PULLING FORCE AND ITS RELATIONSHIP WITH ROOT CHARACTERISTICS OF THE RICE PLANT SEEDLING STAGE

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RINGKASAN

Untuk mendapatkan suatu metoda "screening" toleransi terhadap kekeringan pada padi tanah kering yang sederhana, cepat dan dapat diukur secara kwantitatif, dilakukan penelitian untuk menetapkan apakah metoda pengukuran kekuatan pencabutan bibit padi dapat digunakan untuk metoda yang dimaksud.

Penelitian ini dilakukan di IRRI dari Oktober 1976 sampai dengan Maret 1977.

Dalam penelitian ini ditanam secara sawur tinggal (tanpa pemindahan) 6 varietas yang diduga berbeda-beda tingkat toleransinya terhadap kekeringan di sawah dengan pengairan, 1 bibit per lobang. Dalam penelitian ini digunakan pola "Randomized Complete Block" yang terdiri dari 4 ulangan. Kekuatan pencabutan bibit diukur dengan menggunakan "dynomometer" yang berkapasitas 30 kg, pada umur-umur 3, 4, 5 dan 6 minggu sesudah tanam. Di samping itu juga diamati sifat perakaran dari masing-masing varietas.

Hasil penelitian adalah sebagai berikut :

1. Diketahui adanya hubungan antara kekuatan pencabutan dengan nilai toleransi kekeringan yang diukur secara visuil dengan metoda yang telah ditetapkan oleh IRRI.
2. Diketahui adanya perbedaan varietal yang nyata dalam kekuatan pencabutan, sifat perakaran seperti jumlah akar, jumlah akar besar, panjang akar, berat akar dan percabangan akar.
3. Di antara 4 waktu pengamatan, pengamatan yang dilakukan pada minggu ke 4 dan ke 5 diduga merupakan fase yang paling tepat untuk mengukur kekuatan pencabutan dan sifat perakaran kecuali ratio pucuk terhadap akar.
4. Sifat perakaran yang paling berpengaruh terhadap kekuatan pencabutan ialah jumlah akar besar (garis tengah $>$ 1 mm) percabangan akar, berat akar dan panjang akar.

SUMMARY

An experiment was done at the International Rice Research Institute to search for a simple, fast and quantitatively measurable drought screening method in rice plants. The objective was to determine whether the pulling force technique in rice seedling can be used as a desired method.

In this study, 6 varieties representing different level of drought tolerance were direct-seeded in the wet seed bed, one seedling per hill. Randomized complete block design was used in this experiment with 4 replication. The pulling force was measured using scale or dynamometer with 30 kg capacity, at 3, 4, 5 and 6 weeks after seeding.

The following were the result of the experiment :

1. There was a relationship between pulling force and field drought tolerance rating.
2. There were significant varietal differences in pulling force and root characteristics, especially root number, thick root number, root length, root weight and root branching.
3. Among the 4 dates of observation, 4 and 5 weeks after seeding were the proper time to measure the pulling force and root characteristics except root to shoot ratio.
4. The most important root characteristics which influence the pulling force were thick root number, root branching, root weight, and root length.

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PREFACE

The paper entitled "PULLING FORCE AND ITS RELATIONSHIP WITH ROOT CHARACTERISTICS OF THE RICE PLANT IN SEEDLING STAGE" is the author's report of his short training at the International Rice Research Institute, covering a period of time from October 1, 1976 to March 15, 1977.

INTRODUCTION

Upland rice is an important, although not the major system of growing rice, because its area is nearly a sixth of the world's total rice land. Even the average yield is around .5 – 1.5 tons per hectare, the production would substantially influence total rice production (De Datta, 1975).

It seems that upland rice grain yield are at present lower than it could be. Many experiment stations reported high yield for upland rice, i.e. 7.2 tons per hectare in Peru, 7 tons per hectare in the Philippines and 5.6 tons per hectare in Nigeria (Faye, 1973).

Among other reasons for low yield of upland rice is the lack of improved upland rice variety, which is high in yielding and resistant to drought.

Improved lowland varieties usually could not fit in upland condition because most of them are drought susceptible.

The important factor which inhibits the progress of upland rice breeding program is the scarcity of the fast, simple and practical method of screening drought resistance.

In this study, an attempt is made to find out that required method by studying the relationship between pulling force needed in uprooting of seedling and the components of drought resistance from the root point of view.

REVIEW OF LITERATURE

Levitt (1972) distinguished basic ways in which plants can grow and survive in dry habitat. Adaptation to dry growing conditions consist of two aspects, i.e. escaping drought and resistance to drought. The second aspect is divided into two ways, i.e. drought avoidance and drought tolerance.

Sullivan (1971) mentioned that there are many different techniques available for screening drought resistance, but none of them has ever been critically examined. Because of the complexity of factors involved in drought resistance, no single technique can be satisfactory.

Yoshida et al (1974) summarized promising techniques for measuring drought resistance. From technical point of view, the techniques are well developed.

Most of the techniques need such sophisticated equipment and time consuming that could not handle so many breeding lines in a relatively short time.

Loresto and Chang (1974) used visual field rating based on plasticity of leaf rolling and unfolding, death of leaf, degree of stunted growth in a simulated upland culture and rainfed culture in both the dry and wet season.

Wright (1964) stated that mass screening under range conditions subject to fluctuations of environmental condition on specific location and season which are hazardous, time consuming and sometimes environmental pressure suppress the expression of seedling drought tolerance, and lack of precision. Further, Wright and Jourdan (1970) concluded from their experiment in evaluation among range grass genera and species that artificial selection and evaluation for seedling drought tolerance under program controlled environment is very agree with the performance under natural environment. But the breeding materials that can be evaluated by this method is very limited.

