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* Studies on Drought Resistance in Rice — Part II

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Introduction: Considerable work has been done on the physiology of drought resistance in crop plants. Most of the work, however, represents attempts to find some simple index of measuring drought resistance by means of easily observable anatomical or physiological characters. Studies of such physiological characters as water requirement, transpiration rates, bound water content, osmotic pressure and water balance are some of the popular aspects of approach to the problem of drought resistance.

Among these characters, osmotic pressure and transpiration rate have been studied in great detail by many workers. Root studies have not received adequate attention owing to the difficulty in studying this underground part of the plant. The present studies relate to the above three characters in rice varieties which differ in their degree of drought resistance.

Materials and Method: *Osmotic pressure:* Variability in osmotic pressure of germinating seed of the different varieties was studied by immersion in sugar and salt solution of different concentrations. Sucrose solutions of 0·10, 0·20, 0·25, 0·30, 0·35, 0·40, 0·45 molar strength were used in the trials. The survival of the germinated seeds in the sucrose solution was recorded until the sixth day which was found to be the maximum period after which they tended to become mouldy. Further germination tests in 0·25 molar sodium chloride solution, 3 percent solution of copper sulphate and 3 percent solution of potassium chlorate were conducted. Seeds were soaked in the above solutions for 24 hours and the soaked seeds were germinated in water using germination trays. Counts of germinated seed were recorded everyday till the end of ten days.

Osmotic concentration of the plant sap and root extract of twelve varieties of rice was determined by 'cryoscopic' method using the 'Beckmann apparatus'. The varieties were all grown in the

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puddle under indentical conditions. Sampling of the leaf meterial was done when the seedlings were 60 days old in jam bottles fitted with lids provided with rubber washers and kept in a mixture of ice and salt for pre-freezing for 14 hours and the meterial was 'thawed'. The cell sap was extracted in a hydraulic press at an uniform pressure of 12,000 lb. per sq. inch applied for three minutes. The extracted juice was centrifuged for five minutes to remove the cell debris and freezing point of the sap was determined with the 'Beckmann thermometer'.

Relative Transpiration: Two varieties Co. 13, a wet variety and MTU. 17, a dry variety were subjected to atmospheric drought as per the method evolved by Mallik (1946). Rice seedlings grown in galvanized iron drums at 40 percent moisture level by weight were kept in the enclosures when 30 days old. Evaporation from the soil surface in the drums was prevented by covering with a sheet of rubber cloth. The enclosures were provided with 10' x 10' khus-khus screens on all the four sides to a height of six feet, with the top open. One enclosure served as dry environment and the other as a humid environment. The humid enclosure was kept wet throughout the experimental period by rolling the screen frequently through the column of water underneath.

The experiment was conducted for ten days during which time hourly observations of evaporation and relative humidity were recorded within the two enclosures from 07·22 hours to 17·22 hours with 'Piche evaporimeter' and 'Assmann Phychrometer' respectively kept at the same level as that of the plants. Everyday the loss by transpiration was made up by adding water to the pots through a glass tube running through the soil column. The loss in weight recorded everyday in the evening is the loss due to transpiration from the plant during the day. Leaf area measurements were taken in each plant during the experiment.

Root Development: Development of the root in the seedling stage at defferent levels of water below the soil was studied with root development apparatus obtained from the Director of Agricultural Meteorology, Poona. The apparatus consists of a metallic outer jacket with a lid through which passes an inner cylinder with a perforated bottom. The outter jacket at the bottom has a bent outlet for glass tube attachment on which readings to record levels of water inside the apparatus can be measured. Water is poured into the apparatus through an opening in the lid. The inner cylinder is filled with soil to a depth of 37 inches and rice seedlings are grown in this soil column.

Two sets of experiments were laid out to study the development of the root system of different varieties at flowering. One set consisted of growing plants inside earthen rings buried in the field under dry as well as wet conditions. Twenty four cylindrical metallic pots 12" deapth and 10" in diameter were each filled with 30 lb. of air dry black tank silt resting on a layer of two inches pebbles at the bottom. Water was added through a glass tube passing through the soil and resting on the pebbles. Thirty percent level of moisture by weight was maintained in all the pots throughout the experiment. One seedling of each variety was grown in each pot and 12 varieties in duplicate were studied.

To study the root development in the field, three earthen rings each of the dimension of 12 inches diameter and nine inches depth were buried in the plots placing one ring over the other. The total depth of the ring was 27 inches out of which three inches was kept above the ground level. Pits were dug at three feet apart and earthen rings were buried and filled with the same earth dug out of the pit, care being taken to see that the bottom soil was filled first and the top soil added to maintain the original condition of the field, the operation being done a month in advance of the sowing time for the consolidation of the soil. Growing the plants in the ring facilitates easy washing of the roots without otherwise tearing them.

Review of Literature: *Osmotic Pressure:* A very important characteristic of xerophytes affecting their water relation, is the osmotic pressure in the cell. Maximov (1929) has reviewed the early work of Zalenski (1904), Fitting (1911), Iljin (1917) and others on the important aspect of osmotic pressure in the plant cell. According to Bolsunov (1927), Pavlov (1931), Snoep (1932), Timofeeva (1935), Buchinger (1936), Semikin, (1938) (reviewed by Ashton, 1948) and Bartel (1947), germination test of seed under conditions of limited water availability induced by suitable concentration of salt or sugar solutions, provided an usefull method of determining varietal drought resistance. Aamodt and Johnston (1936) found a relative rapidity of germination of drought resistant varieties of wheats in various concentrations of sodium chloride, potassium chloride and sucrose solutions. Lal and Mehrotra (1949) working on sugarcane found that higher the concentration of solution and osmotic pressure of cell sap the greater was the possibility of the variety to exhibit resistance to drought. Newton and Martin (1930) and Sankaran (1933) however, did not find any relationship between osmotic pressure and drought resistance in crops like wheat and cotton.

Yamasaki (1929 a) in his experiment of seed germination of both lowland and upland varieties of rice in three percent solution of potassium chlorate, three percent copper sulphate, 0·25 molar sodium chloride and 0·30 molar sucrose found that when the soaked seeds were germinated in water the upland varieties germinated and flourished better than the lowland ones. Hector (1927) Yamasaki (1929 b) distinguished the upland and lowland rice by determining the osmotic concentration of the cell sap by the freezing point method while Onodera (1931) did not find any relation between the osmotic pressure of cell sap and drought resistance.

