in continuously-submerged plot is expected when a paddy field is kept in the upland state during the tillering stage and then switched over to the submerged state after the young panicle formation stage. When viewed climatically, the adaptability of such irrigation practice is greater for warm areas than for cold areas; and from the plant growth viewpoint, the adaptability seems greater for the paddy fields in which plant growth is vigorous at the earlier growth period, but is liable to be declined in the later period, e.g., on the *Akiochi* soils of low fertility. And the adaptability of this irrigation practice seems to be greater for direct-sowing cultural practice than for transplanting one.

2. Water and Soil Temperature Control by Means of Irrigation

In the Kyushu and Shikoku Districts lying to the southwest of Japan, paddy field water temperature registers often as high as 40°C in the mid-summer months (July and August), while in Hokkaido, Tohoku or intermountain areas in the Central District, it is not uncommon that paddy field water temperature registers as low as 25°C or lower even at daytime during the mid-summer months. Based on the results of the past experiments on the relationship between rice plant growth and water or soil temperature, the generally-accepted optimum temperature is 30–33°C, though varies a little according to the growth period. BABA (1958) examined the relationship between nutrient absorption and water temperature by setting up the three test plots: optimum temperature plot (28.5–32°C); high temperature plot (37–38.5°C); and low temperature plot (24–25°C), and reported that the absorption of various inorganic nutrients is restricted by temperature whenever it is higher or lower than the optimum temperature. Above all, K_2O and SiO_2 absorption is inhibited to a considerable extent.

The decomposition of organic matters in soils is affected by water temperature. At a high water temperature, soil reduction is hastened markedly and a great quantity of toxic substance (H_2S, etc.) detrimental to rice roots will be produced and accumulated. As a result, nutrient absorption will be inhibited more, and it will give rise to *Akiochi*-growth, thus promoting the outbreak of brown spot disease. In contrast to this, when water temperature is low, the decomposition of organic matters in soils is slowed down, plant growth becomes slow, heading is delayed, diseases (neck rot or rachis-branch blast, etc.) may occur, and the percentage of ripened grains will be lowered, thus showing a decrease in rice yield.

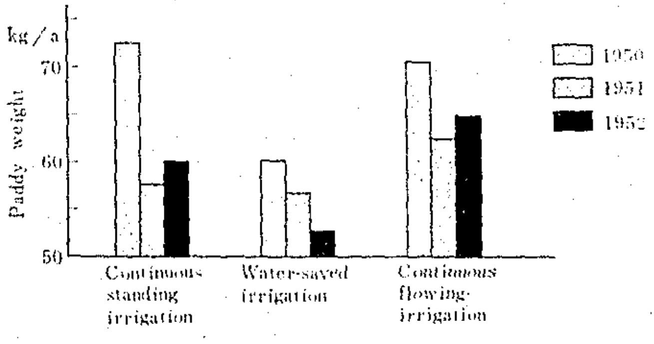
Therefore, in warm districts, it is desirable to practise such irrigation system as may lower the water and soil temperature and may check the abnormal soil reduction, while in cold districts such irrigation practice as may raise the water and soil temperature and may increase the availability of soil nutrients is desirable.

Fig. 6–27 shows the results of an experiment in Kyushu (in 1956), indicating that rice yield in "continuous flowing-irrigation plot" (3–5 centimeters in water depth) is higher than that in usual submerging irrigation plot (5 centimeters in depth) or water-saved irrigation-plot (0–2 centimeters in depth), showing the lowest rice yields in water saving plot. The water temperature is lowest in continuous flowing-irrigation plot and highest in water saving plot, showing the lowering of water temperature by means of a flowing irrigation.

According to the results of the Niigata Agricultural Experiment Station (1955), the flowing-irrigation practised for the period from 35 days before heading to the maturity gave about 7 per cent increase in yield over that in usual submerging irrigation plot, while 8 per cent decrease in yield resulted when the flowing-irrigation was practised throughout the whole growth period, thus indicating the period and time for flowing-irrigation to be of importance.

The flowing-irrigation is practised chiefly for the purpose of alleviating the high temperature damage to rice plants by lowering water and soil temperature. Accordingly, the difference in temperature between water to be used for irrigation and field water becomes an important problem. As the plant growth advances, the space between hills comes to be covered with plant leaves, and the rise in field water temperature is

Fig. 6 – 27. Relationship between Rice Yield and Irrigation Method in Warm Region (SATO)



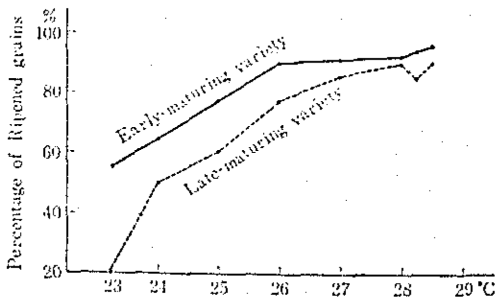
slowed down so that the difference in temperature between water to be irrigated and field water will become less. The temperature of the former will sometimes rise higher than that of the latter. As a result, contrary to expectation, the field water temperature may be raised by the flowing irrigation and the result against expectation may sometimes be brought about.

On the other hand, when the flowing-irrigation is practised for a long time, due to the irrigation water quality, supply of plant nutrients from the irrigation water to paddy field will be increased, or inversely plant nutrients will be lost from paddy field.

Next, water management in cold areas or in cool-damaged years will be discussed. ENOMOTO (1937) stated that when water temperature fell to 24–25°C or lower, plant growth was retarded markedly, heading was delayed, and ripening was obstructed.

TANAKA (1955) reported that the relationship, as given in Fig. 6–28, was observed between water temperature and percentage of ripening. When the former fell to 25°C and lower (in case of early-maturing varieties) or to 26°C and lower (in case of late-maturing ones), the latter would decline rapidly. For this reason, in cool areas it is important

Fig. 6–28. Relationship between Percentage of Ripened Grain and Field Water Temperature at Noon (July 10-Aug. 23) (TANAKA)



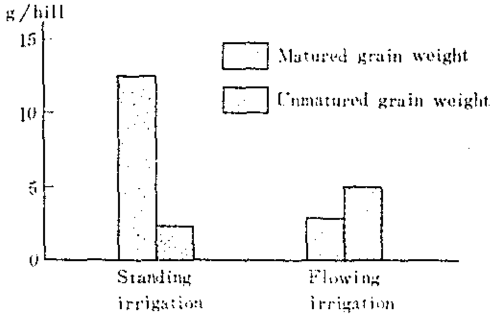
to raise water temperature even by 1°C.

Fig. 6–29 (1955) indicates the difference in rice yields in cool-damaged years in cool areas according to the irrigation method, i.e., overwhelmingly greater being fully-matured grain weight and less unmatured grain weight in "standing irrigation plot" than in flowing irrigation plot. The relationship found in Fig. 6–29 is exactly reverse to that in warm areas stated before. In cool areas, temperatures sometimes fall markedly for a time. In case where such phenomenon occurred at the booting stage (at which rice plants are particularly susceptible to low-temperature damage), a paddy field is submerged to the extent of some 15 centimeters in depth in order to protect young panicles by water. By doing so, the number of spikelet per panicle and the percentage of ripened grains can be increased (SASAKI, 1949).

According to KIDO (1955), in areas where water used for irrigation is very cool, rice yields can be increased by alleviating cool-water damage against young panicles by the draining practice at the booting stage. However, if field soils become dried during the draining, neck rot may occur or the "weight of 1,000 grains" will be declined. It is necessary, therefore, to irrigate at intervals.

In cool areas or in areas where cool-water is irrigated with a view to raising water temperature, it is devised to establish "pool for warming water" or "round-about water ways for warming water" or to practise a dispersion irrigation by the use of straw bundles at the intake in paddy fields. However, it is also necessary to minimize the percolation of water from paddy field. Overpercolation causes a serious cool-damage in cool years because it impedes the lowering in soil and water temperature. There are many instances in which rice yields have been increased by the rise in temperature (by 1–3°C) through such devices as may minimize the percolation by means of bentonite application or soil dressing on paddy fields or by compacting hard pan with bulldozer (1955). By preventing overpercolation, the leaching losses of nutrients from field soils can also be prevented.

Fig. 6 – 29. Effect of Irrigation, by Methods, on Rice Yield in Cold Region
(At the Nagano Pref. Agr. Exp. Sta.)



Note: Sample Variety: Norin No. 17.

Soil-dressing serves also as land improvement, which benefits plant growth.

3. Preventing Soil Reduction by Irrigation and Drainage

With the rise in water and soil temperatures after submergence, the behavior of micro-organisms in soils is increasingly active. As a result, paddy field soils are rapidly brought in the state of reduction and organic acids (e.g., butyric acid, acetic acid, etc.), CH_4, H_2S and CO_2 come to be produced and accumulated in soils. The relationship between these toxic substances and nutrient absorption, plant growth, and rice yields has been clarified by many workers. They report that the presence of such substances induces root-rot and inhibits nutrient absorption, plant growth, and rice yields. In case of ordinary paddy fields, root-rot will begin to occur during the period from the maximum tillering stage to the young panicle formation stage. (During this period, Eh of soil approaches to a minimum, and the respiration of rice roots reaches a peak.) However, the root-rot will break out ealier in an ill-drained field abundant with organic matters, or a field applied with excessive quantity of green manures, barnyard manure and composts. Due to the production of organic acids or CO_2 immediately after the submergence, rooting itself may sometimes be affected adversely. For this reason, in coping with the progress in soil reduction, it is necessary to drain water or to accelerate the percolation of water timely in order to remove toxic substances from soils as well as to supply oxygen to soils with an aim at promoting the activity of plant roots, or to adjust the fertilizer effect.

Percolation loss of water in submerged field varies remarkably according to the soil types, height of groundwater level, or number of times of puddling practised. In the case of sandy soil field, there are many instances in which percolation loss will reach 10 centimeters or more in depth per day, while in the case of heavy clay soil field, percolation loss will approximate to zero. However, in ordinary paddy fields percolation ranges from several millimeters to several centimeters. The effects of percolation on plant growth have been studied from olden times. For instance, with pot experiment in which green manure is applied, HARRISON and AIYER (1913) reported that percolation at 3-day intervals is effective for the growth and yield of rice. MIURA (1933–35) conducted a pot experiment with percolation at 3-day intervals and the percolated water was used again as irrigation water. He reported that dry weight of tops, root weight, and number and length of roots in percolation plot were larger than those in submerged plot. MATSUDAIRA (1941) reported that better plant growth was brought about by percolation in a paddy field to which green manure was applied. HIRANO et al. (1955) made a comparative study on high yielding field and low yielding swampy paddy field, and reported that when the percolation was carried out, the plant growth in the latter was as good as that in the former.

FUJIWARA (1949) reported that one of the factors contributing to the increased rice yield by means of the closed drainage could be ascribed to the effect of O_2 supply to the rhizosphere of rice plants, as well as to the effect of the removal of toxic substances by the percolation during the rice cropping season. TAKISHIMA et al. (1959) reported that in the peaty paddy field soils the rice yield was affected favorably by the percolation. HAYASHI et al. (1960) stated that in the swampy paddy field the ripening and yield of rice were improved by the percolation after the booting stage. They were particularly effective when the light intensity was limited. YAMADA et al. (1961) practised the percolation at the rate of 3 centimeters per day for three types of soils: swampy paddy field soil; relatively ill-drained one; and well-drained one, and reported that in the swampy paddy field soil, rice yield increased as high as 17 per cent by percolation, owing to the increases in percentage of ripened grains, number of panicles, and weight of 1,000 grains, while a slight increase was observed with other types of soils. UEDA et al. (1958) reported that due to the percolation losses of plant nutrients, rice yields dropped off, but when the percolated water was used again as re-irrigation water the yield was increased.

OKUDA (1948) conducted a comparison of rice yields between two plots, "all the year round submerged plot" and "plot drained during the winter and percolated during the summer", under the different fertilizer application such as no fertilizer, calcium cyanamide, ammonium sulfate, compost, and green manure (Chinese milk vetch). The results showed that rice yield in drained plot was as much as or less than that in submerged plot. MATSUURA (1952) reported that rice yields in percolation plots (with various rate of percolation) were generally less than those in submerged plot, decreasing proportionately with the increases in the rate of percolation. SHIROSHITA et al. (1958) stated that when the percolated water was used as irrigation water again, rice yield showed sometimes an increase or sometimes a decrease, varying in effect according to the soil types.

Table 6–26 indicates the results of experiment made by TANAKA et al. (1961). Percolation treatments of 1.5 and 4 centimeters per day were given for the period from the maximum-number-of-tillers-stage to the milky stage of rice plant.

Table 6 – 26. Effect of Water Percolation on Rice Yields
(TANAKA, NOJIMA and UEMURA)

Year	Field	Plot	Panicle weight per hill	Straw weight per hill
1959	Well-drained paddy field (Maebashi)	C	22.0 g	17.9 g
		P_1	20.7	17.4
		P_2	20.0	17.2
	Relatively ill-drained paddy field (Konosu)	C	23.3	18.3
		P_1	24.5	19.3
		P_2	24.1	19.9
	Diluvium ill-drained paddy field (Haruoka)	C	22.6	17.6
		P_1	23.9	19.1
		P_2	23.9	18.4
	Alluvium ill-drained paddy field (Shintone)	C	18.9	15.8
		P_1	20.1	16.1
		P_2	20.0	16.5
1960	Well-drained paddy field (Maebashi)	C	22.0	17.8
		P_1	22.5	18.0
		P_2	23.2	18.9
	Alluvium ill-drained paddy field (Shintone)	C	19.2	15.9
		P_1	20.1	15.7
		P_2	21.0	16.7

Note: C : Check plot.
P_1: *Percolation at 1.5 cm/day.*
P_2: Percolation at 4.0 cm/day.

Four kinds of paddy field soils were used: alluvial swampy soil; diluvial swampy soil; relatively ill-drained soil; and well-drained soil. Of these paddy field soils, the H_2S amount in the soil-water in summer months was greatest in the alluvial swampy soil rich in organic matter. Table 6–26 indicates the fact that panicle weight and straw weight were generally affected favorably by percolation, except the case of well-drained soil in 1959. With respect to panicle weight, according to the statistical analysis, the significant difference at 5 per cent was found in the alluvial swampy soil in 1960 (in which it showed an increased rice yield owing to the removal of toxic substance by the percolation) and in the well-drained soil in 1959 (in which it showed a decreased rice yield owing to the nutrient loss by the percolation), but no significant difference was observed with other plots.

Supply of O_2 both to paddy field soils and to rice plant roots, removal of toxic substances, and leaching of nutrients have been regarded as important effects of the percolation. TANAKA et al. (1961) recognized the fact that a great portion (about 95 per cent) of O_2 supplied by percolation to soils was consumed in the uppermost surface layer (0–2 centimeters) leaving only a small amount to be supplied to the lower layer. With respect to CO_2 and H_2S (both regarded as toxic to roots) in soil-water, it was proved that free CO_2 showed a marked decrease due to the percolation, the decrease being proportional to the increase in percolation. On the other hand, when H_2S was present in large quantity, it decreased clearly by the percolation, but when present in small amount, it showed no decrease or sometimes a slight increase.

Respecting the relationship between percolation and NH_3-N in soils, it can generally be said that with the increase in percolation NH_3-N will be leached away from soils with an increasing rate, but on the other hand, the mineralization of soil organic matters is also accelerated. Accordingly, NH_3-N content in soils was unchanged up to a certain rate of percolation (up to 2 centimeters/day according to our observation in 1961). The rate of percolation, at which the balance between the mineralization of soil organic matter and the leaching of NH_3-N from soils has been upset and NH_3-N content in soils begins to decrease, differs with the amount of fertilizer applied, nutrient-holding capacity of soils, and organic matter-content.

From the above reference data, it can be concluded that the percolation exerts a beneficial effect for the ill-drained soils with abundant production of toxic substances, but the effect can not readily be found in the relatively ill-drained or well-drained paddy field soils in which the production of toxic substances is not abundant. Similarly, in case where green manure, fresh compost or barnyard manure has been applied excessively, the percolation effect is likely to be brought about readily. Adequate rate of percolation should vary according to the amount of toxic substances and the nutrient-holding capacity, but in the case of swampy paddy field soils abundant in toxic substance, the percolation at a rate of 3 centimeters per day seems to be optimum.

Next, the effect of the drainage of paddy fields practised in the course of the plant growth period (the so-called *Nakaboshi*, i.e., mid-summer-drainage) will be described. With the progress in soil reduction, root-rot will begin to occur. That time, as usual, falls on around the time of the young panicle formation stage. Therefore, in the case of paddy fields in warm areas, the drainage is practised for 5–10 days before the outbreak of root-rot by draining surface- and underground-water with the purposes of bringing back the rhizosphere in the oxidized state and of regulating the fertilizer effect.

The time of the midsummer-drainage is about at the later tillering stage (at which the number of panicles has already been fixed) and falls on the intermediate period prior to the forthcoming young-panicle formation stage. The requirement of rice plants for water at this time is the lowest throughout the whole growth period, and little or no ill-effect would be brought about even if the paddy field be kept in the drought state (BABA, 1951 and ARASHI, 1950). This fact also accounts for a practicability of the midsummer-drainage at the later period of the tillering stage. However, when the symptoms of *Akagare* disease (reddish-brown sheath rot) are observed at the earlier time of the tillering stage due to the rapid progress in soil reduction, it is necessary to drain water immediately. The results of tests on the relationship between the time of midsummer-drainage and rice yield made at the Fukuoka Prefectural Agricultural Experiment Station (1952) showed that the drainage practised at the invalid tillering stage caused an increased yield, while the drainage at the early tillering stage or at the most active tillering stage caused a slight decrease or no effect, but the drainage at the booting stage caused a marked decline in the rice yield. Many reports indicate that the effects of midsummer-drainage vary according to the quantities and the kinds of fertilizer applied. For instance, KAGAMI (1902) reported that the drainage practised at two times a week after the first weeding exerted a benefit in yield when fertilizers were applied heavily, but it caused a decreased yield when usual dose of fertilizers was applied. However, the difference in yield was very slight, being only 3 or 4 per cent on a three-year average. The results of the Ibaraki Prefectural Agricultural Experiment Station (1952) showed that no appreciable difference in yield was obtained by the midsummer-drainage plot on the three-nutrient-element plot (nitrogen, phosphate, and potassium) but a marked increase in yield was obtained on the non-potassium plot.

Table 6–27 indicates the results of the experiment on drainage at the Hokuriku Agricultural Experiment Station (average of 1957–60).

As shown in Table 6–27, drainage effect is markedly great

Table 6-27. Effects of Drainage on Rice Yields
(Hokuriku Agr. Exp. Sta.)

	Brown rice weight	*Straw weight*
Chemical fertilizers	kg/a	kg/a
Check plot	51.1	62.7
Earlier drained plot	53.7	63.8
Later drained plot	52.6	65.1
Green manures		
Check plot	49.8	73.0
Earlier drained plot	55.4	70.3
Later drained plot	52.8	74.1

Notes: Earlier drained plot: Plot drained from the end of the valid tillering stage onward and submerged when soil moisture-content reached 70%.

Later drained plot: Plot drained from the panicle primordium differentiation stage onward and submerged when soil moisture-content reached 70%.

Green manure plot: Adding to the chemical fertilizers similar in quantity to the chemical fertilizer plot, Chinese milk vetch of 112.5 kg per are is applied.