In this case Hurd (1971) suggested that in choosing parent material for crossing, elaboration is necessary by greenhouse method and all kinds of elaborate screening method, and range land performance test used as a final rating.

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Studies in the International Rice Research Institute also concluded that drought resistance classified using constant water table 45 cm below surface in the greenhouse, relative plant height in field stress, and visual rating in the field are generally agree. Those three techniques appear to measure the degree of avoidance (IRRI, 1974).

Many researchers associate drought avoidance with the ability to maintain a favorable water balance in water stress by conserving water and improving water uptake. Improving water uptake could be achieved by efficient root system which is reflected by the extensive root growth, specifically in deep penetration and thick root number.

Mac Key (cit Gupta 1973) and Hurd (1975) in their study on root system in wheat concluded that an extensive root system in branching, deeply penetrating are associated with drought resistance and is an advantage to a plant especially in time of water shortage. Mac Key also stated that root patterns are genetically controlled even though are sensitive to the soil environment.

Hasegawa (cit De Datta 1975) stated that roots of upland varieties are longer than roots of lowland rice. Their root to shoot ratio also higher in upland rice.

Minabe (cit De Datta 1975) reported that in his study indicate that drought resistance in Javanese lowland varieties are also associated with root number, total root length, root depth and length of the root.

Research in IRRI (IRRI, 1974) indicated the following point :

– Root of upland rice variety is usually characterized by deeper penetrating, greater amount of thick root and fewer number of total amount of root, while root of typical semidwarf characterized by thinner, fibrous and greater amount.

– The varietal differences in root system was observed at 14 days after seeding, and became obvious at 60 days after seeding. But differences are little on puddled and flooded soil even at 60 days after seeding.

– Drought resistance appear to be associated with depth of the root penetration, the mean diameter of the thick roots and to a lesser extent with the number of thick root.

Hurd (cit Gupta, 1973) stated that simple technique for screening out highly susceptible material early in the breeding program is needed. He reported that some cultivars of wheat produce more root in the seedling stage than other cultivars and that these also had more at maturity by weight.

Hurd (1975) concluded from his study on root characteristics in wheat that an extensive root system is associated with drought resistance. He stated further that root pattern are recessive heriditary character. Under wet condition the difference in the amount of root were small between semidwarf and traditional height, but under severely droughted test, semidwarf root may be reduced more than tall line.

Hurd (1968) again in studying root growth of seven varieties of spring wheat at high and low moisture level concluded that some varieties penetrate its root in the dry soil more quickly than in the wet soil and more quickly than other varieties at both low and high moisture level.

At present, unfortunately there is no simple method to evaluate the root system in different varieties.

Miyasaka (cit De Datta, 1975) indicated in his study that there were some degree of correlation between pulling strength and the cross sectional area of the root.

Rogers et al (1976) in their study on screening of corn population for resistance to corn root worm indicated effectively method by using pulling technique.

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This experiment is to study whether the pulling technique in uprooting of rice seedling can be effectively used in screening drought resistance, specifically drought avoidance.

Objectives of the study

The detail objectives of the study are to try to answer the following questions :

1. Is there any relationship between pulling force and drought resistance, specifically drought avoidance rated by visual field scoring.

2. If the first assumption is true, the second question is that is there any significant differences in pulling force and root characteristics among the varieties. Root characteristics mean the length of the root total number of root, thick root number, root weight, root to shoot ratio and root branching.

3. What root characteristics are closely associated with pulling force.

4. How young a rice plant (between 3 – 6 weeks after seeding) in the wet seed bed can be used to measure root characteristics and pulling force properly.

MATERIALS AND METHODS

The following six varieties representing different level of drought tolerance were used in the experiment.

The seeds of those 6 varieties were direct seeded in the irrigated field after presoaking treatment and incubation for 24 hours, respectively.

Each variety was seeded in 4 rows plot of 1.5 meter length, spacing within and between row were 10 and 20 cm, respectively. There were 4 different seed beds for 4 dates of observation, at the third, fourth, fifth, and sixth week after seeding. Each seed bed was divided into 4 replications/blocks.

Each hill was planted with 3 – 5 seeds and thinned up to 1 seedling per hill at 1 week after seeding.

Varieties were randomized within each replication, and dates of observation were randomized among seed beds. Fertilizer was not applied to avoid ununiform growth of seedling, because of the experiment only cover a short period of time. Hand weeding was done twice, at the first and at the fourth week after seeding succeedingly. Protection from insect was accomplished by application of Furadan granules at 1.5 kg per ha a.i. Water was maintained about 3 – 5 cm high during the experiment.

The following data were recorded from the 2 middle rows and 40 cm from both ends of the row :

1. Pulling force was measured on eight hills, taken alternately, in each variety and each replication. Pulling force was measured by using scale (dynamometer) with 30 kg capacity.

2. Root characteristics which are root number, thick root number, root length, root branching, root weight, and root to shoot ratio after dried in the drying oven at 80 centigrade during 48 hours, were measured and counted on 4 hills, for each variety and each replication.

To determine whether there was a relationship between pulling force and drought tolerance score, based on the standard evaluation system for rice, visual field rating record from the Agronomy Department, IRRI, was also collected.