Relative Transpiration: Various investigators have subjected plants to atmospheric drought and the work has been adequately reviewed by Ashton (1948). Atmospheric drought tests have been reported on sugarcane by Mallik (1946) and Lal and Mehrotra (1949). Mallik tested the drought resistance of two varieties of sugarcane by studying their transpiration rates in 'dry' and 'humid' enviroments and compairing these rates with evaporation rates in the two enviroments with 'piche evaporimeter'.

Root Development: Exact determinations by Rotmistrov (1910) and Modestov (1915) (quoted by Maximov 1929) in Russia and Weaver (1926) have shown that crop plants such as wheat and oats have root system reaching a depth of one to two metres with an equal spread. Miller (1916) found that corn and sorghum could mature crops of grain when the upper two feet of soil was below the wilting coefficient and water was being absorbed from as great a depth as six feet. Sankaran (1933) found that the drought resistant *herbaceum* cotton possessed a much longer and thicker root than the *indicum* type. Ostermeyer (1934) (quoted by Ashton 1948) has recorded in oats that the roots of more drought resistant plants penetrated deeper into the soil, while Aamodt and Johnston (1936) found that drought resistant wheat varieties possessed a more highly branched primary root system than the non-resistant varieties. Root development of wheat varieties in relation to drought resistance has been referred to by Udoljskaja (1936), Stefanovskii (1937 b), Sokolenko (1938), Ivanov (1939) and Ashby and May (1941) (reviewed by Ashton, 1948).

Evans (1939) suggests that transpiring and absorbing surface in sugarcane might give a coefficient for drought resistance and the total water loss might be related in some degree to the total leaf surface. Lal and Mehrotra (1949) found the drought resistant cane 'Rheora' to show a diametrically opposite effect to that of POJ. 2878 with regard to shoot number, green leaf number and total root extension.

A study of branching and depth of root system in rice varieties was made at Coimbatore, (Srinivasan, 1937), while Sethi (1931) has studied the root system of rice varieties both in pots and in fields. Except for the above references in rice, the root system has not been studied in connection with the drought resistance of this crop.

Observations: *Osmotic Pressure of the Germinating Seed :* Cane sugar solutions of 0·25 molar and 0·50 molar strength were used and it was found that the drought resistant varieties, PTB. 28 and PTB. 30 had the quickest growth and better survival followed by MTU. 17, MTU. 18, TKM. 2 and 'Bairuvadlu, while the wet variety GEB. 24 had the least growth in 0·25 molar cane sugar solution. In 0·50 molar solution, on the third day except TKM. 2, PTB. 28, PTB. 30 other varieties had started dying, and on the fifth day the mortality was maximum in both the concentrations while the dead seeds became mouldy. Plate I, Figure 1 shows the differences in survival between the varieties PTB. 30 and GEB. 24 in the two concentrations and it may be noticed that the wet veriety GEB. 24 succumbed in both the concentrations while the dry variety PTB. 30 showed survival in 0·25 molar solution.

The experiment was repeated with solutions of 0·10, 0·20, 0·25, 0·30, 0·35, 0·40 and 0·45 molar sucrose and the survival values of the varieties recorded on the sixth day are given in Table 1, and plate I, Figure 2. In 0·10 and 0·20 molar sucrose solutions, germination and survival of all the varieties were good and the growth of both the radicle and plumule was quite normal. However, on the fifth day some of the germinated seeds in GEB. 24 had died whereas the death in the dry varieties was comparatively few ranging from nil to 21 percent. In 0·25 and 0·30 molar sucrose solution, differences between the wet variety and dry varieties were noticed on the third day and the dry varieties were able to withstand the water deficiency better than the wet variety. In 0·35 molar solution death started on the third day in all the varieties and development of germinated seeds that survived was very slow, the growth of the plumule being 0·4 cm. to 0·6 cm. whereas the radicle growth was quite negligible. In 0·40 and 0·45 molar concentration of sucrose the germinated seeds of all the varieties were unable to withstand the amount of water deficiency and death started from the second day onwards.

The results of seed germination in 0.25 molar sodium chloride solution, 3 percent potassium chlorate solution and 3 percent copper sulphate solution (Table 1) showed that on the first day after setting for germination the seeds had started uniform germination in the control while the germination in 0·25 molar sodium chloride solution was delayed in general but the dry varieties 'Bairuvadlu', PTB. 28 and MTU. 17 had a better start. The total germination percentage shows that the wet rice GEB. 24 had the poorest germination of 79 percent whereas the dry rice varieties showed a range from 94 to 100 percent.

In 3% solution of copper sulphate the development of the radicle was very much arrested though the plumule had come out earlier. The radicle started drying on the third day owing to the toxic nature of the solution. 'Bairuvadlu', a dry rice showed maximum of 97 percent germination. MTU. 18 and PTB. 28 had quick germination. MTU. 17 though slow in germination, had better percentage than the wet rice GEB. 24. Germination in 3% solution of potassium chlorate was comparatively quicker than in copper sulphate solution. Dry rice variety MTU. 17 showed the quickest germination and the germination was mostly complete on the fifth day, the maximum being on the second day. It was found that the radicle was drying owing to taxicity of the solution, but the development of the plumule was normal.

* **Osmotic Concentration of Cell Sap:** The osmotic values of rice tops range from 4·808 atmospheres to 6·969 atmospheres and that of roots, from 0.478 atmosphere to 1·161 atmospheres. The sap concentration is highest in one of the most drought resistant variety, MTU. 17. Among the five early duration varieties tested, all the dry rice varieties show significantly higher osmotic concentration of tops than the wet rice Co. 13. Next to MTU. 17, PTB. 28 and MTU. 18 have higher osmotic concentration followed by PTB. 30. The osmotic values of the cell sap from roots show that the two dry varieties PTB. 28 and MTU. 17 alone have higher concentration than the wet rice Co. 13. In the medium duration group the wild rice T. 1702 and 'Bairuvadlu', a dry rice alone possess higher concentration of tops than the wet rice GEB. 24. The other dry and wild rice varieties have lower values. The osmotic values of the cell sap from roots show that all the dry and wild rice varieties have significantly higher values than the wet rice, GEB. 24.