Figures: Average for the four testing years.

in green manure plot, while less in chemical fertilizer plot, and greater in earlier drained plot than in later drained plot. MIYASAKA (1961) ascribed the increased yield in drainage plot (particularly in earlier drained plot) to the change in photosynthesis due to the drainage, and he observed that the photosynthesis per hill in earlier drained plot was lowered for a while owing to the drainage, but became higher owing to the re-irrigation, thus increasing the number of ripened grains per panicle, percentage of ripened grains, and the weight of 1,000 kernels. YAMAZAKI (1959) practised a drainage for 25 days from the second week after transplanting on the paddy field applied with different amount of Chinese milk vetch and observed the drainage was beneficial when fertilizers were applied heavily but it was adverse under light application of fertilizers. YAMAGUCHI (1953) found that when ill-drained paddy fields were drained at the most active tillering stage or at the later tillering stage, 3 or 8 per cent increase in panicle weight was induced respectively. With respect to the nutrient absorption by rice plants, the absorption rate of N, SiO_2, K_2O, CaO, and MgO was promoted after the drainage, but that of MnO was not. The harvested plant showed higher content of K_2O, SiO_2, MnO, and MgO in the drained plot than in the continuously submerged plot, but the contents of total-nitrogen, P_2O_5, and CaO was lower in the former.

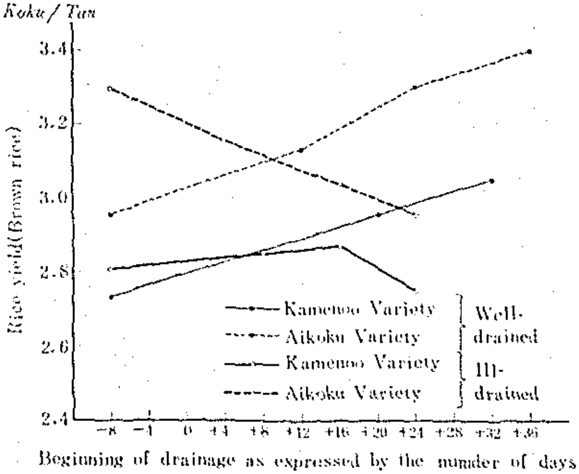
From the above reference data, it can be observed that the midsummer-drainage practice at the later period of the tillering stage is generally most suitable for the plant growth. Under the condition where soil reduction proceeds markedly (as is the case with ill-drained soils or the soils to which Chinese milk vetch is applied liberally), or under the conditions where the ripening of grains may be retarded due to the presence of excessive quantity of nitrogen in soils as a result of heavy application, the effect of midsummer-drainage is brought about readily, because due to the drainage practice, the soils are changed in the oxidized state and the excessive quantity of nitrogen is removed, thus facilitating the ripening process. However, under the condition of light application of fertilizers or of well-drained soils with less production of toxic substances, there is a fear that, due to the loss of nitrogen, the midsummer-drainage may not be beneficial or an ill effect may be realized.

4. Time of Drainage at Ripening Period

Rice grain continues to grow in weight for about one month after the anthesis (flowering). Particularly, until 20 days after the anthesis, the translocation of carbohydrate from culms and leaves is in full swing. Therefore, if the plants are subjected to a shortage of water supply in this period, the photosynthetic production and translocation of carbohydrate to panicles will be retarded seriously. In view of this, it is of importance to know the right time for drainage in order to accomplish the finishing up of successful rice culture. Although the right time for drainage practice varies according to the conditions such as rainfall, temperature, incidence of diseases and insect pests, extent of root-rot occurrence, or moisture-holding capacity of soils, the past researches suggest that it is generally adequate to drain water about 20–25 days after the heading. However, as stated above, the best drainage time differs according to the soil conditions. An example is given in Fig. 6–30 (1923–33).

Fig. 6–30 indicates that in the case of well-drained paddy fields, the earlier the time of drainage, the lower the rice yield, the poorer the rice quality, and the greater the damage caused by neck rot or node blast; while in the case of ill-drained paddy fields, the earlier the time of drainage, the higher the rice yield, but no clear relation is found between the rice quality or disease damage and the drainage time. This difference may be ascribed to the difference in holding of soil moisture, change in soil temperature, and a decrease in root-rot after the drainage between the above two paddy fields. As to the relationship between soil moisture-content after the heading and rice yield, TAKAI (1955) reported that if soil moisture-content be maintained higher than 60 per cent (even the paddy field be in the upland state), the rice yield is approximate to that in submerged paddy field, but if the soil moisture comes down below 60 per cent, a sharp decrease in the rice yield is induced. Accordingly, if soil moisture-content can be held at a certain level after the heading, it seems needless to submerge. In practice, however, as the water management in most cases being made on a group of many paddy fields, it is inconvenient to bring the paddy field under irrigation again when drained once. For this reason, in the case of well-drained paddy fields of low groundwater level, it is practically difficult to hold optimum soil moisture after the drainage, as compared with the paddy fields of high groundwater level. As a result, it is rather

Fig. 6 – 30. Relationship between Rice Yield and Beginning of Drainage at Ripening Stage (Niigata Pref. Agr. Exp. Sta.)



preferable to delay the beginning of drainage in the well-drained paddy field districts, while in the ill-drained paddy field districts, it is recommended to drain earlier with an aim of relieving root-rot or raising soil temperature. Rice quality is closely related to the beginning of drainage at the ripening stage. The earlier the time of drainage, the more broken or discolored rice increases, and the lighter the kernel weight and the poorer the rice quality. However, if the drainage is delayed unduly, the ripening would be delayed, and green rice would become increased and the drying of rice kernels would become insufficient.

5. Irrigation and Weeds

As one of the cogent reasons for the submerged irrigation practice prevalent now widely in rice cropping areas, the great effect of submergence on weed control can be cited. Emergence of weeds and kinds of weeds have close bearings upon the soil moisture-content and the depth of submergence. ARAI et al. (1950, 1955) reported that the amount of weed emerged in submerged plot was about 30 per cent of that in saturated plot (moisture-content of 80–90 per cent), and as low as about 17 per cent of that in upland state plot (moisture-content of 40–60 per cent), respectively. With the increase in depth of submergence, the weed emergence is reduced markedly, particularly barnyard grass (*Echinochloa crus-galli*, competing keenly with paddy rice plants) would hardly emerge under the submersion of more than 9 centimeters in depth. Thus, the effect of deep-submergence in controlling barnyard grass is great. JONES (1933) reported that few or no barnyard grass emerged under the submergence at the depth of 8 inches or more and that the suppression of barnyard grass by the deep submergence could be ascribed to the low concentration of O_2 in deep water, as well as to high water temperature, presence of scum algae, and shadows of rice plants. In recent years, a rapid progress has been made in herbicide use, particularly, in the use of PCP, DCPA, etc. at the earlier stage of plant growth. As a result, the weed control effect of submergence has become lowered in importance. However, in view of the marked weed control effect of the submergence, new cultural methods by using the irrigation practice and herbicides in combination would become an important problem to be tackled in the future.

6. Irrigation and Rice Plant Diseases

Irrigation brings about changes in environmental conditions for plant growth and in the rate of nutrient absorption by rice plants. In parallel with this, the outbreak and spread of diseases and insect pests assume different phases.

It is well known that blast has a close bearing upon the soil moisture-content. HENMI (1949) made clear the following relationship between the outbreak of blast and the soil moisture-content, viz., (i) susceptibility of rice seedlings is increased more markedly by the dry state of soils at the earlier stage than by that at the later stage; (ii) susceptibility to neck rot is more strongly increased by the dried state of soils after the booting stage than by that before the booting stage; and (iii) leaves and panicle-necks of rice plants grown in dry soils are more susceptible to blast than those grown under submersion, irrespective of the quantity of nitrogen and silica application. The reason why rice plants become susceptible to blast when the soil moisture-content is low is ascribed to the decreased soluble silica in the soils owing to the decreased soil moisture-content, and, from the anatomical viewpoint, to the decreased thickness of the "external cell membrane of epidermis" and the "external cell membrane of silicificated cell" which facilitate the invasion of blast fungi into the cells, and to the increased concentration of leaf cell-sap which accelerates the growth of hyphae after the invasion.

In view of the above facts, when the signs of outbreak of blast are observed, it is desirable to bring paddy fields under submergence in cold areas, and to practise flowing irrigation in warm areas. At any rate, attention must be paid so that paddy fields may not be drained. MURATA et al. (1948) reported that in case where a great quantity of green Chinese milk vetch was applied, its decomposition was quickened by exercising the drainage for 3–4 days before the outbreak of blast, so that the outbreak of neck rot was alleviated. As to the relationship between the time of drainage after heading and outbreak of neck rot, MURATA et al. (1948) reported that the earlier the time of drainage, the more the blast was liable to occur, and that when blast occurred, it would better delay the drainage until the hard-dough stage. In the case of cool water areas, it is desirable to drain water at the booting stage and to irrigate at times after the drainage in order to prevent the blast.

KAWAI (1948) recognized that the occurrence of sheath blight and stem rot in continuously submerged plot (9 centimeters in depth) was more severe than the case in the occasionally drained plot. As to the relationship between the occurrence of stem rot and irrigation water depth, ONO (1950) stated that their invasion rate into leaf sheath was higher with deep water than with shallow water, while their development within a plant body was more marked in shallow water than in deep water. Damage degree has a closer bearing upon the development rather than upon the invasion itself.

Brown spot is liable to occur in the ill-drained paddy fields with high groundwater level, and abundant organic matter, when the soil reduction proceeds. In such case, brown spot can be controlled by drainage or percolation.

Summary

As stated above, the irrigation methods vary widely with the various factors such as climatic conditions, soils, fertilizer application, weeds, and diseases. However, the climatic conditions and the fertilizer application can be regarded as two major factors each of which may serve as a basis for the classification of irrigation method. In the classification based upon the climatic conditions, temperature is the chief deciding factor. For instance, in cold climate areas, irrigation methods such as deep water irrigation, prevention of percolation, or dispersion irrigation which may raise, in principle, the soil or water temperature will become important. In contrast to this, in the hot or warm areas, flowing irrigation will be needed to alleviate high-temperature damage and drainage is necessary in order to prevent soil reduction caused by high-temperature. And in the temperate climate areas, either a warm area type irrigation or a cold area type one may be followed according to the climatic conditions in each year.

On the other hand, in classifying irrigation method based upon the fertilizer application, the amount of fertilizer application is an important factor. For instance, under a slight application of fertilizer, submergence will be needed in order to make rice plants absorb fertilizer as effectively as possible, and due to the big dependence upon the nutrients available from soils, it is considered important to keep paddy fields in the submerged state during the greater part of the plant growth period. As the emergence of weeds can be controlled by continuous submergence, submergence is of importance as well, in order to prevent nutrients from being depleted by weeds. However, under a heavy application of fertilizers, the dependence upon the nutrients supplied from soils will become smaller and the submergence will become less important. When fertilizer (particularly nitrogenous fertilizer) is applied heavily, it will become necessary to drain water in order to check the fertilizer effect in response to the climatic conditions or soil conditions (particularly degree of soil reduction). For this purpose, the midsummer-drainage practice at the later period of the tillering stage will become important.

To sum up, it is desirable to adopt the irrigation methods fitted best for the respective areas in the light of temperatures and the amount of fertilizer application.

VII. HARVESTING

Reaping of rice plants is, in most cases, done with hand sickles. The labor required for reaping operation accounts for about 20 per cent of the total of rice cultural labor requirements. Such operations as plowing, puddling, weeding, disease and insect pest control, threshing, husking, winnowing, sorting, etc., are becoming increasingly mechanized, but the harvesting operation, as is the case with transplanting operation, has been unchanged since hundred years ago. As a matter of fact, seedlings are transplanted by hand, amounting to as many as 200,000 hills per hectare, and the ripened plants are reaped with hand sickle one after another.

With a view to improving such old-fashioned harvesting operation, a study of harvester was started after the end of World War II. Consequently, a progress has been made in the study of small-type harvesters suitable for rice culture in Japan. At present, two or three types of hand- or power-harvesters have been brought into practical use. Thus harvesting done with harvesters has come into practice, though not large in area. Harvesting operation consists of reaping and binding, both of which require almost the same much labor. If the reaping operation alone be mechanized, it would be less effective. In view of this, a binder-type harvester which performs the reaping and binding operations in combination is now under study. In recent years, the study of a combine harvester which may perform reaping and threshing operations in succession has been started. It promises well for the future.

1. Ripening of Rice and Right Time of Harvesting

Timely harvesting is important to secure high quality and yield of rice and to increase efficiency in harvesting operation, because when harvested too early, the amount of greenish rice will increase and the rice quality and yield will decrease, while when harvested too late, rice-bran layer will become thicker, grains will lose luster, crashed rice will increase, and rice quality will become inferior. Besides, the rice yield will decrease due to the shattering of grains by wind or due to the damage by wildlife, and the harvesting operation will become harder due to the lodging or breaking of rice plants.

When a great part of the panicles have grown yellowish, though stems, leaves and paddies near to the panicle neck are still green, it may be regarded as optimum harvesting time. Ripening velocity varies with the panicles of each hill as well as with the grains of each panicle. Namely, in the case of panicles of one hill, the panicle of the main culm is earliest in ripening, followed by that of the tillers of the first order and that of the tillers of the second order, in order of tillering. Accordingly, the panicles of later tillers are greenish even when the harvesting time has come and will not become fully ripened. In the case of grains (spikelets) of one panicle, as the ripening proceeds generally from the tip of the panicle downward, the nearer to the basal part of the panicle, the later the ripening. Grains at the panicle neck will not become ripened even when the harvesting time has come, and will be greenish. However, when harvested after these grains have grown yellowish, it will be too late for timely harvesting of a great part of the grains.

Now, let us examine the optimum harvesting time from the viewpoint of ripening process. The starch accumulated chiefly in culms and leaf sheaths before heading and the starch synthesized by photosynthesis after heading will rapidly translocate to the panicle. Thus the grains will become ripened (Fig. 6–31). The growing of the length, width, and thickness of a grain is as given in Fig. 6–32. The length reaches a maximum about 10 days after heading. The width and thickness show a rapid increase until about 10 days after heading, but thereafter the increase slows down, reaching a maximum 20 days after heading. Namely, the size of grain is fixed 20 days after heading. Fig. 6–33 indicates the ripening process of grains after heading as expressed by the increase in 1,000 kernel weight. The final weight of 1,000 kernels varies markedly according to the climatic conditions, but the time when the 1,000 kernel weight reaches a maximum is 45 days after heading, irrespective of climatic con-

Fig. 6 – 31. Changes in Starch-Content in the Various Parts of a Rice Plant according to the Plant Growth

(TOGARI, OKAMOTO, and KUMURA, 1954)

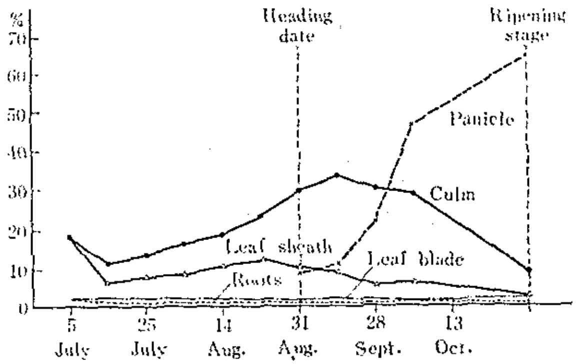


Fig. 6 – 32. Growth of a Rice Grain (MATSUDA)

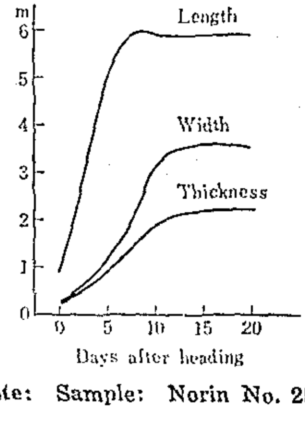
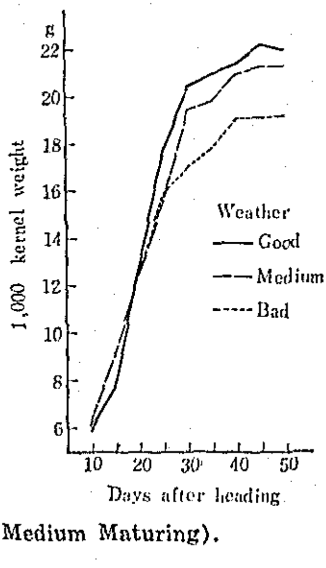


Fig. 6 – 33. Relationship between Number of Days after Heading and 1,000 Kernel Weight

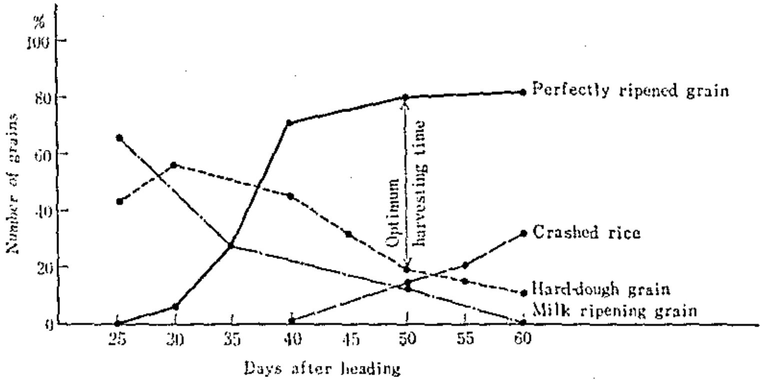


Note: Sample: Norin No. 25 (Medium Maturing).

ditions.

Furthermore, the ripening of grains viewed from the qualitative change is as given in Fig. 6–34.

Fig. 6 – 34. Ripening Process and Number of Days after Heading (SHIBUKAWA)



As seen in Fig. 6–34, the number of perfectly ripened grains will increase rapidly from about 30 days after heading, but it decreases from about 50 days after heading. A turning point is observed clearly on the curve. The turning point coincides generally with the time of a maximum rice yield. The more noticeable fact is that crashed grains (which have a close bearing on the rice quality) show a rapid increase starting from this turning point. Accordingly, the time of this turning point can be said as the optimum harvesting time. Next, the optimum harvesting time will be examined from the viewpoint of nutrient of rice.

Relationship between the number of days after heading and rice components is as given in Table 6–28.

The components and calories contained in 100 grams dry matter can safely be said to reach the fixed amount 30 days after heading. Accordingly, from the viewpoint of the components, the time when the dry matter reaches a maximum is thought to be the optimum harvesting time.

Table 6-28. Changes in Rice Components according to the Ripening of Grains

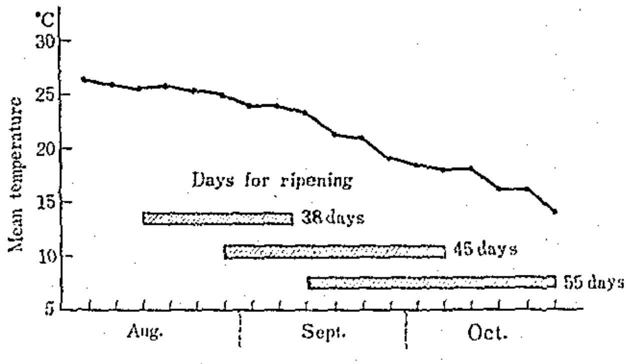
Component	*20 days after heading*	*30 days after heading*	*40 days after heading*	*50 days after heading*
Moisture-content	14.2 %	15.2 %	14.5 %	15.8 %
Calorie	336.9	359.8	346.5	358.7
Protein	8.4 %	9.8 %	8.3 %	7.8 %
Fat	2.6 〃	2.2 〃	2.1 〃	2.0 〃
Carbohydrate	74.5 〃	71.9 〃	76.2 〃	74.8 〃
Fiber	1.31 〃	1.21 〃	0.94 〃	0.84 〃
Ash	1.3 〃	1.2 〃	0.9 〃	0.9 〃
Vitamin B_1	369 γ	350 γ	344 γ	343 γ

Notes: 1. Food Research Institute, Ministry of Agriculture and Forestry.
2. Contents in dry matter of 100 grams.
Sample variety: Norin No. 23.