To compute the correlation coefficient of each pair of the root characteristics, pulling force and drought tolerance score, the following simple formula was used :

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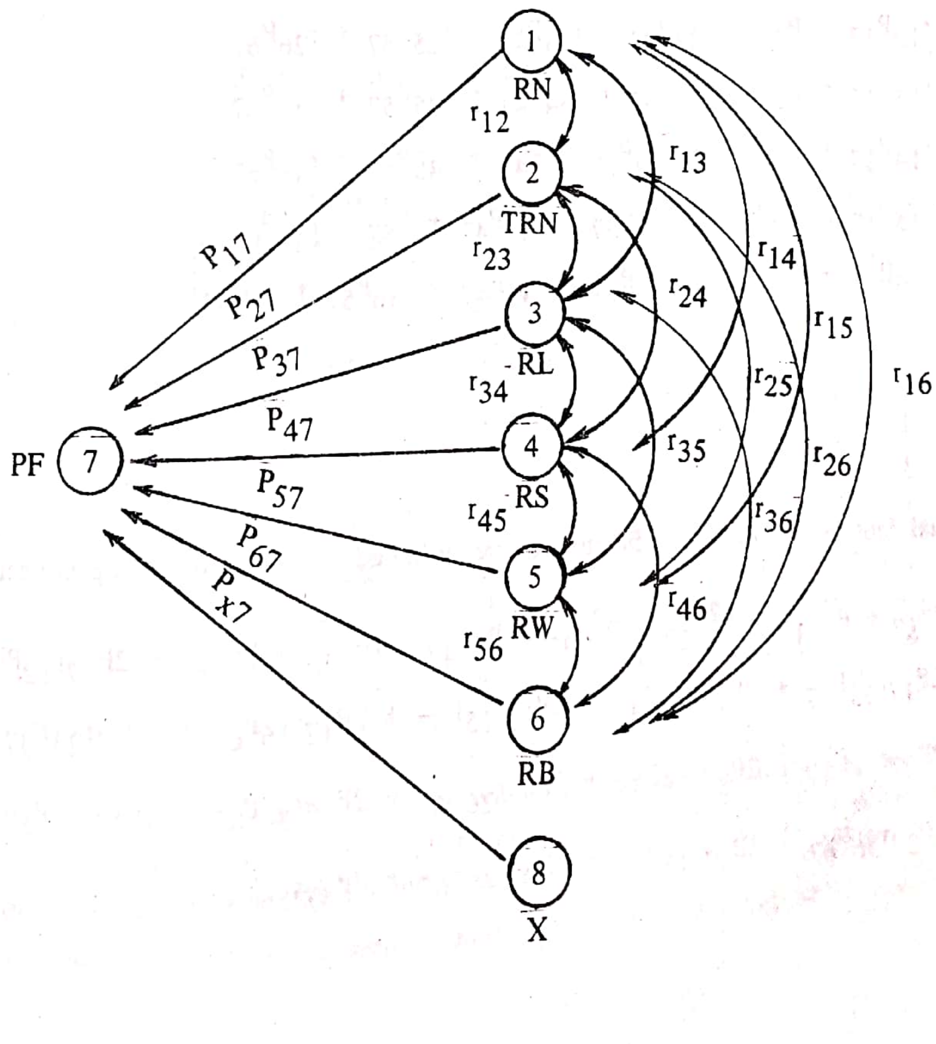
$$r = \frac{\Sigma XY - n\,\overline{XY}}{\sqrt{(\Sigma X^2 - n\,\bar{X}^2)(\Sigma Y^2 - n\,\bar{Y}^2)}}$$

To determine whether there were significant differences among the varieties on pulling force and root characteristics, two ways of classification analysis of variance with 6 treatments and 4 replica - tions was used for each date of observation.

To determine how young a rice plant between 3 and 6 weeks after seeding in the wet seed bed can be used to measure the root characteristics and pulling force properly, it means indicate clearly differences among varieties, ratio of varietal variance and total variance were also computed for each date of observation.

To measure the direct influence of one variable upon another, and permits the separation of the correlation coefficient into components of direct and indirect effects, the path coefficient analysis as given by Dewey and Lu (1959) was used. Seven variables were included in the path coefficient analysis. The nature of the causal system is represented diagrammatically as follows:

In the path diagram, the double arrowed lines indicate mutual association as measured by correlation coefficient r_{ij}, and the single arrowed lines represent direct influence as measured by path coefficients P_{ij}.



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where :

1. RN : Root number
2. TRN : Thick root number
3. RL : Root length
4. R/S : Root to shoot ratio
5. RW : Root weight
6. RB : Root branch
7. PF : Pulling force
8. X : Residual factors, which is assumed to be independent.

The path coefficients in this particular instance were obtained by the simultaneous solution of the following equations, which express the basic relationship between correlation and path coefficient, using abbreviated Doolittle method.

1. $r_{17} = P_{17} + r_{12}P_{27} + r_{13}P_{37} + r_{14}P_{47} + r_{15}P_{57} + r_{16}P_{67}$
2. $r_{27} = r_{12}P_{17} + P_{27} + r_{23}P_{37} + r_{24}P_{47} + r_{25}P_{57} + r_{26}P_{67}$
3. $r_{37} = r_{13}P_{17} + r_{23}P_{27} + P_{37} + r_{34}P_{47} + r_{35}P_{57} + r_{36}P_{67}$
4. $r_{47} = r_{14}P_{17} + r_{24}P_{27} + r_{34}P_{37} + P_{47} + r_{45}P_{57} + r_{46}P_{67}$
5. $r_{57} = r_{15}P_{17} + r_{25}P_{27} + r_{35}P_{37} + r_{45}P_{47} + P_{57} + r_{56}P_{67}$
6. $r_{67} = r_{16}P_{17} + r_{26}P_{27} + r_{36}P_{37} + r_{46}P_{47} + r_{56}P_{57} + r\ P_{67}$

and for the residual factors, its path coefficient can be obtained from the following equation :