Relative Transpiration: Temperature, relative humidity and evaporation recorded in the two environments showed that the temperature in the dry enclosure was higher than the humid enclosure

* A summary of this study was published in April 1957 issue of 'Rice News Teller'

by 1·9°C. on the average. Similary evaporation was about 2·16 times greater and the relative humidity was 11 percent less than that of the humid enclosure. Table 2 gives the mean values for each day of transpiration in grams per square centimeter of evaporating surface from 'Piche' evaporimeter under humid and dry enviroments. The relative transpiration for the two rice varieties under humid and dry enviroments given in the table show that the ratios of Co. 13 and MTU. 17 in the dry enviroment are respectively 52 percent and 58 percent of those in the humid environment.

Root Development in Seedling Stage: This study, as mentioned before, was made in four root development apparatus. Four leaves of water 3″, 6″, 9″ and 12″ below the soil surface were maintained in the four apparatus and two rice varieties were studied at a time, at the four different levels of water. Two seedlings of each variety were grown in each of the apparatus. Both the varieties were grown in all the four levels of water at the same time. The seedlings were examined for their root development when 25 days old. Two wet rice varieties GEB. 24 and Co. 13 were compared with the dry rice varieties MTU. 17, PTB. 28, PTB. 30, 'Bairuvadlu' and T. 1702, a wild rice type. The data are presented in Table 3.

Since the experiments were conducted during the different parts of the year starting from March to December, the same varieties grown during defferent seasons show variation in growth. In the apparatus where the level of water was 12 inches below the soil surface the wet rice Co. 13 showed symptoms of drying at the tip of the leaf and wilting on the tenth day whereas the dry rice variety MTU. 17 survived and looked healthy. On examination of the root system on the 25th day the plants of MTU. 17 showed a deeper and more penetrating root system, going to a mean depth of 34·5 cm., whereas the root length of Co. 13 was a meagre 3·5 cm. The growth of the two varieties in the three inches water level was normal and the wet rice Co. 13 had a better shoot development than MTU. 17. As the free water level increased from three inches to six inches in the apparatus the growth of the dry rice was better than the wet-rice, the root also showing a maked increase in length and development. The growth was maximum in the nine inches water level and here again the development of the root system of the dry rice variety was three times that of the wet rices. The wet rice showed symptoms of wilting on the 15th day and died on the 19th day. Similar results were obtained with two more dry rice varieties PTB. 28 and PTB. 30 and both showed increase in root length over the wet rice Co. 13 in all the four levels of water.

Plate 1, Figure 3 shows the root and shoot development of GEB. 24, a wet rice and Bairuvadlu, a dry rice belonging to the medium duration group. The experiment with GEB. 24 and T. 1702 representing the wild rice *Oryza sativa* var *spontanea* showed that the wild rice had delayed germination, and completed its germiation only on the fifth day after seeding whereas the wet rice had completed its germination on the third day itself. Growth observations made showed, that the wild rice had a quicker growth than the wet rice and the shoot length was more in all the four levels of water as can be seen from table and the root development of the wild rice was much more than the wet rice in all the four levels of water. Here again, as in the previous cases the development of the root was equal to shoot development in the three inches and six inches levels of water whereas it was more in the nine inches and twelve inches levels in both the varieties. The dry weights of root show that the drought resistant types have more root weight than the wet rice in all the four levels of water revealing thereby that even in the seedling stage these varieties produce more number of roots which increase the absorbing surface of the root system.

Root development at flowering phase: Development of the root system of 12 varieties of rice was studied by growing them in pots at 30 percent moisture level. The plants were grown exactly under identical conditions and their roots examined when the last ear had emerged out of the boot.

Growth observations were recorded at weekly intervals and the height of plant, the number of tillers and the number of leaves per plant were counted every seven days and finally the leaf area measured. The drying and death of the leaves was also noted to see at what stage the plants suffered from drought. Finally the roots were washed and the number of roots and also the total length of the root system were determined. The total dry weight of the root and shoot were also determined to ascertain the root/shoot ratio. The data obtained are presented in Table 4.

Observations made regarding the shoot development are as follows:

Height: The averaged height of two plants measured at weekly intervals a fortnight after seeding, in the five short duration varieties show that the initial height of the varieties range from 16·7 cm. to 25·8 cm. Some of the dry varieties TKM. 1, TKM. 2, PTB. 28 and the wet variety Co. 13 had a quicker germination, whereas the wild rice *Oryza sativa* var. *spontanea* was slow in germination. The short duration varieties had quicker growth than those of a medium duration. The growth in the short duration varieties was continuous and quick up to the sixth week after which it appeared to be slow because of the cessation in the vegetative phase of growth before flowering would start when the growth must again be very rapid. The short duration varieties attained their full height quicker than the medium duration ones. Though the growth was slow in the beginning in the medium duration varieties it became continuous and rapid as the plants advance in age.

Tillering : The data regarding production of tillers are presented in Table 5. It was observed that production of tillers commenced from the third week after sowing in all the varieties studied and thereafter it appeared to increase at a rapid pace. The maximum number of tiller production was reached by the ninth week in the short duration varieties and the eleventh week in the medium duration varieties. In the short duration varieties the maximum production of tillers and starting of flowering almost synchronised and very few tillers died away. The tillers started dying only after the tenth week by which time these varieties had completed flowering. It was found, however, that among the short duration varieties, most of the tillers produced by the plants of dry varieties, survived up to the completion of blooming while many tillers died in the wet rice. The same observations were made in the medium duration varieties also. It was observed that the death of tillers was more than 50 percent in the wet rice GEB. 24 by the time it had completed flowering, whereas, in all the dry varieties and wild rice this was much less.

Number of leaves: The leaf production steadily increased from the second week onwards and it was observed that older leaves started dying off from the sixth week. Thereafter the number of healthy leaves, as well as the dried leaves were recorded. Though the death of the leaves went on increasing, the maximum production of leaves was, however found to coincide with the maximum production of tillers. The drying of the leaves increased from the appearance of the shot blade. Again it was found in the short duration varieties studied that the percentage of dried leaves is 50 percent of the total number of leaves produced in a wet rice like Co. 13, whereas it was found to range from 28 to 43 percent in the drought resistant varieties. This is naturally due to higher rate of death of tillers in the tillers in the wet rice, Co. 13 than in the other varieties studied.