From the above fact, it is concluded that the optimum harvesting time is found 45–50 days after heading. (This is applicable to the case of medium-maturing rice varieties grown under the ordinary-seasonal cultural method.)

Ripening velocity varies with the soil fertility, climatic conditions, and rice varieties. Particularly great difference is found depending upon the temperatures during the ripening

Fig. 6-35. Relationship between Temperature and Number of Days for Ripening



stage. Fig. 6–35 indicates the relationship between the temperatures during the ripening stage and the number of days for ripening.

When the same variety is grown under the early-seasonal culture, ordinary-seasonal culture, and late-seasonal culture, respectively, the number of days required for ripening in the early-seasonal culture with high temperature during the ripening period is about 40 days, while in the late-seasonal culture with low temperature, it requires 55 days. The reason for a great difference in the number of days for ripening is ascribed to the difference in the physiological activity of rice plants due to the difference in temperatures during the ripening stage. Accordingly, the number of days for ripening depends upon the genetic factor specific to variety as well as upon the factor affected by the environmental conditions. Relationship between maturing time of rice varieties and the number of days for ripening in the Kanto District is as given in Table 6–29.

Table 6–29. **Relationship between Maturing Time of Rice Varieties and Number of Days for Ripening**

(Kanto District)

Rice variety	*Number of days for ripening*
Very early-maturing	33–37 days
Early-maturing	40–45 〃
Medium-maturing	43–47 〃
Late-maturing	50–60 〃

The above are the discussions on the optimum harvesting time examined from the various viewpoints, but, in practice, the optimum harvesting time is required to be judged by the external appearance of rice plants. As prescribed before, the optimum harvesting time has no bearing upon the color of stems and leaves or panicle necks. It may safely be regarded as the optimum time for harvesting when a great part of grains (spikelets) have grown yellowish. In collecting seeds, the timely harvesting of grains is particularly necessary.

2. Harvesting Operations

1. *Harvesting with hand sickles*

In Japan, reaping of rice plants is done at their base with hand sickles. The harvesting by cutting-off of panicles now prevailing in some South East Asian countries had been prevailed in Japan also until about eight centuries ago. Thereafter, with the progress in the threshing techniques and in the utilization of straws, the present harvesting method has been brought into practice. Reaping of rice plants with sickles is a squat labor and a worker is much fatigued by a continued working. There are two types of sickles: "blade sickle" and "saw sickle." It is more efficient to go on reaping at a right angle to rows, but when rice plants have lodged it is preferable to go on reaping in the direction of lodging. There are two reaping methods: (i) method to cut plants and tie the cut plants into bundles in succession and (ii) method to cut plants and spread them over the field for drying. In case of wet paddy fields or poor weather, it is general to cut plants and bind them into bundles in succession, and hang them on drying racks or stand them in the field for drying. In the case of drained paddy fields or fine weather, the latter is adopted, but in recent years, with a view to improving the rice quality, rice plants are, in most cases, cut and tied into bundles and then the bundles are hung on the drying racks. The cut plants are tied into a large bundle of 50–60 centimeters in diameter or into a small bundle of about 20 centimeters in diameter. However, small bundles are desirable because these are dried better and handled more easily. Moreover, the threshing operation can be done more efficiently.

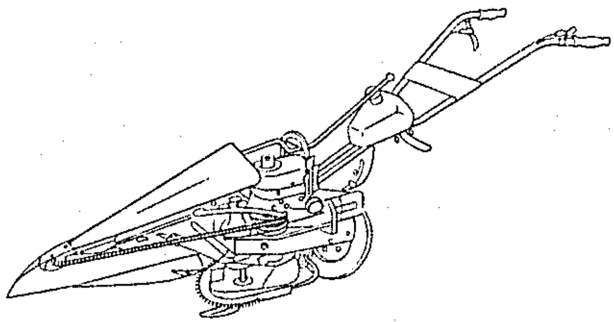
2. *Harvesting machines*

Since the end of World War II, with a view to developing the mechanization of rice harvesting operation, the study of harvesting machines driven by small-type air-cool engines or harvesting machines attached to the small-type tractors has been in progress. Several types of harvesting machines have already been on the market. Among the harvesting machines are four types: windrower type; dropper type; binder type; and combine type. The first three types are the devices for mechanizing operations now done with sickles, but the last type (combine harvester) is quite different from the operation prevailing in the past.

(i) Windrower type harvester (Fig. 6–36)

Harvester of this type is a device simply for rice plant cutting purposes. The cut plants are dropped into a row. The advantages are found in the simplified construction and in the smallness in size. Unless the rice plants have lodged, the cutting operation could easily be done. The required operating hours are 40–60 minutes per 0.1 hectare. However, it is at a disadvantage that the cut plants being laid down in piles into a row, it will take much time in binding operation.

Fig. 6 – 36. Power Windrower Type Harvester



(ii) Dropper type harvester

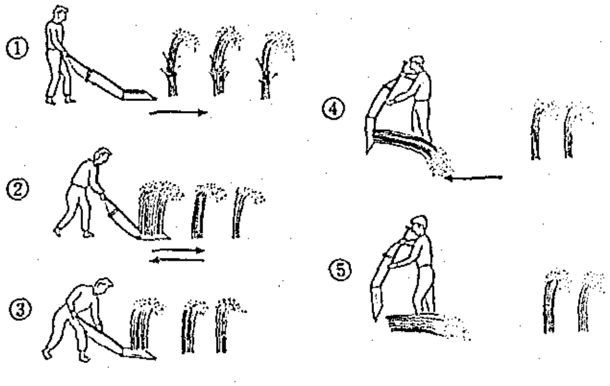
With the harvester of this type, cutting of rice plants and dropping of the cut plants in a bundle are done at the same time. It marks a forward step in progress, as compared with a windrower type harvester which makes binding operation more laborious. In the case of a dropper type harvester, a device for gathering the cut plants in a bundle being equipped, the binding operation is done more efficiently. The harvester of this type is divided into two types: (a) hand type and (b) power type.

(a) Hand dropper type harvester

The operation with hand dropper type harvester being done without bending over, an operator suffers no pain in his waist, unlike the case with the harvesting operation done with sickle. However, as it requires fairly hard labor, he is fatigued much. At present, around 70,000 harvesters of this type are used. The hand dropper type harvester and its operating method are as illustrated in Fig. 6-37 and Fig. 6-38. The time required for harvesting of rice plants per 0.1 hectare is around 3-4 hours, 2-3 times higher in efficiency than the harvesting done with sickles, and cutting and binding operations combined are 1.5-2.0 times higher in efficiency.

Fig. 6-37. Hand Dropper Type Harvester

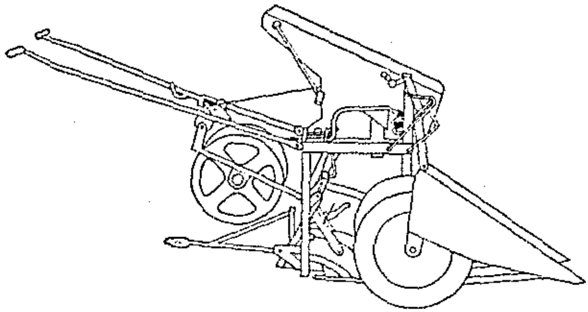
Fig. 6-38. Processes of Operation with Hand Dropper Type Harvester



(b) Power dropper type harvester

With this type harvester, the cut plants are gathered in a bundle of a certain amount and when the cut plants reach a certain amount they are dropped backward. This harvester is also of small type. Unless the rice plants have

Fig. 6-39. Hand Binder Type Harvester



lodged, the harvesting can readily be done. The efficiency is almost similar to that of a windrower type harvester.

(iii) Binder type harvester

With this harvester, cutting and binding are done in combination. A hand binder type has been brought in practical use. The mechanical construction is as illustrated in Fig. 6-39. This machine goes ahead to cut the plants enough to make a bundle and the cut plants are gathered by an up-and-down motion of the lever, and then they are tied into a bundle at one rotation of its handle. Because of a hand operation, an operator is fatigued much. However, the efficiency is high because the cutting and binding are done in combination, requiring only 4-5 hours per 0.1 hectare.

Power binder type harvester has a complicated structure and is liable to become large in size. The study of this type harvester is now under way. It has not been brought into a practical use as yet.

(iv) Combine harvester

In order to increase the efficiency in harvesting operation, the use of a combine harvester (which can operate the cutting and threshing in combination) has come to be devised. However, in introducing combine harvesters prevailing in foreign countries to the harvesting of rice, the following disadvantages must be overcome: (i) owing to the low efficiency in threshing rice, many grains are not separated from straw, (ii) owing to the poor weather durnig the harvesting season, grains are not dried well; (iii) a combine harvester is too large for the present small-sized paddy rice enterprise in Japan. The study of improved combine harvesters suitable for future rice culture in Japan is now under way.

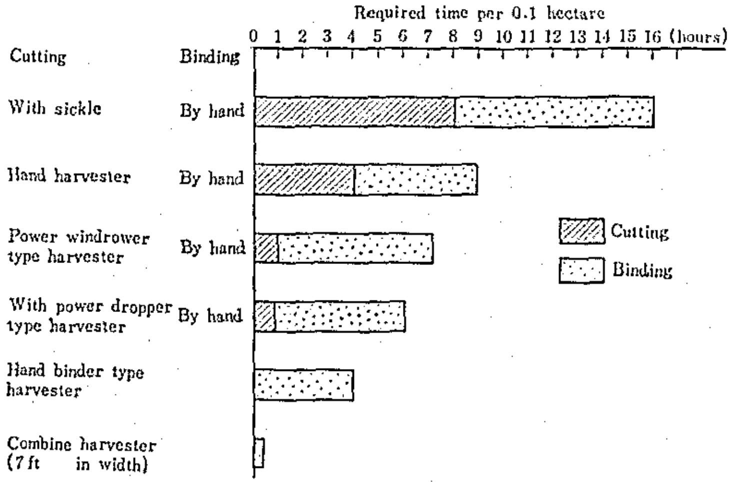
The efficiency in operations from cutting to binding with the above harvesting machines is as given in Fig. 6-40. For the purpose of expediting the mechanization in harvesting operation, the following requirements must be filled.

(i) To relieve rice plants from lodging;
(ii) To transplant seedlings in rows, keeping the distance between rows and within rows in a rectangular form;
(iii) To enlarge more the area of each rice field;
(iv) Betterment of the drainage at the ripening stage so as to introduce harvesters with ease.

3. *Drying*

Drying of the cut plants is important not only for rice-quality improvement but also for increasing efficiency in threshing and husking operations. Grains at the optimum harvesting time generally contain 20 per cent moisture, and

Fig. 6-40. Efficiency in Harvesting, by Sickles and Harvesters



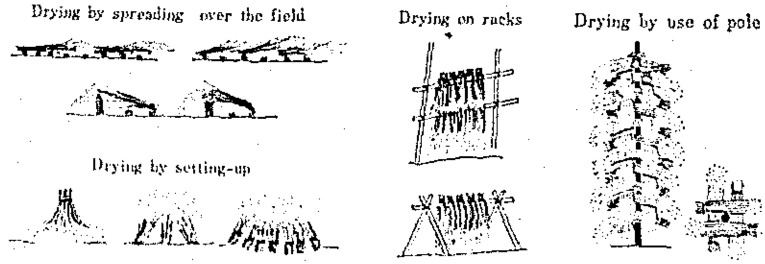
stems and leaves contain 50 per cent or more. Threshing is done after the grains have been dried to 15–16 per cent moisture and the threshed grains are dried to 13–14 per cent moisture, and then husking is done. Like this, at present, the drying is practised two times: bundle drying before threshing and grain drying before husking.

Attention must be paid so as to dry grains slowly and to avoid rapid drying. If dried rapidly, crashed rice would be increased much.

(i) Drying of bundles

Drying of rice bundles is practised in various ways in the respective areas depending upon the weather conditions and dryness of paddy fields. In any case, bundles being dried in the open air, drying is affected much by weather conditions. The drying methods are divided into three: (i) drying by spreading the cut plants over the field; (ii) drying by setting up the bundles on the field; and (iii) drying by hanging the bundles on racks (Fig. 6–41). In recent years, the study of desiccating chemical applicable to rice plants before harvesting has been forwarded. The drying by chemical application will sooner or later be brought into practice.

Fig. 6–41. Three Types of Drying of Bundles of the Cut Plants



(a) Drying by spreading the cut plants over the field

The cut plants are dried by spreading them over the field. Such drying method can be used on the dry fields under fine weather. In this drying method, the cut plants being dried by spreading directly over the paddy field ground, the plants absorb moisture readily during the night, and if rains occur, the downside plants could not easily be dried. As a result, this is nothing but a supplementary measure adopted generally for 2–4 days only.

(b) Drying by setting-up the bundles

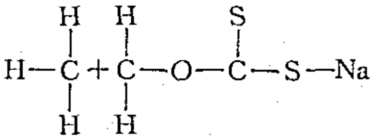
One to 10 bundles of 25–30 centimeters in diameter each are set up in a group on the field or leaves. Bundles are sometimes set up with panicles upward, or sometimes by turning them downward.

(c) Drying on racks

Bundles are hung to be dried on the drying racks made of bamboos or logs. Though some materials are required, this method is the best way for drying bundles. Even if rains occur, bundles could be dried sooner.

(d) Desiccants

As labor and material saving device, it is now devised to spray desiccants on rice plants 3–4 days before cutting with a view to reducing the moisture-content in grains to 16–17 per cent. Sodium ethyl-xanthogenic acid is used as grain desiccant. Its chemical composition is as follows:



This chemical is one of the non-hormone, quick-acting contact type herbicide. When contacted with this chemical, only the contacted part of plant will be dead. The activity of this chemical varies with the temperature, namely, high in the activity at a temperature of 20°C and over, but low at a temperature of 15°C and under. The application of desiccant for drying is now under study. Its effects are as given in Table 6–30. As indicated in Table 6–30, moisture-content in grains decreases from 25–33 per cent at the time of spraying to 15–17 per cent at the harvesting time (3–4 days after spraying), showing a 3–5 per cent decrease from the moisture-content in those of the non-desiccant plots.

Even sprayed with desiccant until about five days before maturity, it shows no decrease in the rice yield, and no injury is inflicted on rice quality and seed germination rate. As a result, the grains can be used for the seeding purpose.

Table 6 – 30. Effect of Desiccant Spraying on Rice Plants

Agr. Exp. Station	*Dosage kg per 0.1 ha.*	*Date of spraying*	*Date of harvesting*	*Moisture-content at the spraying time*		*Moisture-content at the harvesting time*		*Mean temperatures*
				Grain	*Straw*	*Grain*	*Straw*	
				%	%	%	%	°C
Nii-gata	0	Sept. 30	Oct. 10	24.6		17.9		18.4
	1.0					17.5		
	2.0					17.4		
Kana-gawa	0	Aug. 25	Aug. 28	29.5	65.3	26.2	65.0	27.1
	1.5					14.5	37.2	
	2.0					14.0	36.1	
Hyogo	0	Aug. 22	Aug. 26	24.9		21.4		27.2
	1.5					17.5		
	2.0					16.5		
Naga-saki	0	Aug. 16	Aug. 21	33.1	75.5	27.8		27.1
	1.5					17.7		
	2.0					17.2		

Directions of desiccant spray on rice plants are as prescribed below.

Desiccant is to be sprayed 3–4 days before the maturity stage.

Dosage: 1.5–2.0 kilograms (in product) per 0.1 hectare, but the dosage can be subject to change according to the drying purposes.

Desiccant diluted with water of 35 liters per 0.1 hectare is sprayed evenly by using a sprayer.

When the moisture-content in grains has decreased to 16–17 per cent, rice plants are required to be harvested immediately.

Caution: Take care not to make the desiccant attach to the worker's skins or working dress. If attached, wash well.

(ii) Drying of rice grains

The threshed grains contain 16–17 per cent moisture. It is required to be reduced to about 13–14 per cent for husking. For this purpose, grains must be dried. In the past, grains were dried in the sun, but in recent years, individually- or jointly-owned air dryers have come to be used, thus making possible the efficient drying.

(a) Natural drying (drying in the sun)

Grains of about 20 liters are spread sparsely over a straw mat and dried by a help of the solar heat. When the weather is fine, 17 per cent moisture-content in grains can be reduced in 2 or 3 days to some 13 per cent. However, much labor is required in the morning and evening to dry a great quantity of grains.

(b) Drying with air dryer

Almost without exception, the grain dryers which have hitherto been used were thermal type, but now air dryers are prevailing in Japan. In the case of the former, grains are dried by heat with stirring, while in the case of the latter, grains are dried by air forced from the fun without stirring.

Air dryers now used in Japan reached a level of 150,000 in 1960. The annual manufacturing of air dryers amounts to around 80,000. In the subsequent years, the use of air dryers is on the rapid increase in number, while thermal dryers now used is minor in number, and the annual manufacturing of them is estimated only at 500–1,000.

The follow nig can be cited as the contributing factors in the rapid increase in dissemination of air dryers.

(i) Less expensive and easier to be handled;

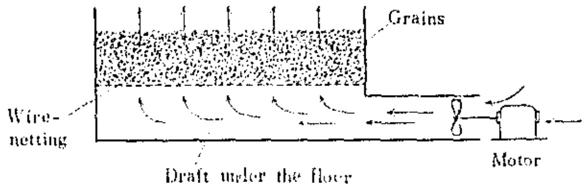
(ii) Smallness in size but higher in efficiency and suitable for small-sized rice enterprise;

(iii) Not only used for grain drying but also widely for drying of pastures or others;

(iv) Lower in drying cost and less in labor requirement.

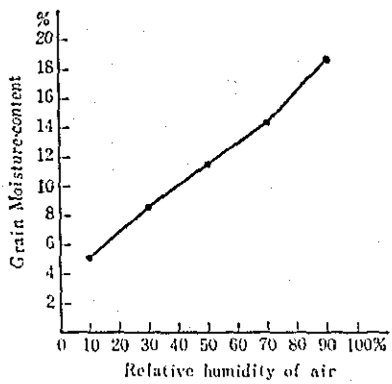
Construction of an air dryer (Fig. 6-42): A dryer con-

Fig. 6 – 42. Cross Sectional View of Box Type Air Dryer



sists of electric motor ,fan, and drying box. A certain quantity of grains taken in the drying box are dried by the air from the fan. As a result, the drying of grains is influenced by the temperature an dhumidity of the air from the fan, namely, at a temperature of 20°C. The balanced moisture-content in the grains is as given in Fig. 6–43. Fig. 6–43 indicates that in order to reduce the moisture-content in grains to 14 per cent, the relative humidity is required to be at 70 per cent and under. If the relative humidity is higher than 70 per cent, the moisture-content in grains could never be reduced to 14 per cent, no matter how many hours for

Fig. 6 – 43. Grain Moisture-Content Balanced to Air Humidity (WATANABE)



drying may be continued. In such case, the temperature of the air must be raised and the relative humidity must be lowered. For the above reasons, and in case where atmospheric temperature is lower and relative humidity is higher or where the drying is desired to be done in a shorter time, it is devised to attach a heater to the air dryer for the purpose of raising the temperature of the air sent from the fan. In drying the grains by using a heater, however, with a view to preventing the increase in cracked rice, it is necessary to raise the temperature of the air blasted from the fan by 10–15°C higher than the atmospheric temperature and to regulate the maximum temperature at 35°C or under.