7. $1 = P^2_{x7} + P^2_{17} + P^2_{27} + P^2_{37} + P^2_{47} + P^2_{57} + P^2_{67} + 2P_{17}r_{12}P_{27} + 2P_{17}r_{13}P_{37} + 2P_{17}r_{14}P_{47} + 2P_{17}r_{15}P_{57} + 2P_{17}r_{16}P_{67} + 2P_{27}r_{23}P_{37} + 2P_{27}r_{24}P_{47} + 2P_{27}r_{25}P_{57} + 2P_{27}r_{26}P_{67} + 2P_{37}r_{34}P_{47} + 2P_{37}r_{35}P_{57} + 2P_{37}r_{36}P_{67} + 2P_{47}r_{45}P_{57} + 2P_{47}r_{46}P_{67} + 2P_{57}r_{56}P_{67}.$

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RESULTS AND DISCUSSION

1. Germination percentage, germination speed index and field drought tolerance rating

Germination percentage and germination speed index were computed based on 50 seeds per variety, without replication, so that statistical analysis could not be accomplished. Germination speed index was computed by adding the quotients of the daily counts of germination divided by the number of days of germination (Please see the following table).

It was observed that even though there were almost no difference in germination percentage, germination speed index of M1–48 variety was the lowest. This fact will explain why the root characteristics of M1–48, especially root to shoot ratio was the smallest in this experiment, and in contrast with the previous result in the IRRI. The previous result in IRRI stated that the root length, root to shoot ratio, and the number of thick root of most of the upland varieties included M1–48 were superior than lowland varieties which are susceptible to drought.

The germination speed index reflects the vigour of the seed growth at least in the early stage of growth.

2. Relationship between pulling force and field drought tolerance rating

Field drought tolerance rating was done by Plant Breeding Department and Agronomy Department of the International Rice Research Institute, during the dry season 1976 both at vegetative stage of growth (Table 3).

Germination percentage and germination speed index of the seeds used in the experiment.

Variety	Germination percentage	Germination speed index				
		2 Days	3 days	4 days	5 days	Total
				after germination		
IR 26	98%	18/2	31/3	0/4	0/5	19.3
IR 20	98%	16/2	31/3	2/4	0/5	18.8
T (N) 1	96%	40/2	8/3	0/4	0/5	22.7
IR 1750 F_5B-5	100%	25/2	22/3	2/4	1/5	20.5
IR 442-2-58	96%	30/2	18/3	0/4	0/5	21.0
M1-48	100%	8/2	34/3	8/4	0/5	17.3

To show the relationship between pulling force and field drought tolerance rating, the regression correlation coefficient were computed. Because of the largest varietal variance to total variance ratio, pulling force measurement at the second date of observation was used in this computation (Fig. 1).

It was observed that there were relationship between pulling force and field drought tolerance rating.

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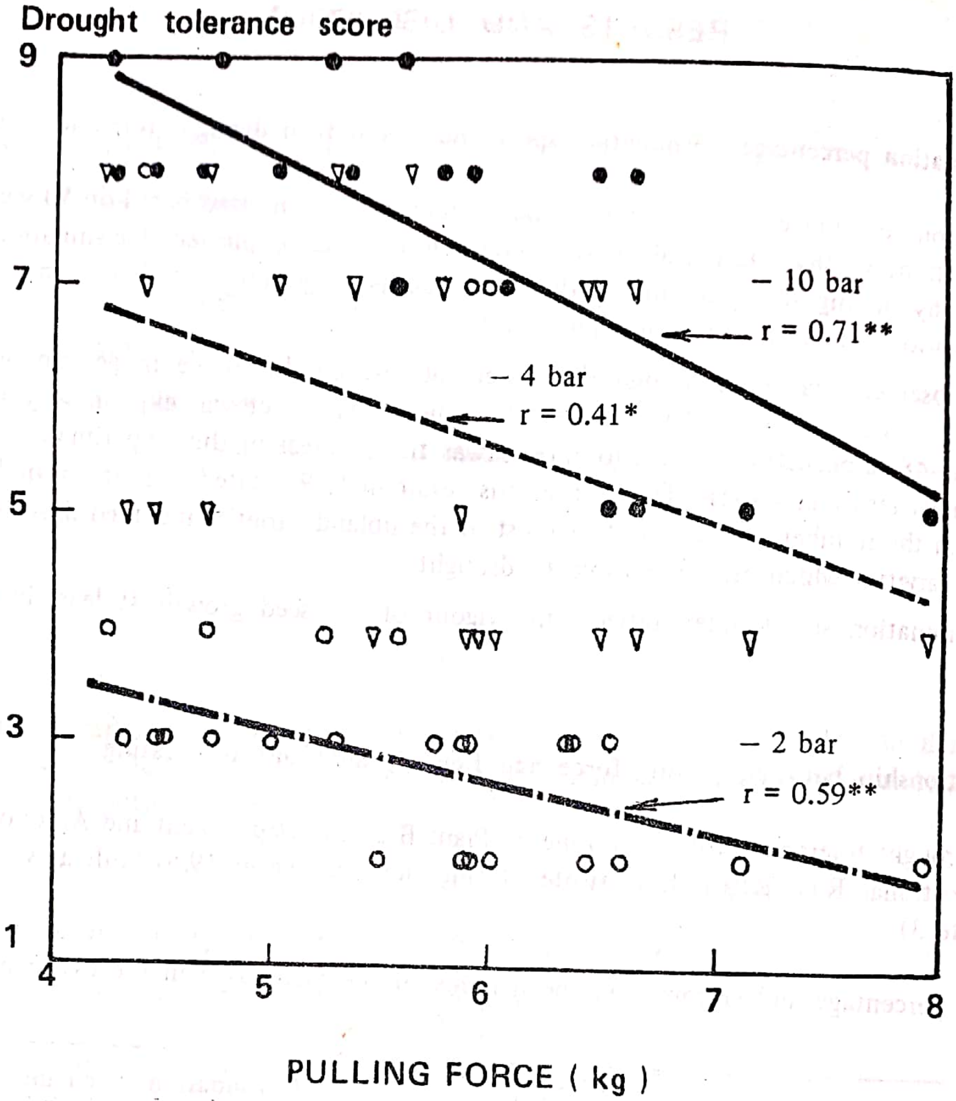

Fig. 1. Relationship between pulling force and drought tolerance score at three progressively severe moisture levels (–2, –4 and –10 bars soil moisture tension). Dry season 1976 upland field screening, IRRI.