Leaf area: This was measured a few days before the plants completed flowering and when the number of leaves was maximum. The length and breadth of a leaf varies in the same plant according to its tropic alignment and spatial disposition and hence the total area of the leaf lamina itself is subject to variation from leaf to leaf. The actual area of bottom leaves of a tiller is less than those in the central region and then again the area of the top most leaf is also less than those of the mid region. In the blooming stage when the boot leaf appears the area of the leaf fluctuate again as the breadth of the boot leaf is always greater than the other leaves though its length is somewhat less in comparison with the others. The area of the boot leaf is, however, less than that of the leaves in the mid region though it is conspicuously the broadest leaf in a rice plant.

Length and breadth of the leaf is a varietal character and some of the varieties like PTB. 28, T. 1702 and 'Bairuvadlu' have long flowing leaves with a length of 37 to 40 cm., whereas other varieties like MTU. 17 and MTU. 18 have but short leaves with a mean length of 23 to 25 cm. The breadth of the leaf varies from 0·58 cm. to 0·81 cm., and the leaf area varies from 34·9 sq. cm. to 59·1 sq. cm. The total transpiring surface of a plant does depend upon the area of the leaf lanina and the number of leaves in a plant, but the differences noted between the varieties in their total transpiring surface do not appear in any manner to be associated with the drought resistance or a wild habit as seen from Table 6.

Root characters: The root system in the pots was massed together and as such the depth of penetration and spread of the root of the defferent varieties could not be studied, the roots being found to be spreading and touching the sides of pots as well as the bottom. But some of the dry varieties possessed a large amount of root system, completely filling the pots and making it difficult to wash the soil from the congested mass of roots seen entangled and matted together at the bottom of the pot wereas the wet rice showed comparetively fewer roots with lateral branches (Plate 1, Figure 4).

Observations were made after the completion of flowering in all the varieties and they show that the least number of 204 roots was met with in the earliest variety MTU. 17 and the maximum number of 556 and 612 in the medium duration verieties GEB. 24 and T. 129 respectively. T. 129 also possessed the maximum number of 63 tillers followed by GEB. 24 with 53 tillers. Though there are a few exeptions, the general trend is, the more the number of tillers and longer the duration the larger the number of roots in the rice plant. Production of roots was almost complete in the medium duration varieties but few new young roots were met with in the short duration varieties at the time of completion of blooming. It was noticed that the dry rice varieties had more of thick roots than thin ones as can be seen from Table 4.

The total length of the root system depends to a large extent on the number of roots in the plant. But the mean length of the root system of all the dry rice varieties are longer than that of the wet rices. For example Co. 13 and GEB. 24, the wet rice varieties have 24·9 and 24·8 cm. of mean root length respectively, whereas in the dry rice it varies from 25·4 to 30·5 cm. The wild rice variety T. 129 has, however, a slightly lower value than the wet rice. The root/shoot ratios determined afte recording the dry weight of root and shoot show that the dry and wild rice varieties have usually a greater ratio than the wet rices, except in the wild rice, T. 129.

Development of root system in a wet field: Nine varieties in duplicate were studied for their root development in a wet field to find out the depth of penetration and spread of the root system. Seedlings were transplanted in earthen rings buried in the field and short duration varieties were examined on the 50th day and the medium duration ones on the 65th day after transplanting. The data obtained are presented in Table 7.

A general study of the root system of the rice plant in the field reveals that most of the thin branched roots are concentrated in the top soil alone. Starting from one to two cm., from the soil surface the roots ramify to a maximum depth of 15 cm. These thin and many branched roots are to be seen running rather horizontally upto 15 cm. along the surface. In marked contrast to this, the more thick and brownish roots are going obliquely as well as vertically downwards from the base of the plants, occupying the central column of the soil and penetrating deeper. Most of these roots are free from any lateral roots in the top 6 to 8 cm. after which numerous lateral roots are met with along the length of the root except the growing tip. A few, very thick, white, smooth roots are also found and these do not have any lateral branches nor do they go deeper.

Depth of penetration: The depth of penetration of the root system varies from 39 to 55 cm. in the short duration varieties while it is found to vary from 48 to 72 cm. in the medium duration varieties. The data show that the wet rice, Co. 13 has a depth of penetration of 39·3 cm., whereas the dry rice varieties have a depth of penetration ranging from 50·8 cm. to 55·2 cm., the maximum being in the case of the drought resistant variety MTU. 17 (Plate 1, Figure 5). In the case of medium duration varieties studied, the wet rice GEB. 24 has a root penetration of 48.9 cm., while the dry rice and wild rice show a much deeper penetration, ranging from 55·2 to 71·5 cm. Fewer roots are found in the top 10 to 15 cm. of the soil in the case of dry rice and thick brownish roots with lateral branches are found growing deeper into the soil.

Spread of the Root: The spread of the root system varies at different depths. In a wet rice, the spread of roots at two to three cm. depth is about 10 to 12 cm. At a depth of about six cm. to ten cm. below soil surface, the roots are found touching the sides of the earthen rings with a maximum spread of 30 cm. The thin fibrous roots arising below the base of the node, travel horizontally and are often seen touching the sides of the rings and then going vertically down to two to three cm. A few roots in the central region again are found going obliquely and touching the sides of the rings at about 16 cm. depth. The root spread below the 16 cm. level is much less, i. e. about 20 cm. and very few roots are met with in the central region of the ring which reach a depth of about 40 cm. In the case of the 'dry rice' the spread of the roots about two three cm. below the soil surface is similar to the wet rice, but below this depth upto 15 cm. the spread is comparatively less than that of the wet rice. Unlike in the wet rice, numerous roots are found concentrated in the central region which after starting from the base of the plant are found going at an angle of 45 degrees with a maximum spread of 30 cm. Most of these roots which penetrate deep into the soil are found in the central region of the ring in a space of about 25 cm. This kind of arrangement enables the roots to minimise their transverse spread and to go deeper.