4. *Threshing operation*

Threshing and husking operations were foremost in mechanization. Particularly, the dissemination of power threshers in the postwar years is remarkable, showing a sharp increase in number from around 370,000 in 1945 to more than 2,500,000 in 1961. The threshing of rice, wheat or barley grains is now done almost with power threshers. Before the invention of foot-pedal threshers in 1910, the threshing had been done chiefly with comb-teeth threshers (*Sembakoki*). In this sense, the foot-pedal threshers can be said to be the forerunner of the modern threshing machines. By 1925, foot-pedal threshers had come to be driven by power and the power winnowers appeared also. Threshing and selecting operations had been done separately, but owing to the mechanization in these two operations, the efficiency has come to be increased greatly. Thereafter, a rapid progress has been made in the study of threshers. Thus the present automatic power threshers (self-feeding power thresher) have been completed.

Among the rice-grain power threshers prevalent now in Japan are: (i) one-man operating power thresher, (ii) two-men operating power thresher, and (iii) automatic power thresher. The efficiency of each type thresher is as given in Table 6–31. Automatic power thresher is 12–20 times higher in efficiency than foot-pedal thresher, showing 5–8 times higher in efficiency per worker. The amount of calories required for the threshing worker is on the decrease with the progress in mechanization, and the threshing has come to be done more easily (Table 6-32).

Table 6-31. Efficiency in Threshing Operation, by Types of Threshers

Types of thresher	*Required horse power*	*Efficiency per hour*	*Labor requirement*	*Efficiency per hour per worker*
One-man foot-pedal thresher	—	1	persons 2	0.5
One-man operation power thresher	0.5-1.0	4-6	4	1-1.5
Two-men operation power thresher	1.0-2.0	7-10	6	1-1.5
Automatic power thresher	2.0-3.0	12-20	5	2.4-4.0

Table 6-32. Intensity of Threshing Operation, by Types of Threshers

Types of thresher	*Intensity of operation*	*Calorie requirement per unit amount*
Foot-pedal thresher	5.3	1.0
Power thresher	4.3	0.5
Automatic power thresher	2.9	0.1

5. *Husking operation*

It is reported that the husking operation in Japan was started from about 1690. Before that year, the milling operation being done directly from paddy (or rough rice), rice had been marketed in the form of paddy. In earlier days, husking was done mainly with husking mortars, but circa 1897, a roller type husker appeared for the first time. It was about 1930 that a power husker was completed. Thereafter, a rapid progress has been made in the study of a power husker. Thus the present automatic power husker was invented. At present, the number of power huskers reaches a level of 750,000. As a result, the husking operation has come to be fully mechanized.

The following four processes are required for the husking operation: (i) removing of husk, (ii) winnowing (separation of husked rice and paddy, from husk), (iii) separation of husked rice (brown rice) from unhusked rice (rough rice or paddy), and (iv) sorting of husked rice from broken rice.

Basing upon the above four processes, huskers can be divided into the following four types.

(i) Husk-removing type;
(ii) Husking and winnowing type;
(iii) Semi-automatic type;
(iv) Automatic type.

Husk-removing type huskers being used only for removing the husk from the paddy, these have recenly become almost out of use. A husking and winnowing husker is a husk-removing type thresher attached with a winnower. Both husk-removing and winnowing operations [(i) and (ii)] are done with this type of husker, and both separating and sorting operations [(iii) and (iv)] must be done with separator (*Mangoku-toshi*) and grain sorter.

A semi-automatic power thresher performs the operations of (i), (ii), and (iii), and the operation (iv) must be done with grain sorter. An automatic power thresher per-

Table 6-33. Efficiency in Husking Operation, by Types of Huskers

Type of husker	*Required horse power*	*Efficiency kg/hour*	*Labor requirement*	*Efficiency per worker*
			persons	
Clay mortar (66 centimeters in diameter)	—	120-150	2	60-75
Husk-removing type (2.5 inches)	—	120-180	2	60-90
Husking and winnowing type (2.5 inches)	0.5-1.0	360-420	3	120-140
Automatic power husker (2.5 inches)	1.0-2.0	480-540	2	240-270
Ditto (6 inches)	3.0-4.0	1,560-1,680	3	520-623

forms the functions in doing the operations from (i) to (iv). Husked rice processed with an automatic power thresher can be packed immediately. The efficiency in husking operation according to the respective type huskers is as given in Table 6–33.

6. System for harvesting operations

Reaping
↓
Binding and drying of bundles
↓
Threshing
↓
Drying of threshed grains (paddy)
↓
Husking
↓
Packing

CHAPTER 7

OTHER RICE CULTURAL METHODS

I. DIRECT-SOWING RICE CULTURE

Direct-sowing rice cultural methods prevailing now in Japan can be classified as follows:

(i) Direct-sowing on cropless fields
  (a) Direct-sowing on submerged fields
  (b) Direct-sowing on dry fields

(ii) Direct-sowing between rows of other crops
  (a) Direct-sowing between rows of wheat or barley crop
  (b) Direct-sowing between rows of other crops.

In any type of the above methods, labor requirements for rice culture are saved more than that of an usual transplanting cultural method, and the labor distribution becomes more rationalized. The characteristics of the various types of the direct-sowing cultural methods will be described below.

Direct-sowing on submerged fields: This method is practised chiefly in the colder parts in the country, e.g., Hokkaido, Tohoku, and Hokuriku districts. As is the case with the transplanting cultural method, the seeding is practised after plowing, harrowing, and puddling. The seeding is done by using a hand-seeder (octopus-shaped seeder) or a hand-drill-seeder. In recent years, a power seeder (Photo. 7-1) has occa-

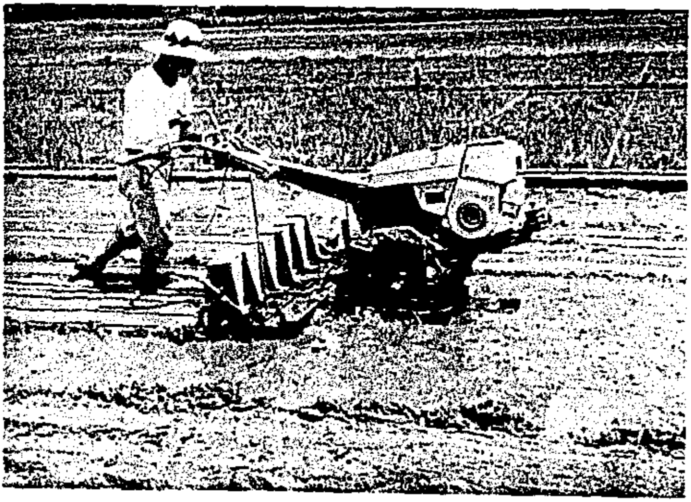


Photo. 7-1. Direct-Sowing Operation with a Small-Type Power Seeder on a Submerged Field

Photo. 7-2. Direct-Sowing Operation with a Large-Type Power Seeder (15 HP Tractor) on a Drained Field

Photo. 7-3. A View of the Rice Plants grown from Directly Sown Seeds
(At the Heading Stage)

sionally come into use. No great difference is found in the operation after sowing from that in the case of the transplanting cultural method. However, it is better to keep fields in the deeply submerged state for about one month after seeding from the viewpoint of bird damage control and weed emergence control.

Direct-sowing on cropless dry fields: This method is prevailing in the warm areas, the Kanto District and westward. Plowing, harrowing, and seeding being carried out in the upland (drained) state, all the operations can be mechanized. Seeding is, in most cases, done by using a small type power seeder, but with a view to improving the labor productivity, a large-type power seeder (Photo. 7–2) will be brought into wide use in the future. Under this method a field is generally kept in the upland state until the time when the seedlings have developed some five leaves, and afterwards a field is brought under submergence. However, in the case of irrigation-water deficient areas, the upland state period is prolonged more. The growth of rice plants at the heading stage is as given in Photo. 7-3.

Direct-sowing between the rows of wheat, barley, and other crops: This method is practised chiefly in the warm areas, as is the case with the direct-sowing on the drained fields. Above all, the direct-sowing between the rows of wheat or barley crop is practised most widely. Under this method, seeds are sown between the rows of wheat or barley crop, and after wheat or barley has been harvested the fertilizers are applied and the field is brought under submergence. As a result, during the earlier growth stage, the growth of seedlings grown between the rows of wheat or barley is poorer than the growth of seedlings sown on the cropless field, but after the submergence the growth of rice plants becomes increasnigly vigorous.

The above-stated features are clearly recognized, but the studies in the past are rather poor, and many a problem in relation to the seeding rate, spacing, fertilizer application, and rice varieties remain still unsolved. Basing upon the past experiment results, the direct-sowing on submerged fields and drained fields will be explained in this Chapter.

1. Germination, Emergence, and Young Plant Standing

In order to obtain the uniformity in seed germination and seedling growth, it is required to sow the seeds of high germination rate. For this purpose, seed selection and seed disinfection are of importance. For instance, as given in Fig. 7–1, seeds infected by diseases are markedly lower in the germination rate than in the case of healthy seeds. However, when the seeds are disinfected, the germination rate is nearly as high as that in the case of healthy seeds.

From the viewpoint of operations, in the case of a direct-sowing on submerged fields, if the levelling and puddling are unsatisfactory, it would be hard to obtain the uniform water depth after submergence, and the uniform seedling-stand would not result. In view of this, the levelling and puddling operations must be carried out carefully so that the field surface may be even and smoothed out.

In the case of a direct-sowing on dry fields, the seed germination and the growth of seedlings are affected greatly by the fineness of the harrowing and the depth of soil-cover. As given in Fig. 7–2, it is evident that when the soil-cover is too deep, the seed germination would be delayed, and, as shown in Table 7–1, the growth at the earlier stage would become slowed down. Therefore, when the seeds are covered with well-crushed soil at the depth of about two centimeters and pressed lightly, the seeds will germinate well and the seedlings grow uniformly. Moreover, if the soil becomes too wet after seeding, the germination would be affected seriously. Therefore, the invasion of irrigation water from the neighboring fields must be prevented, and the rain water must be drained so that it may not stay after rainfall.

2. Seeding Density and Method of Seeding

In direct-sowing, roots of seedlings are not cut because

Fig. 7-1. Seed Disinfection and Seed Germination Rate (Chugoku Agr. Exp. Sta., 1949)

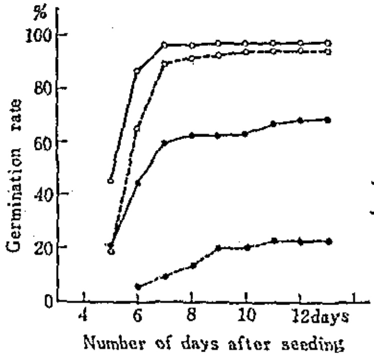


Fig. 7-2. Effect of Depth of Seeding on Seed Germination Rate (Kanto-Tosan Agr. Exp. Sta., 1952)

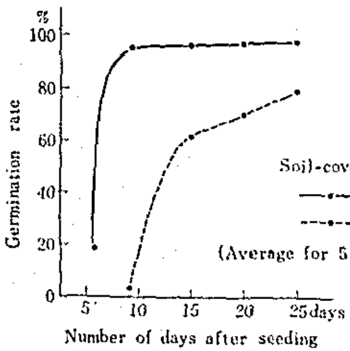


Table 7-1. Depth of Soil-Cover and Plant Height (Kyushu Agr. Exp. Sta., 1961)

Depth of soil coverage	*Plant height (seedlings)*
0-1.0 cm	9.8 cm
1.1-2.0	10.3
2.1-3.0	10.0
3.1-4.0	7.7
4.1-5.0	3.8

Note: Test for drill seeding.

seedlings are not pulled out for transplanting. Owing to the shallow depth of seeding, tillers develop from the lower nodes. It will show more increase in the number of tillers and panicles than in the case of transplanting cultural system. However, it will show decreases in the number of spikelets per panicle and in the panicle weight. As a result, in order to obtain the high yields of rice by means of a direct-sowing cultural method, it is required to adopt the spacing and arrangement of stand by which a goodly number of panicles may be secured to a certain extent and the panicle weight may not be decreased. This problem is at present under study. The past experimental results show that the dense seeding is more advantageous from the yield viewpoint.

Table 7-2. Seeding Density Test in Direct-Sowing on Cropless Fields (TAKAHASHI and SHIBUSAWA, 1947–49)

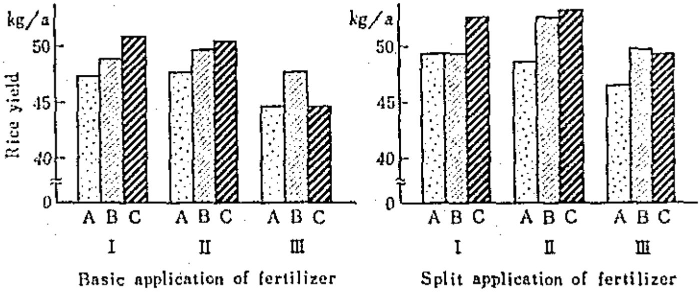
Plot	*Spacing*	*Number of hills per m²*	*Number of panicles per m²*	*Rice yield*	*Yield percentage*
	cm	hill	panicle	kg/are	%
1st plot	30×18	18.2	188	38.8	100.0
2nd plot	45×6	36.4	212	41.2	106.2
3rd plot	45×3	72.7	264	44.9	115.6
4th plot	12×12	72.7	248	43.3	111.5

Note: Figures indicate the 3-year average.
Number of seedling per hill is one seedling.

As seen in Table 7-2, up to 72.7 hills per sq. meters, the closer the spacing, the more the number of panicles and rice yield. However, there is a limit to the density of seeding. Generally speaking, at the earlier stage of plant growth period, the amount of CO_2-assimilation and dry matter production per unit field area will be increased as the density of seeding becomes higher, but when the plant growth proceeds, plants will become impossible to be exposed to the sunlight to a full extent, owing to the over-luxuriance of plants and it will sometimes show a decrease in the amount of CO_2-assimilation and dry matter production, as compared with the case of a sparse sowing. Particularly this tendency will be remarkable when the climatic condition at the later growth stage is unfavorable. However, such tendency will vary according to the arrangement of stand. For instance, as given in Fig. 7-3, in the case of dibbling and drill seeding, it shows an increasing trend in rice yield according as the seeding rate or seeding density increases, but in the case of broadcasting, the yield does not always show an increase with the high seeding rate. Particularly, on the basic application of fertilizer plots (plots to which fertilizer has been applied before seeding), as the initial growth is great, over-luxuriance damage will occur readily and no increase in yield was

Fig. 7-3. Results of Experiment on Seeding Density and Seeding Method

(Kanto-Tosan Agr. Exp. Sta., 1961)



Seeding method	*Seeding rate per m²*	*Between rows*	*Between hills*	*Number of seeds per hill*
	seed	cm	cm	
I Dibbling	A 100	20	20	4
	B 200	14	14	4
	C 400	10	10	4
II Drilling	A 100	20		
	B 200	14		
	C 400	10		
III Broadcasting	A 100			
	B 200			
	C 400			

observed by a dense seeding. Moreover, the yield by broadcast is lower than that by dibbling or drill seeding. Therefore, the stand arrangement with wider spacing between rows and within row, such as dibbling and drilling, can benefit the yield when the seeding rate is very high.

3. Fertilizer Application

Fertilizer application in the direct-sowing on submerged fields is similar to that in the transplanting cultural method.

In the direct-sowing on dried fields, phosphorus and potassium fertilizers are safely applicable before seeding, but the split application is more advantageous with nitrogenous fertilizer, i.e., it is generally accepted that 20–30 per cent of the total nitrogen is applied at the seeding time and the rest is applied immediately before submergence. The reason lies in the fact that when much quantity of nitrogenous fertilizer is applied the nitrification is quickened during the period in which the field is kept in the upland (drained) state, and

Table 7–3. Effects of Nitrogenous Fertilizer on Rice Yield, according to the Time for Application (WATANABE and KOKUBU, 1949)

Time of application of ammonium sulfate	*Nitrogen application (kg/are)*					*Rice yield (kg/are)*
	Before seeding	*2 weeks before submergence*	*1 week before submergence*	*Immediately before submergence*	*At a time of booting*	
2 weeks before submergence	0.19	0.38	0	0	0.19	36.0
1 week before submergence	0.19	0	0.38	0	0.19	38.9
Immediately before submergence	0.19	0	0	0.38	0.19	39.9
No basic application, but applied heavily immediately before submergence	0	0	0	0.57	0.19	37.3

consequently the denitrification and leaching of nitrogen after submergence is accelerated, thus resulting in the lower yield with longer period of upland state (Table 7-3). Moreover, in the direct-sowing on dry fields, water percolation after submergence is great because no puddling operation is carried out unlike the direct-sowing on submerged fields. With the loss of water by percolation, nitrogen will be leached away. Therefore, when fertilizer is applied immediately prior to submergence, it is better to mix fertilizer thoroughly with soils or to cover fertilizer with soils.

4. Irrigation Water Control

In the case of a direct-sowing on submerged fields, it is profitable to keep a field under deep submersion (10 centimeters in depth) for about one month after seeding for the purpose of avoiding bird damage or of weed control. The subsequent practices are as in the case with the transplanting cultural method.

In the case of a direct-sowing on dry fields, fields being kept in the upland (drained) state at the earlier plant growth stage, it is important to submerge timely. The past experiment results indicate that there were some instances in which no decrease in the rice yield was observed even if the fields were kept in the upland state until the young panicle formation stage. However, it is general to submerge after the seedlings have developed some 5 leaves. In this case, if fields were converted suddenly from the upland state into the submerged state, the plant growth would sometimes be checked for a while. Such phenomenon is considered to be ascribed to the fact that when fields are submerged the soils are suddenly brought into the reductive state and the plants which have rooted at the oxidized state during the upland state period have become impossible to adapt to the reduction. On the other hand, when the soils are brought in the reductive state by the submergence, nitrate is changed to nitrite, which exerts ill effect on rice plants. Therefore, in converting the drained state to the submerged state, it is better to do so when the soils are wet after the rainfall or to irrigate little by little and then to bring into the submerged state. By doing so, the above ill effect could be eliminated.