Heavier the stress showed more closely relation as reflected by the significant regression at - 10 bars stress.

3. Differences of pulling force and root characteristics among varieties

Pulling force and root characteristics were measured four times, i.e. at the third, fourth, fifth, and sixth week after seeding succeedingly.

It was observed that there were significantly differences of pulling force, root number, thick root number, and root branching at all dates of observation, significant difference of root length at the first, third and fourth observations, significant difference of root weight at the first, second and third observations, and significant difference of root to shoot ratio at only the second observation (Table 4).

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Except root to shoot ratio, all of the other root characteristics and pulling force showed significant differences among the varieties at almost all four dates of observation.

Root to shoot ratio of variety M1–48 was always lower than the other varieties at all dates of observation. The previous experiment in the IRRI (Annual Report, 1974) showed that root to shoot ratio of upland varieties, included M1–48, are higher than lowland/drought susceptible varieties at 60 days after seeding. The last observation in this experiment was at 42 days after seeding. It is assumed that the largest variation of root to shoot ratio among the varieties which measured by varietal variance to total variance ratio has not been reached yet at 42 days after seeding.

Root length, root weight, and also root to shoot ratio, were not always significantly different at all observations. This fact are agree with the pervious result that concluded that in puddled and flooded condition, the differences of root characteristics are little and not so clear even at 60 days after seeding (Hasegawa, Minabe as cited by De Datta 1975; Hurd, 1975; and IRRI, 1974).

If the experiment to be conducted under water stress or upland condition on the light or sandy soil, the differences might be more clear, even before 60 days after seeding. Using light soil is suggested to avoid difficulties in measuring pulling force under upland condition, i.e. stem/straw broken because of the pulling force needed is larger than straw length.

4. Coefficient of variation and varietal variance to total variance ratio

The coefficient of variation and varietal variance to total variance ratio were used as criteria to determine how young a rice plant between 3 – 6 weeks after seeding in the wet seed bed can be used to measure root characteristics and pulling force properly.

Theoretically, coefficient of variation should decrease and varietal variance to total variance ratio should increase from the first observation up to the fourth observation.

This experiment showed that this tendency was not clear. It is because of the experiment was conducted in the field, where environmental condition, especially micro-environmental could not be controlled perfectly, and measurement of all characteristics were based on the individual plant.

Theoretically, the proper time of measurement should coincide with the lowest coefficient of variation, or the highest varietal variance to total variance ratio. It was interesting to note that for each root characteristics and pulling force, the lowest coefficient of variation always agree with the largest varietal variance to total variance ratio, at the same date of observation except for the root number.

Most of the lowest coefficient of variation and the highest varietal variance to total variance ratio fall at the second and the third observation, or at 4 and 5 weeks after seeding.

Based on this fact, in general can be concluded that the proper time to measure pulling force and root characteristics (root to shoot ratio excluded) on wet seed bed was at the 4 – 5 weeks after seeding.

5. Correlation coefficient and path coefficient of pulling force and root characteristics

To determine what root characteristics are closely associated with pulling force, correlation coefficient between pulling force and root characteristics were computed for the second and third observation, where coefficient of variation and varietal variance to total variance ratio were mostly the lowest and the highest value, based on 24 values (6 varieties x 4 replications) (Tables 6 & 7).

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Omitting root to shoot ratio because there is no direct relationship with pulling force, a number of important relationship can be observed in Table 6 and 7. Pulling force was closely related with root weight, root branching, root length, and a lesser extent with thick root number. The less association of thick root number with pulling force probably caused by its negative correlation with root branch and significantly negative correlated with root number, which in turn, root branching was closely associated and root number was less associated with pulling force. Although root number was less associated with pulling force, its relation with root weight and root branching was significant.

Apparently some of the root characteristics were correlated because of a mutual association, positive of negative with other root characteristics. As more variable are considered in the correlation matrix, these indirect associations assumed to be more complex and less obvious.

Even though path coefficient analysis provides an effective means of untangling direct and indirect causes of association and permits a critical examination of the specific forces acting to produce a given correlation and measures the relative improtance of each causal factor, it will also somewhat perplexing if more than one date of observation to be considered, because of the environmental condition, especially microenvironmental condition, will change from time to time.