Development of root System in a Dry Field: Plants grown in earthen rings in a dry field under extremely dry conditions were examined at the stage when they showed symptoms of wilting. The growth of the rice seedlings in this condition was poor and stunted except for some of the dry rice varieties which managed to withstand the early drought. Symptoms of drying of the leaf tips were noticed in the wet rice Co. 13 and wild rice T. 740 on the 50th day and they wilted beyond recovery on the 65th day while the dry rices, MTU. 17

and PTB. 28 were healthy. The development of the root system was poor when compared to those in pots or the wet field. The dry rice varieties had the maximum root length ranging from 24·7 cm. to 43·5 cm., even exceeding their shoot length but the wild and wet rice showed a shallow root system of 13·8 cm. and 12·4 cm. respectively. GEB. 24 (wet rice) showed a root penetration of only 21·9 cm. while the dry rice MTU. 18 had 48·4 cm. followed by Bairuvadlu with a root penetration of 40·2 cm. One plant of MTU. 18 completed flowering on the 105th day and it had the longest root penetration reaching a depth of 74.9 cm. It had produced 13 tillers with a shoot growth of 80. 2 cm.

Discussion: Among the physiological peculiarities, osmotic pressure, relative transpiration and development have been studied in fair detail in some of the rice varieties with different degrees of drought resistance.

Osmotic Pressure of Germinating Seed: Germinating the seed in solutions of sucrose and sodium chloride has been followed in the study. This kind of subjecting the germinated seed to water deficit has given some valuable results. It has been found that the suitable concentration of sucrose solution for testing osmotic pressure is between 0·25 molar and 0·35 molar sucrose in which concentration the difference in survival between the drought resistant and drought susceptible varieties was quite marked. Beyond 0·35 molar it was deleterious and toxic as well, for the seedling to survive. A period of six days was found to be optimum for the observation of the differential survival rates. The radicle growth was very much arrested and growth of plumule was about one centimater in the course of six days. However, there is indication that the drought resistant types are able to withstand the water deficit to a greater extent than the drought susceptible wet rices. But some of the wild rices did not show any better survival than wet rices. The wild rices are inherently slow in their germination and this may be the cause for their poor survival.

The above results are in conformity with those of Yamasaki (1929 a) who observed the same results in Japonica and Indica races of rice. Yamasaki also noted the same difference in 0·25 molar sodium chloride, 3 percent solution of potassium chlorate. These trials conducted in the present studies show indications of better germination of drought resistant varieties in 0·25 molar sodium chloride solution and 3 percent solution of potassium chlorate.

Osmotic Concentration of Sap: From the observations recorded it has been found that leaves have much higher osmotic pressure than roots as has been reported in other crops by Karmer (1949). Regarding osmotic pressure of the cell sap and drought resistance, opinion seems to be divided among various workers. Newton and Martin (1930) and Sankaran (1933) found osmotic pressure an unsatisfactory index of drought resistance whereas Bartel (1947) and Lal and Mehrotra (1949) found some correlation between drought resistance and osmotic pressure.

In rice, Hector (1927) found a higher osmotic pressure of the cell sap in the highland 'aus' varieties than that of the deep water 'amn' rice whereas Onodera (1931) did not find any such difference in osmotic pressure of the cell sap between varieties differing in drought resistance. The findings in this study show that in the short duration varieties all the drought resistant varieties have significantly higher osmotic concentration than the wet rice types but the osmotic value of the cell sap from root of the medium duration varities shows that the dry and wild rice varieties have higher concentration than the wet rice whereas the osmotic concentration of tops do not have the same difference. It is not, therefore possible to say which of the two, the concentration in the top of the plant or the roots, is more responsible for drought resistance of a rice variety.

Relative Transpiration: It has been found that relative transpiration in the two rice varieties Co. 13, a wet rice and MTU. 17, a dry rice, under dry environment is half of that under humid environment. This definitely indicates the existence of some biological control which tends to cut down the transpirational loss and resist to a large extent the desiccating influence of a dry atmophere. It has also been found that the drought resistant variety MTU. 17 uses water more ecnomically than the drought suceptible rice Co. 13 since the transpirational loss from Co. 13 is one and a half times that from MTU. 17 under both the dry and humid environments. The relative transpiration of the two varieties Co. 13 and MTU. 17 in the dry environment is just 52·0 percent and 58·0 percent respectively of that in the humid environment. This shows that the two varieties behave almost similarly in the adjustments of transpiration in the case of aerial drought.

* **Root Development:** Root studies with the root development apparatus at four levels below the soil surface showed that rice varieties differing in degrees for their resistance to drought show

* A summary of the studies was published in January 1957 issue of 'Rice News Teller'

differences in their root length in the seedling stage. The difference in root length is quite marked in 9″ and 12″ depths where the more drought resistant types have elongated their root system quickly and penetrated deeper. In a few cases the root length has exceeded the shoot growth which shows that the roots have grown at a quicker rate.

The dry weight of roots recorded in the case of these varieties has also revealed that the drought resistant types have a better developed root system. This confirms the fact that the rice seedlings exhibit marked differences in their root length and number from the early stages of their growth and this corresponds with their behaviour towards drought. It was interesting to observe in one of the experiments conducted during the month of March, the driest period of the year, that the wet rice Co. 13 wilted in the apparatus when the level of water was 12" below the soil surface, unable to withstand the severe drought, whereas the dry rice MTU. 17 survived. The root development of this variety showed a penetration of 34·5 cm. whereas the drought susceptible type had a root length of 3·5 cm. This rapidly growing, deeply penetrating root has enabled the plant to obtain water even though the surface soil has dried out during the summer drought. Such hereditary differences in depth and form of root system play a great part in the drought resistance of plants.

Further studies in pots and fields have given more information regarding the depth of penetration, lateral spread, number of roots per plant and total length of root system. In addition, attempts have been made to correlate the development of the shoot portion including height, tillering, number of leaves and leaf area with the development of the underground part of the plant.

A general study of the literature regarding root and shoot relation (Kramer, 1949) shows that the proportion of roots to shoots is determined by the heredity of the plant as well as by its environment. Root and shoot growth are closely correlated and the modification in the development of one affects the other likewise. The physiological characteristics of root system have important effects on the shoot growth.

From the study of plants grown in pots and examined at their flowering, higher root/shoot ratio has been obtained in the highly drought resistant types than in the susceptible forms. This is an important factor which enabled them to withstand drought. By possessing more of underground parts as compared to their shoot, the plants must naturally be able to withstand the water deficit more efficiently. It will naturally possess more of absorbing surface and an efficient conducting system.