5. Weeding

In the case of a direct-sowing on submerged fields, the germination of rice seeds and the emergence of weeds take place almost at the same time. Therefore, weed control at the early stage is important. For the weed control, the field must be submerged at some 10 centimeters deep for about one month after seeding and herbicides such as PCP, BPA, etc. are required to be applied. Thus the weed control at the early growth stage can be attained. After the end of deep

Table 7-4. Comparison of Rice Cultural Labor Requirements between Transplanting and Direct-Sowing (in Cropless Fields) Systems

(In Saitama, 1961)

Operation	*Hours required per 10 ares*		*Remarks*
	Trans-planting	*Direct-sowing in cropless fields*	
Compost spreading	1.10	1.10	750 kg
Plowing	2.40	2.40	Power-tiller is used.
Harrowing	—	0.40	Hand-tractor is used, one time only.
Puddling	1.20	—	Hand-tractor is used, four times repeatedly.
Fertilizer application	0.35	0.35	Broadcasting
Drill-sowing	—	1.20	3-row drilling
Transplanting	14.00	—	
CAT spraying	—	0.25	Power-sprayer
PCP spraying	0.50	0.50	Hand spraying
2, 4-D spraying	0.30	0.30	Power sprayer
Barnyard grass pulling-up	1.40	3.20	By hands
Fertilizer application at time of booting	—	0.40	By hands
Total	22.45	12.10	Labor requirements before harvesting, excluding those for rice-nursery
Ratio	100.00	53.90	

submergence period, 2,4-D or MCP is sprayed at the middle or later tillering stage. Thus, the efficient weed control is possible by the use of herbicides.

In the case of a direct-sowing on dry fields, the fields at the early stage being kept in the upland state, weeds grow well. As a result, the rice yields will be markedly affected adversely by the failure in timely weed control. In the past, the general weed control system was: spraying of PCP or CAT immediately after seeding; hand-weeding or weeding by implement before submergence; weeding by implement immediately after submergence; and spraying of 2,4-D or MCP at the middle or later tillering stage. In recent years, however, it has become evident that DCPA is very effective in the control of barnyard grass or annual weeds during the dry field period. As a result, the weeding system in the future will come to be established basing upon DCPA application during the dry field period, PCP application immediately after submergence, and the application of 2,4-D or MCP at the middle or later tillering stage.

6. Labor

Greater significance of the direct-sowing rice cultural practice is found in the improvement in labor productivity than in the high yielding purpose. In the case of a direct-sowing system, there is no peak labor season like transplanting season peculiar to the transplanting cultural system, and the mechanization of plowing, harrowing, or seeding operations becomes possible. As a result, labor can be saved to a considerable extent (Table 7-4).

7. Rice Yield

It can not hastily be judged which is higher in yield, a transplanting cultural practice or a direct-sowing cultural practice. The highest yield could be obtained when rice plants are cultured by the cultural methods suited best to the respective areas. At any way, both the past experimental results and farmers' experiences indicate that no appreciably great difference in rice yields is found between transplanting and direct-sowing cultural practices. In habitually drought areas or water deficient areas, the transplanting cultural practice often shows a decrease in yield due to the delayed transplanting of rice seedlings. In such areas, there are many instances in which more rice yields have been obtained than the transplanting cultural practice, because the seeding can be done timely.

II. LOWLAND AND UPLAND ROTATIONS

1. Meaning of Lowland and Upland Rotations

Lowlands (paddy fields) are generally submerged in summer months and planted to rice. In winter months, however, single-cropping fields (where the double-cropping is not permitted due to the cold climate) and ill-drained paddy fields even in warm areas are generally laid in fallow. In the case of dry fields where double- or triple-cropping practices are permissible, paddy fields are drained in winter months and planted to wheat, barley, rape-seeds, or vegetables. In the southernmost parts of Japan, rice is planted twice a year although the acreage is not large. In either case, it is general that paddy fields are planted to rice every year. However, paddy fields are sometimes drained for several consecutive years and planted to upland crops, and thereafter the fields are brought again under submerging irrigation in summer months for several consecutive years to grow rice again. Such lowland-upland alternation with several-year-period for each is known as "lowland and upland rotations."

2. Types of Lowland and Upland Rotations

The lowland and upland rotation practices are at present prevalent over the nation, though small in the total acreage. The land rotation practices prevalent in Italy can be cited as the most well-known case in point. In Italy, under a 3–9 year rotation system, pastures are planted on the drained land. Such land rotations are found also in the USA, the USSR, India, and Java. In Japan also, the lowland and upland rotation system has been practised since the fairly olden times. The rotation system is divided into the following three types.

(i) Pastures in rotation (this type is found mostly in Europe and America).

(ii) Sugar canes and other industrial crops in rotation (mostly in the tropical or subtropical zones).

(iii) Horticultural crops in rotation (mostly in Japan).

In Japan, type (i) rotation practice also is becoming popular in recent years.

3. Effects of Lowland and Upland Practices

1. Increase in the yields of upland crops

In case where lowlands are converted to the uplands, if water is drained to the full extent, most of the upland crops could be planted. It would show no decrease in the crop yields, but rather show an increasing trend, as compared with the crop yields in ordinary uplands, except for the case of extremely heavy clay soil paddy fields. The comparison of crop yields between converted uplands and ordinary ones is shown in Table 7-5 and 7-6. The crop yields in the converted uplands are, in most cases, higher than those in ordinary uplands. However, in the first year of upland period, it is unprofitable

Table 7-5. Crop Yields in the Converted Uplands (At Tono)

Year	*Number of years after conversion to upland*	*Name of crops*	*Crop yield per 10 ares*	*Index (crop yield in ordinary farm=100)*
	year		kg	
1948	1	White potatoes	1,250	67
1950	3	White potatoes	2,190	109
1948	1	Barnyard millet	216	133

Table 7-6. Crop Yields in Converted Uplands
(At Tamai)

Crop sequence	Crop	Crop yields per 10 ares				Ratio to crop yields in ordinary uplands			
		1948	1949	1950	Average	1948	1949	1950	Average
		kg	kg	kg	kg				
Soybeans	Soybeans	210	182	224	205	150	130	186	152
-barley	Barley	454	398	467	440	98	96	128	108
Maize (corn)	Maize	289	382	382	350	102	101	116	106
-barley	Barley	480	426	449	452	101	107	124	111

for tuber crops because soils are liable to become hardened. Table 7-5 indicates that the potato yield in the first year (1948) is less than that in the ordinary upland. However, the crop yields are becoming increased according as the soil becomes to have a character of upland soil.

2. *Increase in rice yield*

Rice plant growth in the reconverted paddy field in the first year after reconversion from the upland is far more vigorous than that in the continuous rice cropping field. Namely, the rooting of seedlings after transplanting is very rapid and the subsequent plant growth is excellent, i.e., rice plants are superior to those in the continuous rice cropping field in the plant height, the number of stems, and the leaf color. It shows a 20–50 per cent increase in the rice yield over that in the continuous rice cropping field. The rate of increase in yield varies according to the soil property, duration of upland period, and kinds of upland crop grown. In general, the rate is high in case where soil contains much organic matter, upland period is long, and deep-rooted or requiring deep-plowing crops have been planted. The increasing rate of rice yields in the reconverted paddy field is highest in the first year after reconversion and shows a decreasing trend in the second year and the third year in order. Accordingly, it is better to convert the paddy fields again to uplands after some consecutive years. Rice yields in the re-

Table 7-7. **Brown Rice Yields in the Reconverted Lowlands**
(At Konosu)

(kilograms per 10 ares)

Plot	*Years for upland cropping* / *Upland crops during upland period* \ *Years after reconversion*	*3 years*			*2 years*			*1 year*		
		1 year	*2 years*	*3 years*	*1 year*	*2 years*	*3 years*	*1 year*	*2 years*	*3 years*
Fertilizer application	Soybeans-Wheat	546.0	496.5	441.8	496.5	425.3	410.6	480.8	432.0	391.5
	Sweet potato-Wheat	569.3	482.3	436.5	525.0	453.8	404.6	459.0	414.8	389.3
	Red clover	544.5	504.8	453.8	536.3	453.0	408.0	—	—	—
	Soybeans-Rape seeds	576.0	481.5	438.8	538.5	429.8	408.0	493.5	410.3	374.1
	Sweet potato-Horse beans	566.3	490.5	432.6	544.5	451.5	401.0	522.8	400.5	390.0
	Soybeans-Barley	579.8	489.8	433.8	513.8	453.0	397.5	—	—	—
Non fertilizer application	Soybeans-Wheat	436.5	332.3	247.5	353.3	261.8	217.2	293.3	238.5	196.5
	Sweet potato-Wheat	509.3	324.0	263.3	397.5	279.8	230.6	316.5	246.0	209.6
	Red clover	504.0	350.3	296.7	417.0	251.3	212.3	—	—	—
	Soybeans-Rape seeds	453.8	327.8	255.8	356.3	272.3	216.3	334.5	238.5	194.1
	Sweet potato-Horse beans	510.8	314.3	259.0	426.8	258.8	198.5	404.3	234.8	209.7
	Soybeans-Barley	442.5	314.3	270.3	353.3	268.5	210.8	—	—	—

	Plot	1 year	2 years	3 years
Continuous rice cropping lowland	Fertilizer applied plot	474.8	427.5	404.6
	Non-fertilizer applied plot	273.8	252.0	217.5

Table 7 – 8. Brown Rice Yield Index

Plot	Years for upland cropping / Years after reconversion / Upland crops duringd upland period	3 years			2 years			1 year		
		1 year	2 years	3 yevrs	1 year	2 years	3 years	1 year	2 years	3 years
Fertilizer application	Soybeans-Wheat	115	116	109	105	100	102	101	101	97
	Sweet potato-Wheat	120	113	108	111	106	100	97	97	96
	Red clover	115	118	112	113	106	101	—	—	—
	Soybeans-Rape seeds	121	113	109	113	101	101	104	96	93
	Sweet potato-Horse beans	119	115	107	115	106	99	110	94	96
	Soybeans-Barley	122	115	107	108	106	98	—	—	—
Non fertilizer application	Soybeans-Wheat	159	132	114	129	104	100	107	95	90
	Sweet potato-Wheat	186	129	121	145	111	106	116	98	96
	Red clover	184	139	136	152	100	98	—	—	—
	Soybeans-Rape seeds	166	130	118	130	108	100	122	95	89
	Sweet potato-Horse beans	187	125	119	156	103	91	148	93	96
	Soybeans-Barley	162	125	124	129	107	97	—	—	—

Note: Brown rice yields in the continuous rice crop ping lowland in Table 7–7 are represented by 100.

converted paddy field as affected by the period of upland state and the years after reconversion to lowland are shown in Tables 7–7 and 7–8.

3. Increased yields of the winter crops grown in the reconverted lowlands

The growth of wheat and barley crops planted in the reconverted lowlands is, in most cases, more vigorous than that of wheat and barley crops planted in the continuous rice cropping lowland and it shows increased yields. Table 7–9 is cited as an example.

Table 7–9. Yields of Wheat Crops (as Succeeding Winter Crops to Rice) Grown in the Reconverted and Continuous Lowlands (At Shimoina)

Lowland	*In the first year (1951) of reconversion*				*In the second year (1952) of reconversion*			
	Plant height	*Number of panicles in 50 cm distance*	*Seed weight per 10 ares*	*Index*	*Plant height*	*Number of panicles in 50 cm distance*	*Seed weight per 10 ares*	*Index*
Continuous	83	71	264	100	67	96	244	100
Reconverted	87	73	370	140	64	121	251	103

Notes: 1. Upland cropping years lasted 3 years.
2. In the case of the reconverted lowland, soybeans and wheat crops have been grown during the upland period.

4. Decrease in weed emergence

When the land rotations are practised, it shows a decrease in weed emergence both in the upland cropping years and the rice cropping years after reconversion. As a result, the weeding labor can be saved much. Repeated conversion from lowlands to uplands and from uplands to lowlands, implies a great change in environmental conditions. The decrease in the weed emergence is ascribed to the death or decrease of hydrophytic weeds and hygrophytic weeds closely akin thereto during the upland period, as well as to the death or decrease of mesophytic weeds and hygrophytic weeds closely akin thereto during the lowland period. Table 7-10 indicates that in the first year of the converted upland period, the weed emergence, particularly the mesophytic weed emer-

Table 7-10. Weed Emergence in the First Year after Conversion to Upland (At Konosu)

Kind of weeds / *Crops* / *Plots*	*Soybeans*		*Red clover*	
	Ordinary upland	*Converted upland*	*Ordinary upland*	*Converted upland*
	g	g	g	g
Mesophytic weeds	11.7	2.0	33.9	3.3
Hygrophytic weeds	4.6	6.5	1.5	3.8
Hydrophytic weeds	0	0.8	0	12.1
Unknown weeds	1.5	0.8	1.2	1.5
Total	17.8	10.1	36.6	20.7

Note: Sampled on Aug. 6. Figures are represented by air-dry weight per 3.3 m².

Table 7-11. Weed Emergence in the Reconverted Lowland in the First Year after Reconversion to Lowland (At Konosu)

Kind of weeds / *Plot* / *Preceding crop*	*Continuous lowland*	*Upland period (years)*					
		3 years		*2 years*		*1 year*	
	Rice-Wheat	*Soybeans-Wheat*	*Sweet patato-Wheat*	*Soybeans-Wheat*	*Sweet potato-Wheat*	*Soybeans-Wheat*	*Sweet potato-Wheat*
Hydrophytic	1,123	239	480	261	581	462	574
Hygrophytic	186	69	93	71	101	105	113
Total	1,309	308	573	332	682	567	687

Note: Sampled on July 25. Figures indicate the number of weeds per 3.3 m².

Table 7-12. Changes in Weed Emergence in the Reconverted Lowland after Reconversion
(At Konosu)

(Number of weed plants per 3.3m²)

	*Rice seasons**			*Winter seasons***		
	1951	*1952*	*1953*	*1951*	*1952*	*1953*
(Number of years after reconversion)	*1 year*	*2 years*	*3 years*	*1 year*	*2 years*	*3 years*
Continuous lowland (A)	1,344	1,251	2,007	2,284	9,726	8,477
Reconverted lowland (B)	525	1,169	1,944	177	3,832	8,287
(B/A)	39	93	97	8	39	98

Notes: * Measurement on July 25.
** Average of measurement in early-December and late-March.

gence, in the converted upland is less than that in the ordinary upland. And as shown in Table 7-11, weed emergence in the reconverted lowland in the first year is less than that in the continuous rice cropping lowland, and it shows a decreasing trend in weed emergence with the longer upland period. However, the weed emergence is increased according as years after reconversion proceed (Table 7-12). As a result, from the viewpoint of weed control also, it is preferable to return the reconverted lowland to upland again within a certain period of years.

5. *Changes in soils*

(a) Physical changes

When lowlands are converted to uplands, lands are kept in the state of uplands in summer, and as the dehydration of soil colloid will be promoted, the lands would not readily be restored to normal lowland state even if irrigated. The soil becomes less adhesive, less sticky, and lower in moisture holding capacity. Even after reconverted to the lowland, the soil will be liable to dry, if the water is drained. Table 7-13 indicates the soil moisture at one month after drainage in autumn. The moisture content in the reconverted lowland soil is less than that in the continuous rice cropping lowland, and the logner the upland period, the less the soil moisture content. And as shown in Tables 7-14, 7-15, and 7-16, the reconverted lowland soils become easily plowed due to the

Table 7-13. Soil Moisture Content at One Month after Drainage (At Yamagata)

Contiunous lowland		44.0 %
Reconverted lowland	1 year upland period	42.0
	2 year upland period	39.9

Table 7-14. Effect of Lowland-Upland Rotation on the Soil Cohesion (At Konosu)

Date \ Plot		*Continuous lowland (Paddy rice-Wheat)*	*Soybeans-Wheat*	*Sweet potatoes-Wheat*
		kg	kg	kg
Upland period	Sept. 1949	22.3	16.7	19.9
	Apr. 1950	22.3	16.0	19.6
	Sept. 1950	16.3	12.5	13.9
Lowland period	June 1951	10.4	9.0	8.7
	Dec. 1951	17.2	12.9	13.0
	Nov. 1953	17.8	14.2	14.3

Note: Measurement was made on the "3-year upland period plot".

Table 7-15. Effect of Lowland-Upland Rotation on the Hardness of Soils (At Konosu)

Date \ Plot		*Continuous lowland (Paddy rice-Wheat)*	*Soybeans-Wheat*	*Sweet potatoes-Wheat*
		mm	mm	mm
Upland period	Dec. 1950	6.48	2.52	3.84
Lowland period	June 1951	4.80	3.68	1.52
	Dec. 1951	6.40	4.64	5.78
	Dec. 1953	9.20	8.32	8.96

Note: Measurement was made on the "3-year upland period plot" by using YAMANAKA's soil hardness tester [reading (in mm) of 8 kg-panel tester].

Table 7 – 16. Effect of Lowland-Upland Rotation on the Draft Resistance of Soil
(At Konosu)

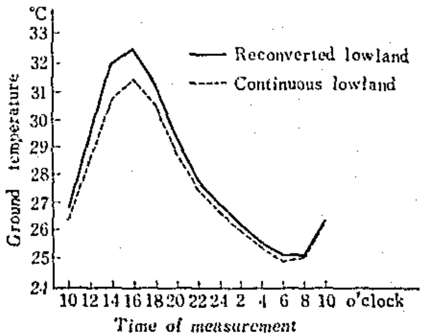
		Draft resistance	Index
Continuous lowland, Rice-Wheat		kg 1.5	100
3-year upland period plot	Soybeans-Wheat	1.2	80
	Sweet potatoes-Wheat	1.0	67

Note: Measurement was made in the wheat stands in the third year of the upland period.

lowering in the soil cohesion, hardness of soils, and draft resistance.

When the upland period lasts longer, small pore spaces or cracks will appear in the soil, and as a result, the water permeability and the transmission of heat accompanied with the downward movement of water are promoted in the reconverted lowland soil. Fig. 7-4 indicates that the soil-temperature of the reconverted lowland is higher than that of the continuous lowland, particularly marked at about

Fig. 7 – 4. Ground Temperatures of Reconverted Lowland and Continuous Lowland
(At Konosu)



Note: Ground-temperature at the depth of 5 cm in the second year after reconversion to lowland after 3-year upland period.

2 o'clock p.m.

(b) Chemical changes

During the upland period, the soils are kept under the well-aerated condition, particularly due to the exposure to high temperature in summer in several years, the decomposition of soil organic matter is promoted and humus content will usually become decreased. Table 7–17 indicates the decreases in the total carbon contained in the various soils which were placed in the glasshouse during 12 months under the upland condition. In this case, since the humus of stable form is increased, little change will be found in the base exchange capacity, though the humus content decreases (Table 7-18).

Viewed from the changes in NH_3-N originated from the decomposition of organic matter in soils, "the effect of soil-drying" and "the effect of temperature raising" are, in most

Table 7 – 17. Decrease in Total Carbon Content in Soils Kept under the Upland Condition
(At Konosu)
(% per 100 grams of dry soil)

Soil	*Lowland condition*	*Upland condition*
Konosu	2.69	2.48
Tamai	1.37	1.33
Kita-takanesawa	7.14	7.00

Table 7 – 18. Changes in the Base Exchange Capacity in Soils Kept under Upland State
(At Konosu)

Soil	*Lowland condition*	*Upland condition*
Konosu	m.e. 20.3	m.e. 19.4
Tamai	13.0	13.5
Kita-takanesawa	17.8	18.2

Note: Measured by SCHOLLENBERGER Method.

cases, lower in the reconverted lowland field than in the continuous lowland field, because the former contains less readily-decomposable organic matter (Table 7–19).

Table 7–19. "Effect of Soil-Drying" and "Effect of Temperature Raising" as Influenced by Lowland-Upland Rotation (At Konosu and Yamagata)

(*mg of NH^3–N per 100 g of dry soil*)

Place	*Effect of soil drying*		*Effect of temperature raising*	
	Continuous lowland	*Reconverted lowland*	*Continuous lowland*	*Reconverted lowland*
Konosu	6.1	5.0	3.6	3.0
Yamagata	18.6	14.7	12.9	10.0

Note: Reconverted lowland field after 3-year upland period.