To determine further the direct effect of each root characteristics upon pulling force and measures the relative importance of each causal factor, based on the above reason, the path coefficient was computed only at the second date of observation, where the variety variance to total variance ratio of the pulling force was the largest (Fig. 2)

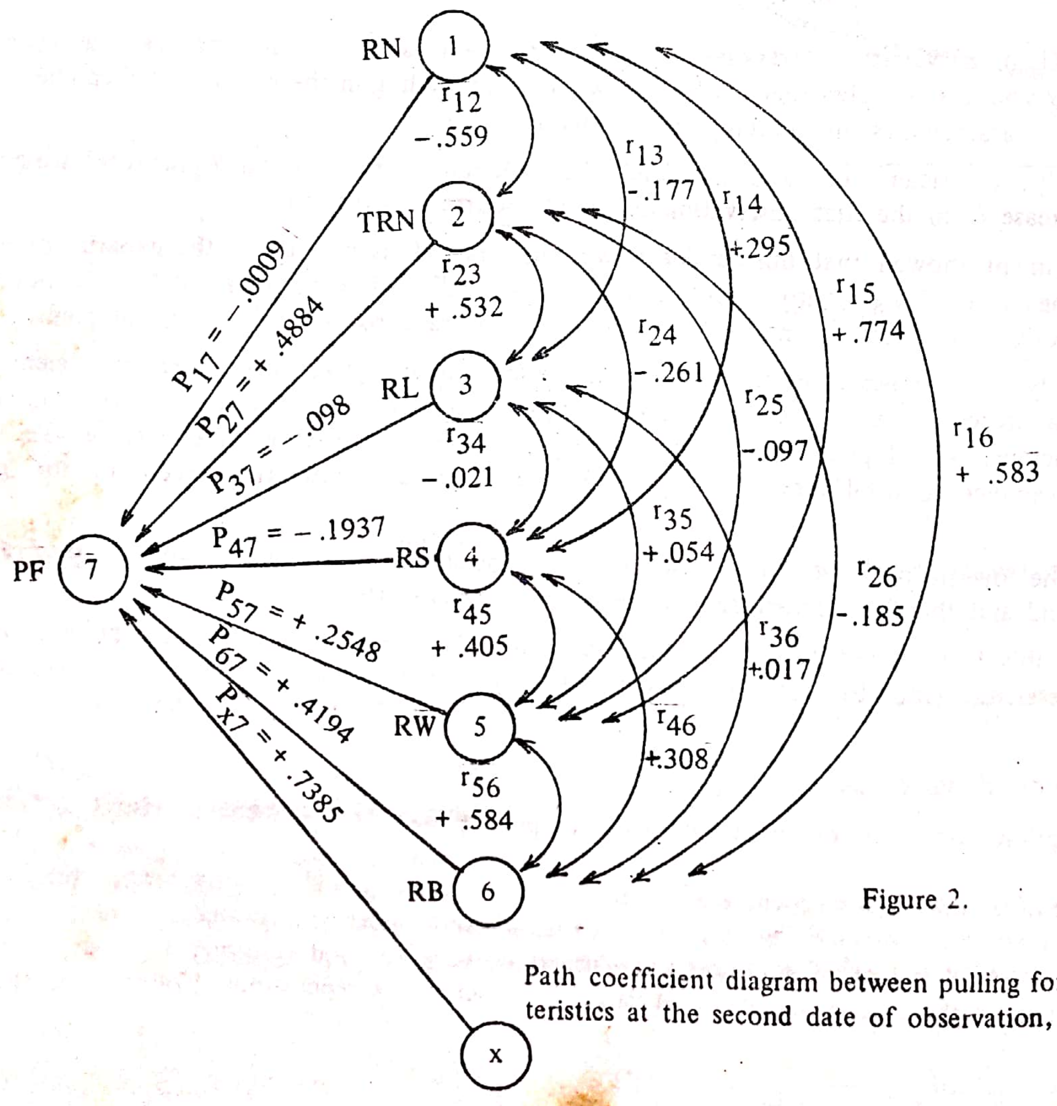

Figure 2.

Path coefficient diagram between pulling force and root characteristics at the second date of observation, based on 24 values.

The diagram shown in Fig. 2 facilities the understanding of the nature of the cause and effect system. The diagram showed that pulling force is the result of root number, thick root number, root length, root weight, root branching, and a composite variable that includes all other factors affecting pulling force. This composite was called residual and assumed to be independent. The first 5 variables are themselves interrelated; consequently, each factor influences pulling force by a direct contribution and by acting in combination with the 4 other variables with which it is correlated.

Although there is no direct relationship between root to shoot ratio and pulling force, root to shoot ratio was included in this diagram because of its close relationship with drought tolerance.

The following are the break down of each relationship of root characteristics and pulling force.

Root number vs. pulling force		r_{17} : + .128
Direct effect of RN (P_{17})	: –.0009	
Indirect effect of RN via TRN ($r_{12}P_{27}$) ...	: –.2730	
Indirect effect of RN via RL ($r_{13}P_{37}$) ...	: +.0173	
Indirect effect of RN via RS ($r_{14}P_{47}$) ...	: –.0571	
Indirect effect of RN via RW ($r_{15}P_{57}$) ...	: +.1972	
Indirect effect of RN via RB ($r_{16}P_{67}$) ...	: +.2445	
		+
		+ .128

Thick root number vs. pulling force		r_{27} : + .385
Direct effect of TRN (P_{27})	: + .4884	
Indirect effect of TRN via RN ($r_{12}P_{17}$) ...	: + .0005	
Indirect effect of TRN via RL ($r_{23}P_{37}$) ...	: –.0521	
Indirect effect of TRN via RS ($r_{24}P_{47}$) ...	: + .0506	
Indirect effect of TRN via RW ($r_{25}P_{57}$) ...	: –.0247	
Indirect effect of TRN via RB ($r_{26}P_{67}$) ...	: –.0776	
		+
		+ .385

Root length vs. pulling force		r_{37} : + .187
Direct effect of RL (P_{37})	: – .0980	
Indirect effect of RL via RN ($r_{13}P_{17}$) ...	: + .0002	
Indirect effect of RL via TRN ($r_{23}P_{27}$) ...	: + .2598	
Indirect effect of RL via RS ($r_{34}P_{47}$) ...	: + .0041	
Indirect effect of RL via RW ($r_{35}P_{57}$) ...	: + .0138	
Indirect effect of RL via RB ($r_{36}P_{67}$) ...	: + .0071	
		+
		+ .187