The mean root length of the root system of the drought resistant types is higher than that of the susceptible forms which enables deeper penetration. The resistant types were characterised by more of thicker roots than the thin and fibrous ones. Such comparatively thicker roots will have more of absorbing surface. The number of roots in a variety is closely associated with the duration of the variety and the number of tillers per plant. The total length of the root system has been found to depend on the number of roots.

The rate of growth of the shoot depends also on the duration of a variety and as such height and rate of growth could not be correlated with its drought resistance. Number of tillers and number of leaves per plant depend upon the variety. It has been found that most of the tillers formed in the drought resistant types survived up to flowering, whereas in the drought susceptible types, the reduction by death of tillers in the course of tillering is more. The difference in the percentage of reduction of tillers between the drought resistant and the drought susceptible types was quite marked in the varieties studied. Ramiah and Narasimham (1936) suggest the possible cause for such a reduction of tillers as a result of the late tillers not producing any root system to enable them to lead an independent existence. Hence the better survival of most of the tillers in the drought resistant types is due to efficient root system. Reduction of tillers resulted in reduction in the number of leaves. An indication of more leaf withering in the drought susceptible plants was noticed during the study though it was not uniform in all the varieties studied.

The transpiring surface as determined by the leaf area did not give any clue regarding the drought resistance of a variety. Thus it is found that varieties with least number of leaves per plant do not differ substantially in their total leaf area from those with maximum number of leaves. In general, when the leaf area is small, the number is more, whereas leaves are few when they are long and broad which is typical of the dry and wild rice varieties.

The study of root penetration and root spread in the field has revealed the natural disposition of the root system of the rice plant in addition to the type of the root system. Two kinds roots as observed by Sethi (1931) were noticed. The drought resistant varieties were characterised by the presence of more of thicker roots which go obliquely and vertically downwards and concentrated in the central region. The root spread was less in these varieties, whereas the drought susceptible varieties have their roots which are mostly thin occupying the surface soil up to a depth of 15 cm. Depth of penetration is much more in the resistant varieties confirming the observations made in the study of the hybrid progenies of the drought resistant crosses in the field as well as the varieties grown in the root development apparatus.

The number of roots and the total length of the root system are higher in the drought resistant varieties and higher root/shoot ratio has been obtained in all of them in the study made in a wet field at a particular stage of growth showing thereby that the drought resistant types posses a characteristic root system despite the supply of abundance of moisture.

The observations made in the dry field under extremely drought condition showed the plants were slow in their growth with poor production of leaves and tillers. Plants wilted at different periods according to their susceptibility to drought, the wet rice being the first to wilt followed by the wild rice *Oryza sativa* var *spontanea*. The development of the root system under this severe condition of water deficit was poor corresponding to that of the shoot development. However, the depth of penetration of the root system showed the inherent capacity of the drought resistant types to elongate their root system into the deeper layers of soil.

Summary: Osmotic pressure of the germinating seed was tested in solutions of sucrose, sodium chloride, copper sulphate and potassium chlorate. By such germination tests it has been possible to distinguish between the drought resistant and drought susceptible types by their differences in percentages of survival. Tests with sucrose solution gave more precise information. Osmotic concentration of tops and roots of rice varieties determined by 'cryoscopic' method showed that in short duration varieties the drought resistant rices have significantly higher osmotic pressure of tops than the drought susceptible varieties. The root extract did not show similar difference. In the medium duration varieties the root concentration was higher in all the drought resistant varieties than the susceptible ones.

Two rice varieties MTU. 17 and Co. 13 tried for their aerial drought resistance were equally efficient towards aerial drought but MTU. 17 uses water more economically and consequently is capable of withstanding soil drought better than Co. 13. Development of the root system in the seedling stage at three inches, six inches, nine inches and twelve inches level of water below the soil surface revealed that the drought resistant types, viz., 'dry' rices extend their root system at a much quicker rate than the drought susceptible 'wet' rices.

Development studies of the root and shoot at 30 percent moisture level in pots have shown that the rate of shoot growth and height of plant are not associated with drought resistance while duration plays a greater part in determinning the rate of growth. The survival of tillers till the blooming stage, is found to be more in the drought resistant types than in the susceptible types due to the better development of the root system in the resistant types which prevent the death of tillers in large numbers. A similar association between the death of leaves and drought susceptibility has been found. More of leaves die away in the drought susceptible types in the early duration varieties. The total leaf area of different rice varieties studied, does not seem to play any part in their drought resistance.

The number and total length of the roots depend upon the duration and the number of tillers. Drought resistant varieties possess more of thick roots and have a greater mean length of the root system. The 'dry' varieties have a greater root/shoot ratio in general than the 'wet' rices though the wild rices are found to be an exception.

The depth of penetration of the root in the wet field shows that the dry rices and wild rices have a longer root system going into the deeper layers of soil. The typical arrangement of the root system in the resistant types, which have more of thick roots going obliquely and vertically down into the soil help them to go deeper. In the drought susceptible types more of thin fibrous roots are found concentrated in the top soil and the depth of penetration is much less. The root number, total length of the root system and dry weight are more in the case of drought resistant types, and a high root/shoot ratio has been obtained in all of them.

The study of the root system in a dry field has shown that the 'wet' rices are the earliest to wilt followed by the 'wild' rices. Root penetration is greatest in the 'dry' rice varieties even exceeding their shoot growth. The 'wild' rices have a slightly longer root system than the 'wet' rices.

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TABLE 1

Percentage survival of rice varieties in solutions of sucrose, sodium chloride, copper sulphate and potassium chlorate

S. No.	Name of variety	Percentage surviving on the sixth day							Percetage germination after ten days		
		Strength of sucrose solution (molar)							0·25 molar sodium chloride	3 percent copper sulphate	3 percent potassium chlorate
		0·10	0·20	0·25	0·30	0·35	0·40	0·45			
1	GEB. 24 (wet rice)	88	80	77	66	57	27	5	79	78	72
2	MTU. 17 (dry rice)	100	100	100	100	99	75	33	94	86	99
3	MTU. 18 do	100	100	100	100	87	55	17	98	85	98
4	PTB. 28 do	98	97	95	90	85	34	18	100	81	89
5	Bairuvadlu do	96	96	93	89	79	62	21	100	97	95
6	PTB. 30 do	99	99	89	82	81	30	15	..	..	..
7	TKM. 1 do	91	87	79	74	72	30	7	..	..	..
8	TKM. 2 do	97	97	93	87	84	65	19	..	..	..