However, under the natural condition, the soil of the reconverted lowland field is easily dried for a further extent than the soil of continuous lowlands. As a result, the actually mineralized amount of nitrogen becomes larger in the case of the former. Therefore, a larger amount of nitrogen becomes available to crop. It is particularly remarkable in the first year after reconversion to lowland. Therefore, it is sometimes better to reduce the amount of nitrogen fertilizers to be applied.

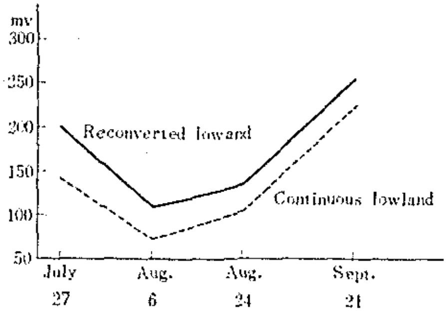
Due to the lower "effect of temperature raising," the mineralization will not be accelerated even at higher temperatures in summer and accordingly there will be no fear for delay in growth in the later growth period. Thus the rice growing can be stabilized.

As described before, in consequence of lowland-upland rotation, cracks in the soil will appear, the soil will become more permeable to water, and readily-decomposable organic matter will decrease. Accordingly, even after submergence it will give rise to less deficiency in oxygen. The oxidation-reduction potential in the reconverted lowland soils is generally higher than that in the continuous lowland soils (Fig.

7–5).

To sum up, both the physical and chemical properties of soils become improved by the rotation practices, making the environmental conditions better for the rice plant growth, and the rice yield will be raised.

Fig. 7 – 5. Oxidation-Reduction Potential in Reconverted and Continuous Lowland



6. *Labor-saving effect*

At the initial year of the converted upland, it sometimes will take much more labor for plowing and harrowing, than in the case of an ordinary upland, particularly in the case of heavy clay soils. But according as the years after conversion pass, it will become similar to the case of an ordinary upland. As mentioned above the weeding labor can be saved much in the converted upland field as compared with the case of ordinary uplands. As a result, even though the labor for plowing and harrowing is required somewhat much, the total labor requirement can be saved, as shown in Table 7–20.

In the case of the reconverted lowlands, the labor requirements can be saved much because it will take less time for plowing and harrowing owing to the loosened soils, particularly in the first year after reconversion, as shown in Table 7–21.

Table 7-20. **Plowing, Harrowing, Intertillage and Weeding Labor in Converted and Ordinary Uplands (Hokkaido, 1947)**

Upland	*Plowing*	*Harrowing*	*Intertillage and weeding*
	prs.	prs.	prs.
Ordinary	2.7	3.5	9.6
Converted			
In the first year	3.5	5.3	1.4
In the third year	3.0	3.0	2.0

Notes: 1. Crop grown: White potatoes.
2. Figures indicate the required number of laborers per 10 ares.

Table 7-21. **Plowing, Harrowing, Intertillage and Weeding Labor in Reconverted and Continuous Lowlands (Hokkaido, 1948)**

Lowland	*Plowing and harrowing*	*Intertillage and weeding*
	prs.	prs.
Continuous	9.2	34.9
Reconverted		
In the first year	3.3	21.0
In the third year	8.8	26.7

Note: Figures indicate the required number of laborers per 10 ares.

4. Conclusions

Lowland and upland rotations are, as stated above, the recommendable land utilization devices, but a further study is required from the broader viewpoint of a new paddy field cropping system as the paddy field management improvement measures, without sticking merely to the increased production of the respective crops.

III. EARLY SEASONAL RICE CULTURE

Among the principal natural disasters incidental to the traditional ordinary seasonal rice cultural practice are: (i) cool damage during the seasons from summer to fall in Tohoku and Hokkaido, (ii) typhoon damage (followed by tidal damage) in September (heading date) in the southwestern warm part of Japan, and (iii) drought damage in August which happens throughout the country. The early seasonal rice cultural practice has the primary object to escape from the above natural disasters and to secure the stability of rice cropping. In addition, owing to the moving up of the rice growing period by the early seasonal rice cultural practice, forage crops or vegetable crops have come to be planted as the second crops after the rice harvest, which could not be done under the past cropping system: "wheat or barley—paddy rice". The early seasonal rice cultural practice is regarded as an important rice cultural practice for the purpose of intensive land use in the future. The moving up of the rice growing period contributes also toward the labor distribution because the labor peaks in spring and fall seasons are smoothed out.

Besides the above, in the early seasonal culture, the occurrence of root-rot in swampy paddy fields or *Akiochi* fields becomes less frequent and it has become clear that the rice yield will show more increase than that in the ordinary seasonal cultural practice. In the case of upland rice culture also, the early seasonal culture shows more increase in yield than that in the ordinary seasonal culture, because in the former, it is needless to refrain the heavy application of nitrogenous fertilizer for fear of drought damage. The early seasonal rice cultural practice is noteworthy as high-yielding rice cultural practice.

1. Brief History

An attempt to culture rice considerably earlier than the customary cultural season was made for the first time in Kochi Prefecture as the first crop of the two-time rice cropping in a year by making use of the newly-selected extremely early-maturing superior varieties. The early seasonal culture of early-maturing varieties which was brought into practice in order to avoid flood damage in the low swampy fields in the Tone River (in Kanto) basin was set about by the introduction of an early-maturing variety, Norin No. 1.

Subsequently, owing to the appearance of protected nursery practice, a rapid progress was made in growing seedlings under low temperature. About 1950–51 it was made clear that the early seasonal rice culture practice could be improved markedly by the use of protected rice nurseries. In recent years, owing to the appearance of efficient agricultural chemicals, particularly of organo-phosphoric compounds, it has become possible to control rice stem borers, which had checked the development of the early seasonal rice cultural practice. As a result, the early seasonal rice cultural practice has become popular with rapidity. It is expected that in the near future the extent of early seasonal rice culture area will reach about one-fourth of the total paddy field area in the southwestern warm part of Japan, including the Kanto district.

2. Cultural Methods

Among the principal rice varieties planted mostly in recent years are Norin No. 1, Norin No. 17, Ginmasari, etc. Most of these varieties are harvested in August, but when the transplanting is delayed due to the delayed harvesting of the preceding crops or due to the lack of irrigation water, the rice harvesting is done after the opening of September. Seeding is done during the dates from middle or late March to early April and seedlings are mostly grown in protected rice nurseries particulary in the protected semi-irrigated rice nurseries, and transplanted in late April to early May. Transplanting of the seedling grown in vinyl-covered non-irrigated rice nurseries become possible when the mean air temperature has reached 13–14°C.

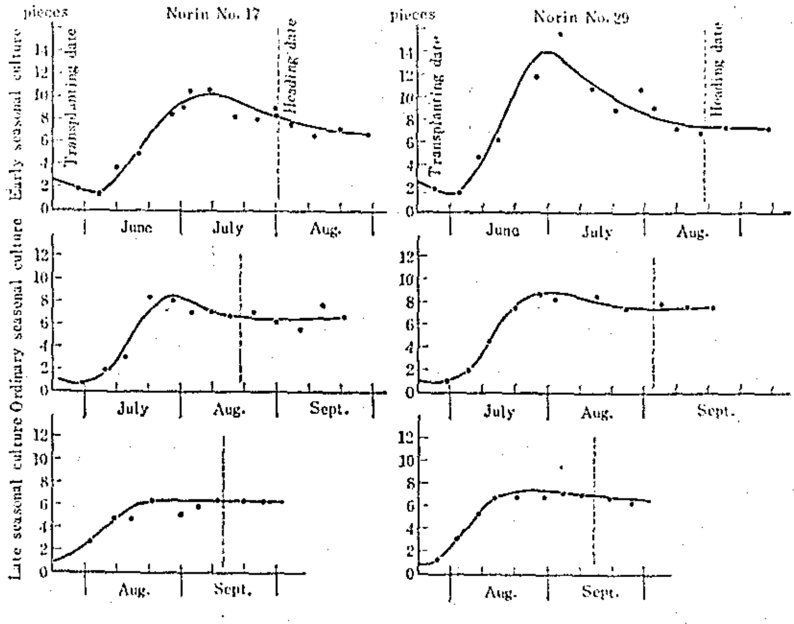
The seedlings at the time of transplanting are desired to have five leaves and to be about 30 to 40 days after seeding in the nursery. In order to quicken the rooting and tillering, seedlings are required to be planted shallowly. Seedlings are planted closer by 20–30 per cent (about 24 hills per sq. meter) than in the case of the customary cultural practice. In order to facilitate the care-taking operations. the spacing is, in most cases, fixed in a rectangular form.

The early seasonal rice culture depends upon the fertilizer application to a further extent than the ordinary seasonal culture. With moderate fertilizer application, the yield could not be raised. Particularly, the yield depends greatly upon nitrogenous fertilizers. The majority of nitrogenous fertilizer is applied as basic dressing and the remaining portion is applied in the later growth period. Phosphate fertilizers are absorbed by plants until the later growth period and the effect of phosphate application on volcanic ash soils or on the unripened field soils is great. As the rice ripens at the time of high temperature, the ripening period has become shortened considerably. Rice ripens within 30 to 35 days after heading. As there is much fear of increase in cracked kernels, rice is required to be dried gradually, instead of drying rapidly by exposing it directly to the intense sunlight.

3. Morphological Features of Early Seasonally Cultured Rice Plants

The comparison of plant growth between early, ordinary and late seasonal culture is as indicated in Fig. 7–6. In the early seasonal cultural practice, plants show no increase in the number of tillers for a while after transplanting and it takes a long time until they begin to show an increase in the number of tillers, but soon they show a rapid increase, and the number of tillers at the maximum tillers stage is the greatest among the three. Such difference in the plant growth is ascribed to the difference in the air temperature at the tillering stage. Tillers can increase in number in proportion to the low night temperature. Since the plants of early seasonal culture grow at low temperature, they show a marked increase in the number of tillers, but the percentage of valid tillers will show a decrease in proportion to the prolongation of the growth period. However, owing to the high carbohydrate content of the plants of early seasonal culture (as described later), the decrease in the percentage of invalid tillers is relatively less than in the case of ordinary seasonal culture, thus showing the better plant growth.

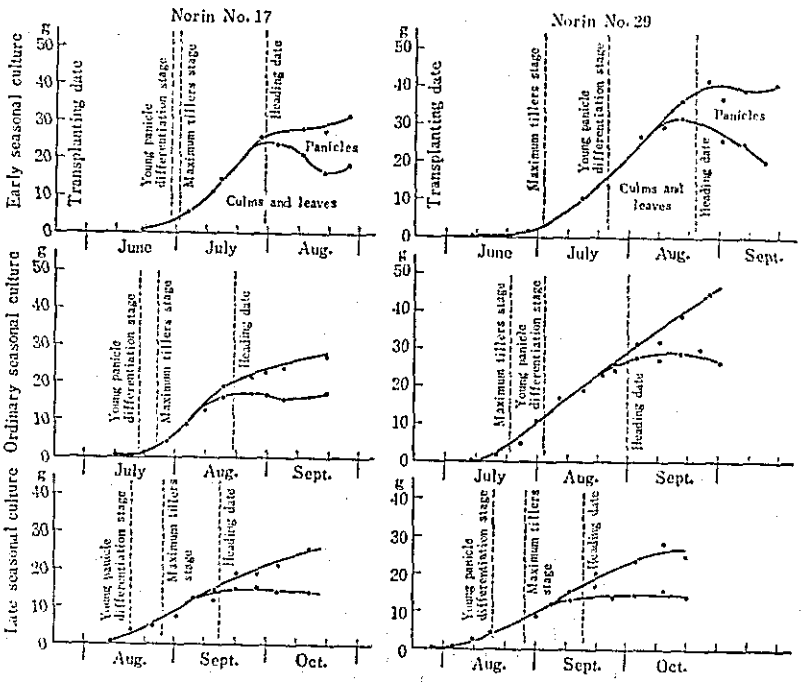
Fig. 7-6. Changes in the Number of Tillers according to the Cultural Season
(YAMADA, 1956)



Dry weight of tops of early-seasonally cultured rice increases very slowly during the period of about one month after transplanting (this period lasts longer as the transplanting date is earlier). Thereafter, it shows a rapid increase in the dry weight, showing a marked increase at the heading stage, as compared with that of the ordinary seasonal culture (Fig. 7-7).

Since the increase in the dry weight after heading varies

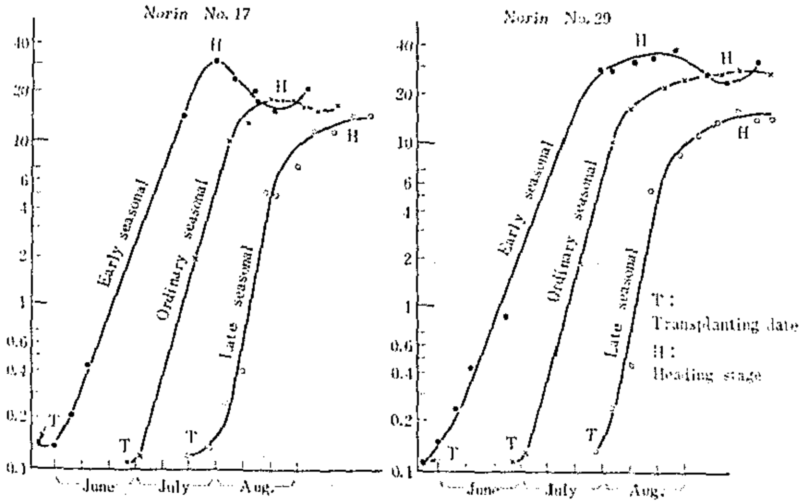
Fig. 7-7. Changes in Dry Weight of Tops during Cultural Seasons (YAMADA, 1956)



with the nutritional state of plant and sunlight intensity after heading, it sometimes will differ from that shown in Fig. 7-7. In the early seasonal rice cultural practice, however, it shows a marked decrease in the dry weight of culms and leaves after heading, indicating that the starch and sugars (the photosynthetic products accumulated much in culms and leaves) are translocated rapidly to the panicles to bring up grains. This can be regarded as a salient feature of the early seasonal rice cultural practice.

Relative growth rate of dry matter: As shown in Fig. 7-8, in the early seasonal rice culture, though the absolute quantity of dry matter is great, the relative growth rate in dry weight is rather low. On the contrary, in the late sea-

Fig. 7-8. Relative Growth Rates of Dry Matter of Culms and Leaves (YAMADA et al., 1956)



Notes: *T: Transplanting date.*
H: Heading stage.

sonal culture, the growing rate is highest, though the absolute quantity of dry matter is small. Such difference is caused by the difference in temperatures during the period of dry matter growth. Reflecting such difference in the relative growth rate as above, the composition of dry matter must be different with different seasonal culture.

4. Changes in Soil Oxidation-Reduction Potential and Root Activity in the Early Seasonal Culture

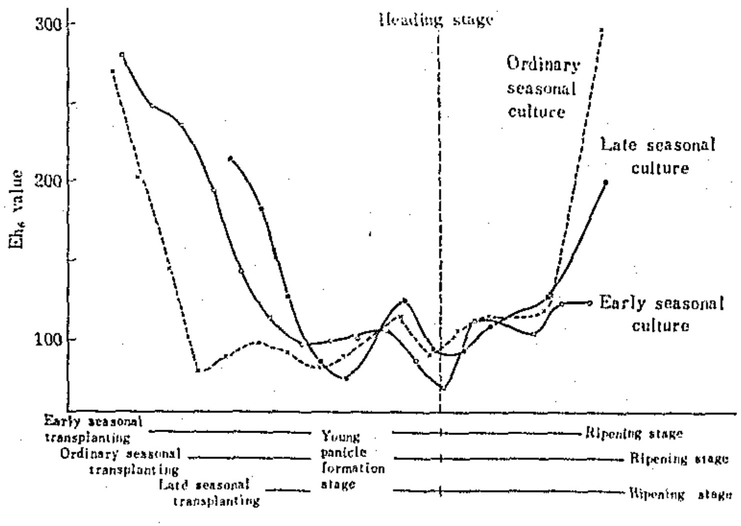
The soil oxidation-reduction potential is an indicator showing the quantity of soil oxygen and has a close bearing upon the evolution of soil fertility and the occurrence of harmful substances. Namely, the low value of oxidation-reduction potential indicates the degree of soil-oxygen-deficiency, and the formation of harmful substances, e.g., hydrogen sulfide or organic acids, and also indicates that there is a great possibility of ammoniacal nitrogen, phosphate, silicate, iron, and manganese to become available. In case where the oxidation-reduction potential is high, the reverse is the case.

In view of the above, when we consider the seasons in which paddy rice is cultivated, it is very important to clarify the relationship between the plant growth stages and the soil oxidation-reduction potential.

The period from the transplanting date to the time when the soil oxidation-reduction potential reaches a minimum is about 60 or 70 days in the early seasonal culture while it is about 30 days, and 15 to 20 days, respectively, in the ordinary and late seasonal culture. But, no appreciably great difference is found in the minimum Eh value for each case (Fig. 7–9).

Now, the relation between plant growth stages and soil oxidation-reduction potential is as follows. In the early sea-

Fig. 7 – 9. Changes in Oxidation-Reduction Potential in Paddy Field Soils (SAMOTO et al., 1959)



sonal culture, Eh value reaches a minimum toward the heading stage, while in the ordinary and late seasonal cultural practices Eh value reaches a minimum prior to the young panicle formation stage. In consequence, in the early seasonal culture, the field soil is in the comparatively oxidized state and the plants grow under the condition that the soil reduction proceeds slowly, while in the ordinary or late seasonal cultural practice, the soil reduction proceeds rapidly and the plants are forced to grow under the more reductive condition than in the case of the former.

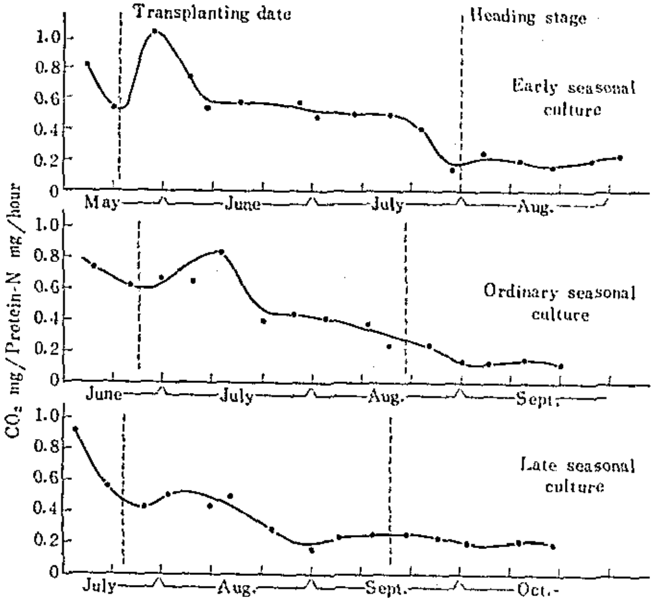
The physiological activity of roots of the rice plants grown under the above conditions can be indicated by the respiratory rate. As shown in Fig. 7–10, rice plants grown in the earlier season are higher in respiratory rate than those grown in ordinary season, notwithstanding the longer vegetative period. This is partly ascribed to the abundant supply of respiratory substrate from the tops to the roots with plants grown in the earlier season. Moreover, in the early seasonal culture, Eh value of soils being, as described above, comparatively higher, the plant roots can keep the high physiological activity, suffer little from root-rot and can absorb nutrients well. Thus high yields can be obtained even under the poor soil conditions.