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Root to shoot ratio vs. pulling force	....	r_{47}	: − .087
Direct effect of RS (P_{47})	: − .1937		
Indirect effect of RS via RN ($r_{14}P_{17}$) ...	: − .0003		
Indirect effect of RS via TRN ($r_{24}P_{27}$) ...	: − .1275		
Indirect effect of RS via RL ($r_{34}P_{37}$) ...	: + .0021		
Indirect effect of RS via RW ($r_{45}P_{57}$) ...	: + .1032		
Indirect effect of RS via RB ($r_{46}P_{67}$) ...	: + .1292		
			+
			: − .087

Root weight vs. pulling force	....	r_{57}	: + .368
Direct effect of RW (P_{57})	: + .2548		
Indirect effect of RW via RN ($r_{15}P_{17}$) ...	: − .0007		
Indirect effect of RW via TRN ($r_{25}P_{27}$) ...	: − .0474		
Indirect effect of RW via RL ($r_{35}P_{37}$) ...	: − .0053		
Indirect effect of RW via RS ($r_{45}P_{47}$) ...	: − .0784		
Indirect effect of RW via RB ($r_{56}P_{67}$) ...	: + .2449		
			+
			: + .3679

Root branching vs. pulling force	....	r_{67}	: + .416
Direct effect of RB (P_{67})	: + .4194		
Indirect effect of RB via RN ($r_{16}P_{17}$) ...	: − .0005		
Indirect effect of RB via TRN ($r_{26}P_{27}$) ...	: − .0904		
Indirect effect of RB via RL ($r_{36}P_{37}$) ...	: − .0017		
Indirect effect of RB via RS ($r_{46}P_{47}$) ...	: − .0597		
Indirect effect of RB via RW ($r_{56}P_{57}$) ...	: + .1488		
			+
			: + .4159

Specific example of the first relationship will be described to illustrate the utility of the method as an aid in analyzing correlation coefficient.

The correlation coefficient of root number with pulling force (+ .128) consist of 6 components, i.e. direct effect of root number − .0009, indirect effect via thick root number − .2730, via root length + .0173, via root to shoot ratio − .0571, via root weight + .1972, and via root branching + .2445. So the largest contribution of root number to the pulling force was via root weight and root branching, while its direct effect was negative.

Based on the size of P_{x7}, it seems that there were still many other factors influencing pulling force. From the path diagram it was observed that the most important contributors to the pulling force were thick root number, root branching, and root weight.

Unfortunately, the effect of root length upon pulling force could not be seen in this diagram, because there was no significant difference of root length at the second date of observation. Its effect might be clear if path diagram of the third observation to be constructed, because there was a significant correlation between pulling force and root length at the third observation.

Based on the path coefficient diagram (Fig. 2) and correlation matrix (Tables 6 & 7), thick root number, root branching, root weight and also root length should be considered in breeding program to develop drought tolerance rice variety.

CONCLUSION AND SUGGESTIONS

Conclusion

1. There was a relationship between pulling force and field drought tolerance rating. It means that larger the pulling force, more tolerant to drought. The relationship will be more clear under heavier stress. So the pulling technique might be used as a new screening method for drought tolerance, specifically drought avoidance in race.

2. There were significant differences of pulling force and root characteristics among the varieties tested. It means that both pulling force and root characteristics were genetic control. To study further the inheritance of pulling force and root characteristics, hybridization and evaluation of segregating material are required.

3. Among the four dates of observation in this experiment, the second and the third observation (4 and 5 weeks after seeding) considered to be proper growth stage to measure pulling force and root characteristics, except for root to shoot ratio.

4. The most important root characteristics influencing pulling force are thick root number, root branch, root weight, and root length.

Suggestions

1. For the future experiment in screening of breeding material for drought tolerance using pulling technique, planting on light/sandy soil and under upland/water stress condition should be considered.

2. Improvement device for measuring pulling force should be done to minimize personnel influence and increasing precision. Drawing of suggested device is attached.

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Figure 3. Method used to measure the pulling force in this experiment. A : Scale (Dynomometer) is operating. B : Seedling that was uprooted.

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Figure 3. Method used to measure the pulling force in this experiment. A : Scale (Dynomometer) is operating. B : Seedling that was uprooted.