TABLE 2

Relative transpiration in Co. 13 (wet rice) and MTU. 17 (dry rice) in dry and humid environments

Transpiration in grams per sq. cm. of leaf area				Evaporation in grams, (Piche) per unit area of exposed surface		Relative transpiration. Transpiration by evaporation			
Co. 13		MTU. 17				Co. 13		MTU. 17	
Humid	Dry	Humid	Dry	Humid	Dry	Humid	Dry	Humid	Dry
1·07	0·54	0·47	0·46	0·24	0·57	4·46	0·95	1·96	0·81
0·64	0 87	0·32	0·57	0·24	0·53	2·67	1·64	1·34	1·08
0 27	0·41	0·30	0·46	0·22	0·41	1·23	1·00	1·37	1·12
0·21	0·63	0·13	0·36	0·12	0·35	1·75	1·80	1·09	1·03
0·56	0·44	0·25	0·32	0·22	0·37	2·55	1·19	1·14	0 86
0·31	0·41	0·23	0·30	0·17	0·38	1·82	1·08	1·35	0·79
0·34	0 44	0·27	0·34	0·14	0·37	2·43	1·19	1·93	0·92
0·38	0·37	0·33	0·19	0·14	0·28	2·71	1·32	2·36	0·68
Mean 0·47	0·51	0·29	0·38	0·19	0·41	2·46	1·27	1·57	0·91

TABLE 3

Root and shoot development of wet, dry and wild rice varieties at 3″, 6″, 9″ and 12″ water level below the soil surface

(Mean values)

Name of variety	3″ water		6″ water		9″ water		12″ water	
	Length in centimeters							
	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Co. 13 (wet rice)	18·4	12·9	3·9	9·3	15·5	10·1	8·1	3·5
MTU. 17 (dry rice)	8·0	10·7	13·4	13·7	22·7	30·4	11·8	34·5
Co. 13 (wet rice)	35·7	35·3	38·5	34·7	41·5	42·7	34·9	47·8
PTB. 28 (dry rice)	48·6	46·4	41·9	35·1	46·4	47·9	47·8	52·8
Co. 13 (wet rice)	36·5	28·7	40·2	36·2	40·9	36·9	38·4	37·4
PTB. 30 (dry rice)	33·5	32·8	34·9	34·1	38·1	42·1	34·3	45·8
GEB. 24 (wet rice)	39·1	32·7	30·0	24·9	39·4	34·5	38·7	34·8
Bairavadlu (dry rice)	51·7	34·9	52·2	35·2	40·5	40·9	44·4	41·2
GEB. 24 (wet rice)	20·5	28·5	24·3	24·3	29·9	34·5	27·7	35 6
T. 1702 (wild rice)	31·5	32·4	32·3	32·5	35·8	38·9	35·7	43·7

TABLE 4

Development of root and shoot of rice varieties grown in pots at 30 percent moisture level

(Mean values)

Name of variety	Time of flowering (days)	No. of roots	Thick roots	Thin roots	Total length of root Cm.	Mean length of root Cm.	Dry weight of root gm.
				ROOT			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Short duration:							
Co. 13 (wet)	91	336	129	207	8367	24·9	7·69
MTU. 17 (dry)	72	204	119	85	6141	30·1	6·34
MTU. 18 (dry)	75	319	198	121	9133	28·6	9·16
PTB. 28 (dry)	82	219	152	67	6471	29·5	6·33
PTB. 30 (dry)	75	218	157	61	6493	29·8	8·24
Medium duration:							
GEB. 24 (wet)	117	556	222	334	13773	24·8	10·58
TKM. 1 (dry)	113	422	272	150	12869	30·5	13·99
TKM. 2 (dry)	109	449	277	172	11405	25·4	10·66
Bairuvadlu (dry)	103	451	287	164	12084	26·8	12·76
T. 129 (wild)	109	612	195	417	14331	23·41	9·06
T. 740 (wild)	113	395	282	113	11401	28·9	9·27
T. 1702 (wild)	109	259	172	87	6445	24·9	8·82

Name of variety	Height of shoot Cm.	Number of tillers	No. of productive tillers	No. of leaves	Dry weight of shoot gm.	Root/shoot
			SHOOT			
	(9)	(10)	(11)	(12)	(13)	(14)
Short duration:						
Co. 13 (wet)	121·3	24	15	113	31·83	0·242
MTU, 17 (dry)	86·1	32	24	103	22·36	0·283
MTU. 18 (dry)	82·7	36	27	143	29·49	0·311
PTB. 28 (dry)	127·6	12	11	70	25·14	0·252
PTB. 30 (dry)	91·2	31	21	104	26·92	0·306
Medium duration:						
GEB. 24 (wet)	89·8	53	24	189	40·91	0·259
TKM. 1 (dry)	94·9	21	15	128	35·17	0·398
TKM. 2 (dry)	112·1	26	14	130	37·21	0·287
Bairuvadlu (dry)	104·7	26	14	126	35·59	0·359
T. 129 (wild)	94·9	63	30	218	44·01	0·206
T. 740 (wild)	101·8	26	18	129	37·58	0·247
T. 1702 (wild)	109·6	19	12	86	26·53	0·333

TABLE 5

Tillering of dry, wet and wild rice varieties grown in pots at 30 per cent moisture level measured at weekly intervals. (Mean values)

A

Short duration varieties			Number of tillers	
Co. 13 (wet rice)	MTU. 17 (dry rice)	MTU. 18 (dry rice)	PTB. 28 (dry rice)	PTB. 30 (dry rice)
0	0	0	0	0
3	3	3	3	4
6	7	6	5	7
11	13	13	10	14
15	17	22	11	20
19	26	31	12	23
23	28	35	12	26
24	31	36	12	28
24	32	36	12	28
24	..	36	12	31
24	..	..	12	..
20	..	..	..	..