5. Nitrogen and Carbohydrate Content in Rice Plants Grown in Early Season

Glucose is the first product of photosynthesis of rice plants. Out of the glucose, various carbohydrates are synthesized. On the other hand, glucose is consumed as the respiratory substrate, but a part of glucose is, in its process, used as an ingredient for synthesizing amino acids or protein by receiving nitrogen absorbed by the plant roots.

As sucrose or starch is readily reconverted into glucose, it is important for the metabolism of plant. After heading, sucrose and starch translocate from culms and leaves to panicles and contribute to the growth of kernels. Therefore, these are very important contributing elements to

Fig. 7-10. Respiratory Rate of Roots on Protein Basis (YAMADA et al., 1958)



Notes: 1. Variety: Norin 17.
2. Temperature at the measurement: 30°C.

rice yield.

The carbohydrate content becomes higher toward the end of the rice nursery stage. Particularly, a great quantity of starch is stored in leaf sheaths. When the seedlings are transplanted to the paddy field, they absorb much nitrogen from the field by developing new active roots, and show a sharp increase in nitrogen content. In order to grow by transforming the absorbed nitrogen into amino acids and then into protein, the starch reserved by the seedlings at the nursery stage is consumed rapidly, thus decreasing the starch content and almost running out toward the maximum tillers stage. Thereafter, the photosynthetic production will become relatively greater in quantity, due to the enlargement of photosynthetic leaf area, than the absorption of nitrogen.

Namely, new protein formation is on the decrease, while the photosynthetic production continues to increase. As a result, the photosynthetic product is reserved in the form of starch, at the basal portion of plant (culm and leaf sheath) and the starch acculmulation continues to increase until the heading stage. After heading, the starch thus reserved in culm and leaf sheaths is translocated rapidly to the panicles. About 25-30 days after heading, almost all the starch contained in culms and leaves will run out. Such increase or decrease of carbohydrate content is always observed though some differences take place in the content according to the difference in fertilizer application and other cultural conditions. Such change in carbohydrate content as associated to growth is the basic pattern peculier to paddy rice plants cultivated by the transplanting method.

The change in the carbohydrate contained in the rice plants cultivated in the early season can be distinguished from those cultivated in ordinary or late season in the following two points:

(i) The carbohydrate content, particularly starch content, in the rice plants cultured in early season is remarkably higher than that in the rice plants cultured in ordinary or late season. Starch content in the culm and leaf sheath portion at the heading stage is two or three times greater than that in the ordinary seasonal cultural practice;

(ii) Though the starch content in seedlings is low, it will show an increase during the period for 20-30 days after transplanting. The starch accumulation can also be observed even in the leaf blade, despite of the fact that in general starch accumulation does not take place in the leaf blade. While nitrogen content shows a decrease for a while after transplanting. This fact indicates that the photosynthetic product is accumulated for a while in the form of starch, because though the plant growth is checked by low temperature, the photosynthesis is affected relatively little by the temperature. Consequently, the changes similar to the aging of seedlings in the nursery bed take place after transplanting

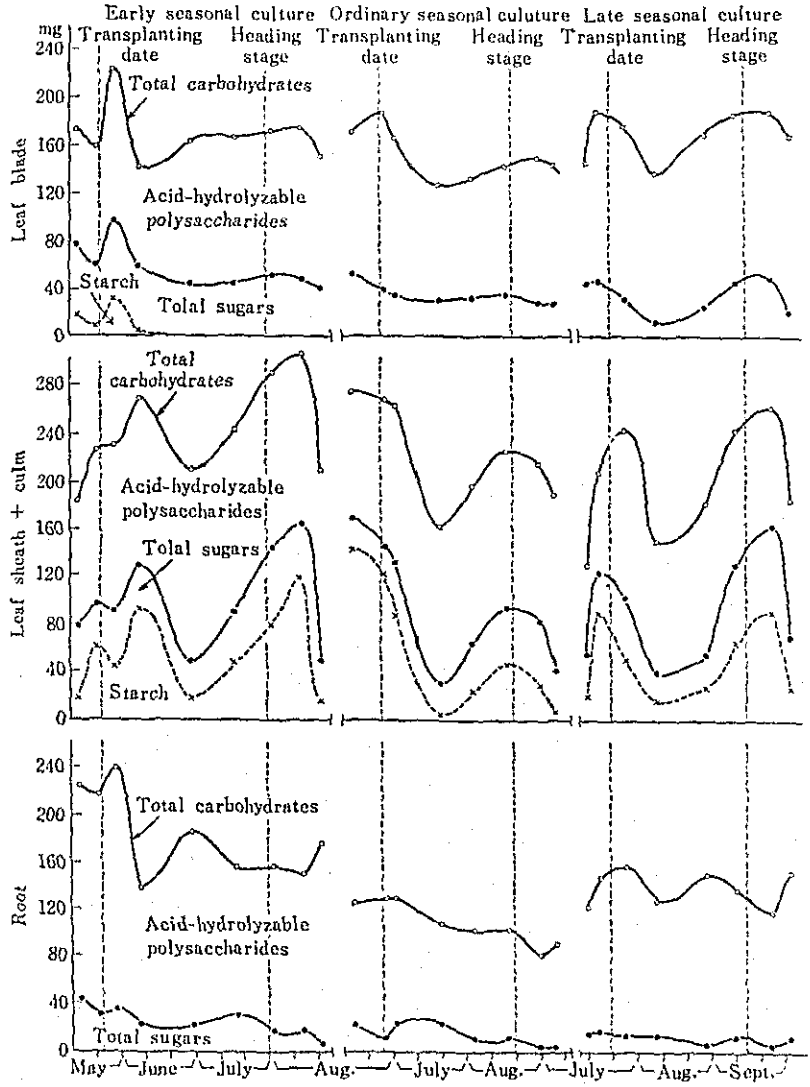
(Fig. 7-11).

Such feature of the rice plants cultured in earlier season is ascribed to the fact that the temperature in their growth period is lower than that in the growth period of rice plants cultured in ordinary season. Namely, at the low temperature, a greater portion of photosynthetic product is transformed into the cell content in the form of sugars and starch, and only a small portion is used to make up the components of cell membrane such as cellulose, hemicellulose, etc. Contrary to this, at high temperature, the portion of photosynthetic product which changes into sugars and starch becomes less, because a large amount of the product is utilized to build up cell membrane. In connection to this, the relationship between the carbohydrate content and the nitrogen content in the seedlings different on seeding dates is shown in Table 7-22. Namely, according as the seeding is done earlier, the growth in dry weight is less, but the seedlings are rich in carbohydrate and nitrogen content. While, when the seeding was made later, the growth in dry weight is of course great, but carbohydrate and nitrogen content is poor, because almost all photosynthetic product has been consumed to make cell membrane, and not to make cell content.

Table 7-22. Components of Seedlings Sown at Different Dates (Analytical results of 45-day old seedlings)

Components \ *Seeding date*		*April 15*	*May 15*	*June 14*	*July 14*
Culm height	(cm)	18.9	25.8	34.8	60.1
Dry weight	(g/plant)	0.136	0.167	0.287	0.388
Respiration rate (CO_2 mg/hr/dry weight)		5.7	3.5	2.2	2.1
Total nitrogen	(mg/g)	17.2	15.7	11.2	14.3
Reducing sugar	(〃)	15.9	10.8	2.7	6.4
Total sugar	(〃)	45.3	38.9	27.3	21.9
Starch	(〃)	153.9	122.4	98.4	35.6
Acid-hydrolyzable polysaccharides	(〃)	115.0	124.5	94.2	91.8
Total carbohydrate	(〃)	314.2	285.8	219.8	149.2

Fig. 7 – 11. Carbohydrate Content in Various Part of Rice Plant
(YAMADA et al., 1956)
(mg glucose/g dry weight, Norin No. 17)

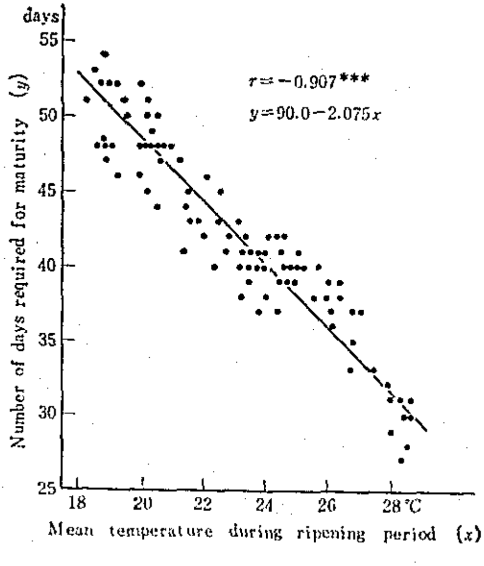


The same trend can be found when the rice plants grown in the cold part of the country are compared with those in the warm part, i.e., rice plants in cold part are rich in carbohydrate content.

6. Ripening Process of Rice Plants in Early Seasonal Cultural Practice

As the rice plants grown in early seasonal cultural practice flower and ripen in the mid-summer season at the highest temperature, the ripening is rapid, but the ripening period is shortened markedly. The relationship between the mean temperature during the ripening period and the number of days for ripening is as given in Fig. 7–12. Namely, in the range of mean temperatures from 18° to 29°C during the ripening period, as the temperature rises by 1°C, the number

Fig. 7–12. Relationship between Mean Temperature during Ripening Period and Number of Days for Maturity (YAMAKAWA and NISHIYAMA, 1953)



of days for ripening is shortened by 2.075 days. In addition to this, due to the high temperature during the ripening period, the consumption of photosynthetic product is increased (because of an increased respiratory rate under high temperature), so that the net production becomes less. This results in the decrease of carbohydrate supply to the panicles. These two factors, the short period allowed for ripening and the decrease in net production of carbohydrate during the period, are the disadvantages of early season culture.

But, in spite of these disadvantages, the early season culture can obtain the high yield in actual practice. This is due to the following two reasons. The plants contain a large amount of starch and sugar accumulated in culms and leaves before heading and it is translocated into panicles. The sunlight intensity in the ripening period is generally higher and day-length is longer in the case of the early seasonal cultural practice than in other cultural season. These things can easily overcome the above disadvantages in ripening.

IV. HIGH YIELDING CULTURAL TECHNIQUES OF RICE

1. Brown Rice Yields in the Respective Districts in Japan

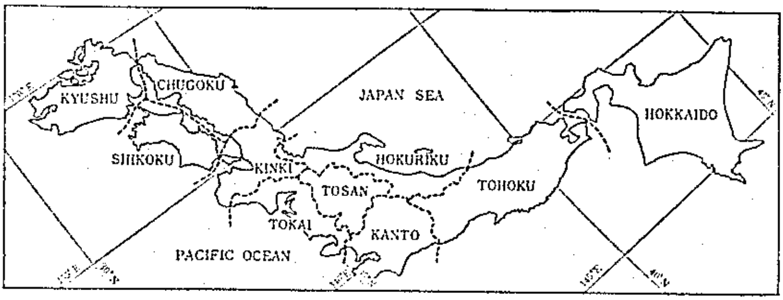
In Japan, stretching from south to north (from 31.0° to the 44.0° north latitude), rice cropping is practised in almost every part of the country. Table 7-23 indicates the yearly trends in brown rice yields per 10 ares in the respective regions. As shown in Table 7-23, the national average yields are on the increase year after year, except the period 1943-47 depressed by World War II. During the 30 years from 1923-27 to 1953-57, it shows a 17.5 per cent increase. If taken the period from 1923-27 to 1958-59, it shows as high as 36 per cent increase. In recent years, sharp increases

Table 7-13. Yearly Trends in Brown Rice Yields by Districts

(kg per 10 ares)

District	1923-1927	1928-1932	1933-1937	1938-1942	1943-1947	1948-1952	1953-1957	1958-1959
Hokkaido	205	166	202	215	236	295	245	386
Tohoku	282	279	272	305	285	338	377	418
Kokuriku	293	293	324	330	308	326	353	410
Tosan	317	326	345	367	358	383	385	427
Kanto	270	281	296	308	296	327	318	365
Tokai	285	308	315	323	311	316	316	320
Kinki	318	338	347	346	323	333	342	369
Chugoku	272	288	306	287	280	310	326	373
Shikoku	287	297	303	290	252	285	314	376
Kyushu	279	290	321	297	281	310	322	375
National average	280	287	303	317	293	322	330	381

Fig. 7-13. Agricultural Region in Japan



in rice yields are observed in the cold parts of the country such as Hokkaido, Tohoku, Hokuriku, and Tosan Districts.

While the rice yields in recent years in the warm southwestern parts of Japan show increases over those in the years before 1952, but showing decreases from the national average. The most of the first prize winners at the annual All Japan Rice Yield Contests are the farmers from the cold parts of Japan. When taken the country as a whole, the brown rice yields show increases, but the increasing rates vary according to the districts. Climatic conditions can be considered as the chief contributing factor.

2. Climatic Conditions and Rice Cropping

Temperatures: Supposing the minimum average temperature in the rice plant growth period be 15°C, the duration permissible for rice growing in the respective districts would reach as follows:

Hokkaido,	about	110	days
Tohoku	"	130	"
Kanto,	"	150	"
Kyushu,	"	195	"

The duration in the southwestern warm parts of the country, the Kanto District and westward is longer than that in the cold parts, and there are many days having a temperature exceeding 30°C.

In the cold areas, if the ripening of rice plants is delayed to the late autumn, the plants will suffer from cool damage, while in the warm areas, though the duration permissible for growing rice lasts for a long period from early spring to late autumn, if transplanted earlier in spring the rice plants would be liable to be attacked by rice stem borers, and in the later growth period there would be much fear of suffering from typhoons. Excessive high temperatures are undesirable for the rice plant physiology as well as for keeping the healthy state of the plant roots. Soil fertility will also be depleted due to the excessive high temperatures.

Solar radiation: Brown rice yields are greatly affected by the quantity of solar radiation during some 20 days after heading. The solar radiation cannot be discussed merely from the length of sunshine hours, but, for a convenience, it will be dealt here merely from the length of sunshine hours. In most of the cold areas, the sunshine hours in August (heading stage) reach 200 or more, while in the warm areas the sunshine hours in September (heading stage) is 150–160 or less. Even in the case of the cold areas, the sunshine hours in the Japan Sea side area are lonegr than that in the Pacific side area.

The increasing rates of brown rice yields and the high yields are considered to be affected greatly by the different climatic conditions as described above.

In recent years, owing to the establishment of the rice stem borer control system based on the progress in agricultural chemicals and the progress in techniques for growing seedling, early transplanting practices have become possible both in cold and warm areas, thus showing a rapid increase in brown rice yields. However, the effect of climatic conditions can not be overlooked in attaining the high production of rice.

3. Soils of Highly Productive Paddy Fields

Highly productive paddy fields are found mostly in undulating areas where paddy fields are lying side by side with uplands, but rarely in great plains crowded with paddy fields only. Even in great plain areas, if drainage can be practised artificially or naturally, highly productive paddy fields can also be found. In such high yielding fields, there is a difference in the head between the field-water surface and the groundwater level or spring-water level during the irrigation period, so that the irrigated water can percolate through the pore spaces or cracks in soils. And if irrigation is kept in abeyance for several days, air will readily penetrate

Table 7－24. Yield of Regional No. 1 Prize Winners at Japan Rice Yield Contest and Thickness of Top Soil

District	*Brown rice yield, 1950-54 average*	*Average thickness of top soil*
	kg/10 a	cm
Hokkaido	610.80	17.0
Tohoku	773.85	18.2
Hokuriku	762.15	16.9
Kanto	588.90	20.0
Tokai-Kinki	683.40	19.5
Chugoku	614.55	20.2
Shikoku	749.70	20.0
Kyushu	705.00	13.0

into the inner parts of soils. Therefore, highly productive paddy fields are mostly well-drained fields (field surface water and air can permeate into the inner parts of soils), excepting the degraded paddy field where no oxidized deposits are observed at the top soil and the plow sole, but not ill-drained swampy ones (of high groundwater level). The depth of top soil is greater than that (10–14 centimeters) of ordinary paddy fields, being mostly 17–20 centimeters in thickness (Table 7–24).

Highly productive paddy field soils contain fairly much clay, but not sandy soils. In some instances, the soil contains fragile gravels that may be broken when rubbed between the fingers. Soil organic matter is not so much, and the humification seems to be advanced relatively. In other words, the easily-decomposable organic matter is relatively small in quantity. This is due to the fact that in the case of well-drained paddy fields, as the soils become dried during the period from the draining time up to the flooding season in the year following, some portion of organic matter will change into the easily decomposable state, and most of the easily-decomposable organic matter is subject to the aerobic decomposition at the time of low temperature immediately after submersion.

As to the kind of clay, soils consisting chiefly of 2:1 type clay minerals are higher in productivity. Paddy field soils of this type contain much quantity of various bases, iron, manganese, and available silicon, and are strong in NH_4^+ and K^+ absorbing and holding ability. Paddy soils of this type possess a buffer action for the redox-potential and are regarded to show the co-existence of reductive portions and oxidative portions in the mozaic state under submergence. When dried, a structure is easily formed. Paddy soils of this type are distributed more widely in the northeastern cold areas than in the southwestern warm areas.

Highly productive area will have close bearings on the distribution of soils of this type, adding to the climatic conditions.

4. Relationship between Soils of Highly Productive Paddy Fields and Rice Plant Growth

Plants at the vegetative growth stage carry on protein synthesis very actively. For this reason, it is more advantageous to contain in the top soil a fairly great quantity of nutrients necessary for the protein synthesis at the beginning of the plant growth stage. However, if nitrogen supply is plentiful at the end of the vegetative growth stage, it would result in an increase in the number of invalid tillers, insufficient exposure of base of hills to the sun, poor elongation of roots, and soft tops, and the plants would become more susceptible to diseases, insect pests, or lodging at the ripening period. But if the nutrient supply is too short at the reproductive stage, it would show a decrease in the number of panicles and in the number or weight of paddy per panicle, thus resulting in a decreased yield. As the highly productive paddy fields are well-drained ones, the decomposition of organic matter will be hastened with fair rapidity when irrigated. Accordingly, at the early growth stage, nitrogen and phosphorus are mineralized, thus favoring the increase in the number of tillers. Toward the end of the vegetative growth stage, the soil temperature approaches to a peak. However, toward that time, the decomposition of organic matter becomes decreased so that, there is no fear for the excessive presence of nitrogen, but, as the top soil is deep, nitrogen will be absorbed gradually according to the development of the roots. Therefore, there is no fear for a shortage in the supply of nitrogen at the reproductive stage. As soils are dried or moistened alternately, the weathering of soil minerals will be promoted and, thus, the various nutrients other than those supplied from organic matter become available. The balance of nutrient supply can thus be secured.

Even though the nutrient supply is plentiful, if the functions of roots are injured, the absorption of K_2O, P_2O_5, and SiO_2, is seriously inhibited, and that of NH_4, Mn, and H_2O is also inhibited. Thus the balance of nutrient absorption would be disturbed, causing unhealthy growth of the plants.

It is after the plant growth has reached the reproductive stage that the development and the activity of the plant roots begin to slow down, but as the highly productive paddy fields are well-drained ones, the aerobic decomposition of organic matter has proceeded by that time, and even if the soil-temperature rises at that time, the decomposition of organic matter in large quantity could not take place. Accordingly, it will give rise neither to the oxygen-deficiency nor to the formation of toxic substances which may injure the activity of roots. Even if toxic substances might be produced, these could be removed by the percolation of water. Consequently, the normal absorption of nutrients can be continued during the reproductive period.

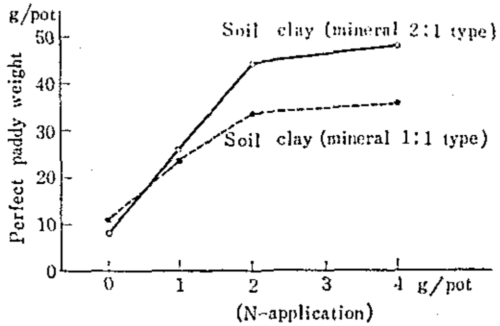
In the district with soils consisting chiefly of 2:1 type clay materials, not only the river water which is used for irrigation but also the soils themselves are rich in the content of various available inorganic elements. As such soils can absorb and hold well NH_4 or K, even when a fairly great quantity of them is applied, neither much leaching loss nor sudden oversupply occurs, and the fertilizer effect will be kept longer. Moreover, as no abnormal reduction of soil occurs, the nutrient absorption by rice plants can proceed favorably. As a result, as shown in Fig. 7–14, a high rice yield can be obtained with heavy application of nitrogen.

The above facts furnish a suggestion that, even in the paddy fields consisting of materials other than clay mineral of 2:1 type, if the cultural practice is improved by taking into consideration the above point, it is possible to secure a fairly high rice yield.

5. Characteristics of High Yielding Cultural Techniques

In Japan, intensive cultural techniques are practised throughout the country. Particularly, the leading points common to the high yielding cultural techniques are as described below.

Fig. 7-14. Effect of Different Soils and Different Amount of Nitrogen Application on the Rice Yield (Agr. Exp. Sta. at Konosu)



1. Rice varieties, transplanting, and plant protection

To be a rice variety of high yielding ability, the rice plants must be strong enough to stand up to the panicle weight and not be blown down. In view of this, rice varieties of strong and relatively short culm and of high disease resistance are preferable. The number of hills planted per 3.3 sq. meters is about 70 or more, somewhat denser than in the case of usual culture. Hills are generally transplanted in the rectangular arrangement. Such arrangement of hills is considered favorable for light-receiving, air-circulation, or soil utilization.

In order to enable the rice plants to grow under the favorable climatic conditions, transplanting is practised earlier than in the ordinary case. Accordingly, efforts are made for growing healthy and firm seedlings. During low-temperature season, protected nurseries or electric nursery chambers are utilized.

Controls of disease, insect pest, and weeds are made timely and carefully.

2. Depth of plowing

Top soil is generally more fertile than the lower layer soils. Fertilizers are applied to the top soil. Roots of rice plant could elongate as deep as one meter, if circumstances permit, but this is an exceptional case. The majority of roots spread usually in the top soil and near-by soils. When the top soil is moderately deep, the dense planting as well as the early transplanting of long duration varieties with an aim of obtaining prolonged vegetative growth period can be adopted, in order to secure an increased number of panicles per unit field area, because the deeper the top soil, the more the nutrients in the soil are available. And, at the later growth period, a shortage of nutrients will not occur. However, when soils are of particularly good quality, deep top soil is not always in need. Contrary to the above, if the top soil is too deep, rice plants would lodge and there is a fear of undue delay in the ripening.

Top soil can be deepened by deep plowing. When deeply plowed, big clods are exposed to air, and are dried well. By this, not only the "effect of soil drying" is brought about, but also the property of soil can be ameliorated. The depth to plow is suggested by the thickness of top soil shown in Table 7-25. When planting density higher than the above is to be practised, a deeper plowing than the above will be favorable.

Owing to the deep-plowing, the weathering of lower layer soils is promoted, but as the drying of soil is necessary for the weathering, it requires an appropriate lapse of drying time after plowing. If the plowed clods are small in size, the bottom layer soils could not be dried fully and the upper dry soils would become moistened by the rainfall to the inner part of the clods, and soil organic matter contained in the clods would be decomposed before transplanting, thus incurring a great loss of nutrients.

3. Fertilizer application

In the well-drained fields, the content of organic matter in the sub-soil is in general lower than that in the top soil. Consequently, organic matter content in the new top soil made by deep plowing is lower than that in the old top soil. When the soils of well-drained field are plowed deeply, and the drying and moistening of soils are repeated, the readily-decomposable organic matter would become decreased as years pass. In order to keep the certain content of organic matter and in order to make it available, stable manures or composts are generally applied liberally (Table 7-25).

Table 7-25. Result Obtained by the First Prize Winners at the Japan Rice Yield Contests

Year	*Brown rice yields*	*District*	*Thickness of top soil*	*Composts or stable manure application*
	kg/10 a		cm	kg/10 a
1949	766.0	Tosan	18	750
1950	777.0	Shikoku	17	750
1951	857.7	Hokuriku	20	1,125
1952	919.8	Shikoku	16	2,250
1953	875.1	Kyushu	11	2,625
1954	994.5	Hokuriku	18	3,000
1955	1,014.6	Hokuriku	15	1,125
1956	868.8	Tosan	20	2,250
1957	856.0	Tosan	17	1,125
1958	1,023.9	Tosan	16	1,875
1959	959.0	Tohoku	21	3,000
1960	1,052.2	Tohoku	18	2,250

While in the case of an ordinary rice cropping, composts or stable manures of about 500-1,000 kilograms are applied per 10 ares.

Stable manures contain various nutrients, and the nitrogen contained therein produces slow effect, thus making possible the healthy growth of rice plants. Little or no denitrification can be observed.

Fully-ripened stable manures or composts are required to be used, and the use of fresh ones must be avoided because the plant roots will be injured by them.

As to chemical fertilizers phosphorus and potassium are applied generally less in quantity than nitrogen in the ordinary paddy fields, while in the high yielding fields, potassium application is characterized by the amount equivalent to or more than nitrogen application. Application amount of each element varies according to the climatic conditions, soils, rice varieties, and cultural practices.

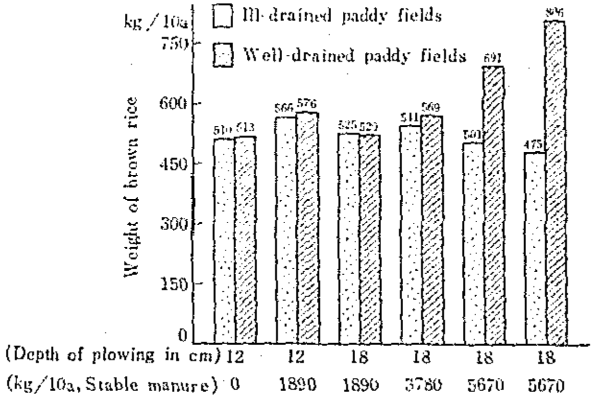
4. Water management

Highly productive paddy fields are irrigated, as is the case with ordinary paddy fields, from the time immediately before transplanting to the time of about one month after heading. At the season of high temperature, the irrigation is stopped for several days, i.e., the so-called "midsummer drainage" is practised several times repeatedly, and cool water irrigation is also sometimes practised.

The main purpose of such practices is to keep the plant roots healthy. As highly productive paddy fields are well-drained ones, oxides are plentiful in soils and dissolved oxygen is supplied to the soils by the percolation of surface water, but because the fields contain plentiful organic matter due to the remaining stubbles and the application of composts or stable manures, there will be an exhaustion of oxygen due to the microbial consumption of oxygen. As a result, plant roots will often be suffocated or injured by the emergence of toxic substances. The season of high temperature just falls on the time when the development and the physiological activity of the roots begin to slow down. The decrease in root activity is pronounced by the increased consumption of oxygen by soil micro-organisms. The midsummer drainage practice is very effective in supplying oxygen from air to the soils and removing toxic gases, and the cool-water irrigation will contribute chiefly to the lowering of soil-temperature, thus suppressing the microbial activity.

Fig. 7-15 indicates the comparative rice yields (in brown rice) in the well-drained and ill-drained paddy fields to which stable manures were applied at different rates. In the well-drained paddy fields, the yield can be increased with the increased application of stable manure, while in the ill-drained ones, the yield will be rather decreased with the increased application of stable manure. In the case of the latter, the yield increase could not be obtained due to the lack of oxygen in spite of the increased supply of nutrients.

Fig. 7–15. Effects of Deep Plowing and Heavy Application of Fertilizers on Rice Yields Both in Well-Drained and Ill-Drained Paddy Fields
(Agr. Exp. Sta. at *Konosu*)



Notes: 1. Sample Variety: Kinmaze.
2. Chemical fertilizers: 11.3 kg/10 a of N., P_2O_5 and K_2O, respectively, and dolomite of 38.0 kg were applied with Nitrogen of 3.8 kg was applied additionally.

If chemical fertilizer (nitrogen) is applied much, adding to the plentiful stable manure or compost, the activity of soil micro-organisms is animated and the decomposition of organic matter is hastened more. The Fig. 7–15 indicates also *that without increased application of stable manure, however,* the effect of deep plowing could hardly be brought about.

Even in cold areas, the water management described above is practised because the temperature in the mid-summer is high, but as the temperature immediately after transplanting is low, various devices are attempted to raise the water- and soil-temperatures.

It will take much time for ripening the stable manures or the composts. When unripened ones are applied much, it becomes necessary to practise more careful water control. In recent years, mainly due to the lack of materials used in making stable manures or composts, an attempt to establish high yielding cultural techniques based on the use of chemical fertilizers, instead of them, is on progress.

5. *Soil admixture or soil dressing (admixture of borrowed soils to ameliorate paddy field soils)*

It is well known that when clay soils which have not been overweathered or overdecomposed are dressed on the degraded paddy field soils, higher effect can be brought about. Such degraded paddy fields are mostly of sandy soils. When supplemented yb clay, iron or other effective inorganic matter, the production of toxic substances will be checked, and nutrient-holding power of soil is increased. In some cases, the water holding capacity can be increased. Even in the case of paddy field soils inheriting no specific defects, various effective components in top soil are removed downward to the lower layer according to the percolating water. Moreover, in the case of highly productive paddy fields, the soil fertility will be depleted more by the plants than in the case of ordinary paddy fields. Therefore, when the soil fertility is not maintained without returning the deprived nutrients the top soil would become increasingly degraded.

In the case of highly productive paddy fields, the leaching losses of nutrients are sometimes compensated by the nutrients carried by water, but as it is not sufficient, soil-dressing is usually practised to ameliorate the top soil. When the top soil is new and excellent in quality, soil admixture is, needless to say, of no use.

Of materials for the soil admixture, clay is generally accepted as important material. Clay soils, not so advanced in weathering process and rich in bases, available silicon and iron are recommendable. The more the better so far as the water percolation is not impeded. However, in general, nitrogen, phosphorus and organic matter contained in the materials used for soil admixture are poor. Therefore, in soil admixture practices, the fertilizers are required to be applied more according to the increased amount of the soils for admixture.

The techniques of high yielding culture are closely connected with each other. In order to attain the desired result, the integrated techniques are required to be adopted in harmony with the environmental conditions.

CHAPTER 8

FUTURE OF RICE CULTURAL TECHNIQUES IN JAPAN

Agriculture in Japan had played an important role in securing the rehabilitation and stabilization of the national economy through the food production increase to overcome the food shortage immediately after World War II. A further rapid progress has been made in agriculture through the subsequent progress in agricultural techniques, the provision of the Government loans or investments, and the agricultural price policy. Thus the present agricultural production has reached the level by far higher than the prewar level. Though the agricultural productivity showed a marked increase, the agricultural growth is relatively slow as compared with the recent outstanding rapid national economic growth, and the agricultural workers' income level is relatively low. If the present status should remain unimproved, there is a fear that the disparity in income between farm workers and other industrial workers would become increasingly greater.

Viewed from the current situation of international trade (e.g., trade liberalization, etc.), the influence of foreign agriculture upon agriculture in Japan will become increasingly serious. The prospects of agriculture in Japan is not always bright because it is inferior to that in some other advanced countries in the international competition.

Lowness in farm workers' income level and inferiority in the competition in the international market can after all be ascribed chiefly to the low agricultural productivity. Originally speaking, the pygmy farming on a fragmental pieces of land is a predominant type in Japan. Part-time farmers constitute a great part of the total and most of them are engaged in the production of their own food, by using small patches of arable land and small sum of capital with relatively ample supply of labor. The low labor productivity lies in such a specific agricultural structure.

On the other hand, non-agricultural workers will be in strong demand in response to the growing national economy. Though the population of productive age is expected to increase for several years ahead, it will thereafter show a decreasing trend. As a result, the supply of farm workers in the future will show a fairly sharp decrease.

In order to meet the requirements of the national economy, it is necessary for agriculture to contribute toward the ample supply of agricultural products to consumers, efficient utilization of human and natural resources, expansion of internal market, and the stability and growth of the national economy. In order to cope with the national economic requirements, and in order to maintain the balance between farm workers' income and other industrial workers' income, it is of prime importance to actuate the improvement in farm labor productivity.

In future, the importance of starch-content food will be decreased, and animal products and fruits and superior quality vegetables will be in strong demand. However, since rice culture is the mainstay of agriculture in Japan, it is firmly convinced that great importance will still be placed on rice culture. In view of this, it is of vital importance to raise labor productivity in rice culture.

Rice production in Japan is on the steady increase, particularly noticeably in the areas of Hokkaido and East Japan including Tohoku, Kanto and Hokuriku Districts.

Among the principal contributing factors toward the recent sharp increase in rice production are: (i) increase in area planted to paddy rice owing to the stable profitability of rice crop; (ii) marked improvement in rice cultural techniques and the extension of the improved techniques (e.g., extension of superior rice varieties, extension of protected rice nurseries, rice cultural improvement—particularly extension of early transplanting and early seasonal rice cultural practices—fertilizer application improvement and soil amelioration, wide-use of new agricultural chemicals, improvements in disease and insect pest control practices, nation-wide distribution of power tillers and sprayers, general application of herbicides, etc.) ; and (iii) strengthening of the groundworks for rice production through the land improvement program.

Rice cropping is pre-eminent above the rest in the stability of acre-yield, and far superior in progress in the technical researches and in the equalization of techniques. Rice being kept under the Government control, the market for rice is stable from year to year. Farmers will make more efforts for rice culture to secure their food self-sufficiency also. At present under the Government control rice is by far more lucrative than any other crops, and the profitability of rice culture is expected to be upheld as ever before, even though the production of other farm crops should attain more prosperity than ever before.

However, the effect of farm labor shortage on the future rice production should not be overlooked. In recent years, farm labor force is on the sharp decrease. This is partly due to the increasing flow of rural youths fresh from schools into non-agricultural segments. In some areas, due to the decrease in farm workers, part-time farmers and old-age or woman workers are on the increase. There is a fear that agriculture in Japan may receive more careless attendance.

In order to meet such critical situation, it is absolutely necessary for rice culture to actuate the labor saving and labor distributing devices. For this purpose, the labor is required to be saved by farm mechanization, and the peak labor seasons are required to be smoothed out by shifting the cultural season so that the timely operations can be permitted for a longer period. In general, labor input (man-hour) per unit area for rice culture shows a decreasing trend year after year, particularly noticeable in plowing, puddling, and weeding operations, while in the cases of transplanting and harvesting operations, little or no labor saving is practised due to the delay in mechanization. Consequently, great importance must be attached to the development and extension of labor saving device in the transplanting and harvesting operations in which much labor is needed. Respecting the cultural method, the rapid progress in the direct sowing practice has been made. It is now recognized that the direct-sowing practice has brought about the excellent result comparable to the transplanting practice in every part of the country, except Hokkaido. The cultural methods suitable for respective areas are expected to be developed and expanded. Besides the present plowing operation or threshing, husking, winnowing, and sorting operations, all other operations are in the pressing need to be brought under the integrated operation by means of mechanization. Transplanting or harvesting machines (e.g., self-propelling combine, etc.) are now at the trial making stage. Such machines will shortly be brought into practical use. The present small-type machines (e.g., power tillers, etc.) will be replaced step by step by higher efficient medium- and large-type machines. Direct sowing of rice seeds and spraying of agricultural chemicals both from airplanes are expected to come into wide use. Thus the present rice cultural principle sticking chiefly to the increased yield of rice based upon the intensified labor will be switched-over radically to the increased labor productivity through labor saving device, i.e., mechanization. On the other hand, the groundworks for rice production will have to be founded firmly as quickly as possible through the enlargement of size of holdings by means of land grouping, and on this new groundwork, new cultural technique should be established through the promotion of farm mechanization and the efficient use of land and water.

Since the rice cultural techniques prevalent in present Japan and their future course have been handled by the respective subject-matter specialists in the previous chapters, in this chapter the future technical development program as may bring about radical reform in rice culture in Japan will be pointed out.

(i) Establishment of farm groundworks for mechanized production (expansion of size of farm management such as enlargement of size of plots of rice fields and construction of farm roads and irrigation or drainage facilities, so that the utmost use of modernized facilities and the radically improved techniques may become permissible);

(ii) Breeding of new rice varieties (varieties suitable for the mechanized direct sowing method, high efficient varieties to be grown within a short period, varieties well adapted for water-saving cultural practice, varieties of high resistance to diseases, etc.);

(iii) Extension of improved techniques for the production of seedlings in a large-scale vinyl-house rice nursery, and of improved methods of growing seedlings suitable for the use of transplanting machine;

(iv) Extension of the direct-sowing practice (in irrigated or non-irrigated fields, etc.);

(v) Breeding of quick-maturing varieties and adjustment of cultural seasons by early or late transplanting as well as early or late seasonal cultural practice;

(vi) Use of plant growth regulating chemicals;

(vii) Application of more effective fertilizers and agricultural chemicals, and adoption of labor saving device by the improved techniques for fertilizer application, weeding, and disease and insect pest control;

(viii) Mechanization of transplanting and harvesting operations;

(ix) Improvements in drying methods (by the use of desiccants, large-type artificial dryers, etc.) in order to save labor for processing and for the purpose of rice quality improvement;

(x) Rationalization of water use by means of water-saving culture, or by lowland and upland rotations;

(xi) Establishment of mechanized cultural practices by using the machines (large-, medium-, and small-type machines including helicopters, and their combination) according to the areas and management types;

(xii) Establishment of methods for the intensified use of paddy fields (planting of vegetable and forage crops).

For founding the groundworks for the mechanization in rice production and for the purchase of large-type machines, a fairly great amount of capital will be required. It could not readily be financed by farmers themselves. In this respect, great expectations are entertained for the Government agricultural policy. In order to appeal forcibly to the Government so that it may carry out the agricultural structure reform or provide the required loans or investments or carry out the program for full employment of unemployed farm workers, it is absolutely necessary for farmers to strengthen their organization so as to have a voice in the agricultural policy. On the other hand, in order to enlarge the management scale and the utmost use of large-type machines, the cooperated operations or corporated management will be required. It can safely be asserted that the modernization of human relationship and the strengthening of farmers' organizations on the initiative of their own are of prime importance for pushing forward rapidly such improved rice cultural techniques as described above.

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