B

Medium duration varieties				Number of tillers		
GEB. 24 (wet rice)	TKM. 1 (dry rice)	TKM. 2 (dry rice)	Bairuvadlu (dry rice)	T. 129 (wild rice)	T. 740 (wild rice)	T. 1702 (wild rice)
0	0	0	0	0	0	0
3	4	3	3	4	3	2
6	8	8	6	6	6	3
12	13	13	11	12	11	7
21	18	21	18	25	17	12
32	19	24	23	36	22	17
46	21	25	26	49	25	19
50	21	26	26	53	26	19
52	21	26	26	57	26	19
53	21	26	26	63	26	19
53	21	26	26	63	26	19
46	21	25	24	60	24	16
45	21	22	21	59	24	14
35	20	19	20	56	23	13
26	17	..	..	..	22	..
24	..	..	..	..	..	..

TABLE 6

Leaf area of wet, dry and wild rice varieties

(Mean values)

S. No.	Name of variety		Number of leaves	Length in cm. (1)	Breath in cm. (b)	Leaf area in sq. cm. (21 x b)	Total transpiring (area sq. cm.)
Short duration							
1.	Co. 13	(wet rice)	113	28·3	0·66	37·4	4221·7
2.	MTU. 17	(dry rice)	103	25·5	0·73	37·2	3833·7
3.	MTU. 18	,,	143	23·5	0·77	36·2	5175·2
4.	PTB. 28	,,	70	37·9	0·78	59·1	4138·4
5.	PTB. 30	,,	104	26·0	0·81	42·1	4380·4
Medium duration							
6.	GEB. 24	(wet rice)	189	33·1	0·47	31·1	5876·0
7.	TKM. 1	(dry rice)	128	34·8	0·60	41 7	5337·6
8.	TKM. 2	,,	130	34·2	0·68	46·5	6042 4
9.	Bairuvadlu	,,	126	37·9	0·59	44·7	5630·9
10.	T. 129	(wild rice)	218	30·3	0·41	24·9	5421·7
11.	T. 740	,,	129	30·1	0·58	34·9	4502·1
12.	T. 1702	,,	86	39·9	0·69	55·1	4738·6

TABLE 7

Development of root and shoot of rice varieties grown in a wet field

(Mean values)

Name of variety	Root							
	Depth of penetration cm.	Approximate lateral spread cm.	No. of roots	Thick root	Thin root	Total length of root cm.	Mean length of root cm.	Dry weight of root gm.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Short duration:								
Co. 13 (wet)	39·3	25–30	101	49	52	2356	23·3	1·19
MTU. 17 (dry)	55·2	20–25	144	81	63	3684	25·6	1·49
PTB. 28 (dry)	50·8	20–25	94	56	38	2397	25·5	1·25
Medium duration:								
GEB. 24 (wet)	48·9	25–30	127	25	102	2873	22·6	0·80
TKM. 1 (dry)	71·8	20–25	251	142	109	8738	34·8	3·97
TKM. 2 (dry)	55·2	20–25	152	83	69	4139	27·2	1·71
Bairuvadlu (dry)	61·9	20–25	166	111	55	4272	25·7	1·97
T. 129 (wild)	63·7	25–30	263	194	69	7222	27·5	4·39
T. 740 (wild)	63·1	25–30	243	152	91	6326	26·0	3·10

Table 7 (Contd.)

Name of variety	Shoot				
	Height of shoot (cm)	No. of tillers	No. of leaves	Dry weight of shoot (gm)	Root/shoot
	(10)	(11)	(12)	(13)	(14)
Short duration					
Co. 13 (wet)	80·4	10	37	7.33	0·154
MTU. 17 (dry)	75·7	14	32	5·44	0·274
PTB. 28 (dry)	87·5	5	20	5·16	0·242
Medium duration					
GEB. 24 (wet)	59·3	9	31	4 54	0·176
TKM. 1 (dry)	85·3	11	43	14·98	0·265
TKM. 2 (dry)	71·8	8	33	7·76	0·220
Bairuvadlu (dry)	82·7	6	26	8·49	0·232
T. 129 (wild)	67·7	14	48	13·91	0·316
T. 740 (wild)	87·6	14	46	13·37	0·232

APPENDIX

Description of rice varieties used in the study

1. **PTB. 28.** 'Kattamodan'. Isolated from Kattamodan, a dryland variety common in the West Coast. When sown in June it matures in 100 days. Under good manuring it yields upto 2,000 lb. per acre. It is grown in wetland also for its short duration. Duration: 100 days, Grain size: L. 8·7 mm., B. 3·1 mm., T. 2·2 mm. Glume colour: Straw; Rice: red.

2. **PTB. 29.** 'Karutha (Black) modan'. Isolated from Karuthamodan, a dryland variety popular in West Coast. This is slightly earlier than Kattamodan. It matures in 90—95 days when sown in May—June, Duration: 90 to 95 days, Grain size: L. 8·8 mm., B. 3·0 mm., T. 2·2 mm., Glume colour: Black; Rice: Red.

3. **PTB. 30.** 'Chuvanna (dirty glume) modan'. Isolated from Chuvannamodan, a dryland variety grown in the West Coast. It is earlier than blackmodan. Duration: 85-90 days, Grain size: L. 8·5 mm., B. 3·0 mm., T. 2·2 mm, Glume colour: Brown furrows; Rice: red.

4. **MTU. 17.** 'Kodi Budama'. Isolated from Kodibudama, a variety grown in the heavy black soils of Godavary, Krishna and Guntur districts, purely under rainfed conditions between the months of June-October when a rainfall of 20 to 30 inches is received. Under favourable condition it yields upto 1,500 lb. grain per acre. Time of harvest: Middle of October, Grain size: L. 8·2 mm., B. 2·9 mm., T. 2·1 mm., Glume colour: Dull straw; Rice: Red.

5. **MTU. 18.** 'Kodi Jillama'. Isolated from Kodijillama, a variety grown in the heavy soils of Godavari, Krishna and Guntur districts, purely under rainfed condititions. It is a fortnight later than MTU. 17. Under favourable conditions it yields 1,500 lb. grain per acre. Time of harvest: End of October, Grain size: L. 8·2 mm., B. 2·9 mm., T. 2·0 mm., Glume colour: Dull straw; Rice: Red.