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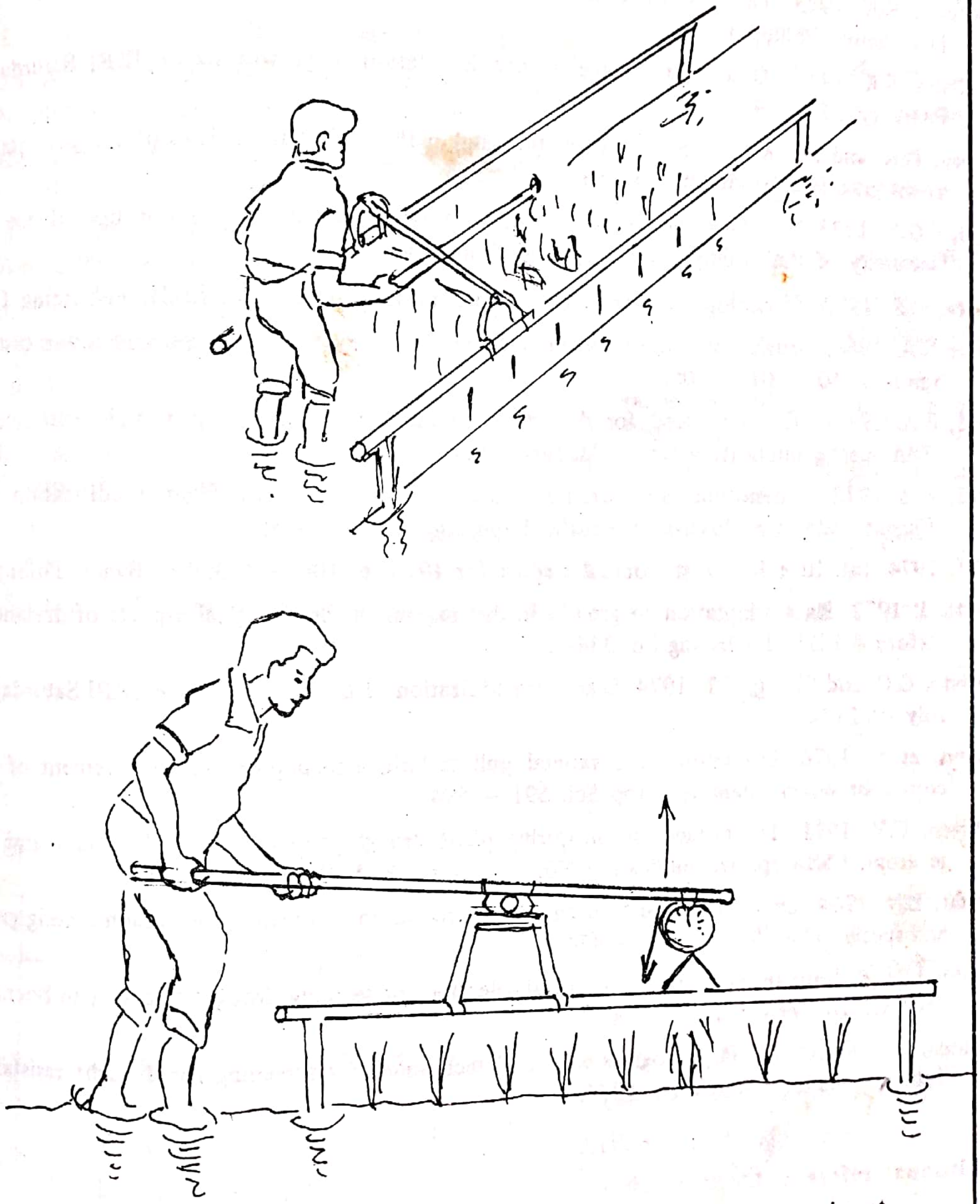

Figure 4. Suggested device to measure pulling force for the next experiment.

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Table 1. Origin and parents of the varieties used in the experiment.

No.	Varieties	Parent / Origin
1.	IR 26	IR 24 x TKM 6
2.	IR 20	IR 262–24–3 x TKM 6
3.	T (N) 1	Dee geo woo gen x Yuan chon
4.	IR 442–2–58	(Peta/2 x TN 1) x LMN
5.	IR 1750–F_5B–5	E 425 x IR 22
6.	M1–48	Local upland rice from the Philippines

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Table 2. Analysis of variance table used in the experiment.

Source of variation	df	M.S.	E (MS)
Varieties	n − 1	MS V	$\sigma_e^2 + r\,\sigma_v^2$
Replication	r − 1	MS R	$\sigma_e^2 + n\,\sigma_R^2$
Error	(n − 1)(r − 1)	MS E	σ_e^2

n = No. of varieties and r = No. of replication

σ_e^2 = MS E : Error Variance

$$\sigma_v^2 = \frac{\text{MS V} - \text{MS E}}{r}$$

$\sigma_e^2 + \sigma_v^2$ = Total Variance

Table 3. Pulling force and field drought tolerance rating of the 6 selected varieties.

Variety	Pulling force (kg)		Field drought tolerance rating			
	2nd obs.	Av. of 4 obs	Plant Breed.*	Agronomy**		
				−2b	−2b	−10b
IR 442–2–58	7.03 a	10.26	4	2	4	5
IR 26	5.83 b	9.31	5	2	4	7
T (N) 1	5.76 bc	8.34	7	3	7	8
IR 1750–F_5B–5	5.63 bcd	9.59	4	3	7	8
IR 20	4.93 cd	7.77	7	4	8	9
M1–48	4.82 d	7.01	4	3	5	8

* At vegetative stage : 1–2, R; 3–4, MR; 5, I; 6–7, MS; 8–9, S.

** At vegetative stage : 1 = none to slight effects of stress;
9 = plants apparently dead.

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Table 4. F calculated AOV of treatment/variety of pulling force and root characteristics at all of 4 dates of observation.

Pulling force and root characteristics	F calculated at			
	1st Obs	2nd Obs.	3rd Obs.	4th Obs.
Pulling force	5.44**	8.58**	5.23**	3.23*
Root number	19.60**	12.23**	25.02**	8.11**
Thick root number	6.94*	14.50**	25.50**	11.11**
Root length	3.22*	2.50^{ns}	3.64*	4.70**
Root to shoot ratio	.56^{ns}	5.65**	1.30^{ns}	.74^{ns}
Root weight	9.33**	7.60**	6.35**	2.64^{ns}
Root branching	4.62**	9.74**	26.67**	11.00**

* – F .05 (15 df) = 2.90; ** – F .01 (15 df) = 4.56

Table 5. The coefficient of variation and varietal variance to total variance ratio of root characteristics and pulling force at four dates of observation.

Pulling force and root characteristics	C.V. (%)				$\frac{\sigma^2_V}{\sigma^2_{Total}}$ (%)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Pulling force	13	10	14	16	53	65	51	36
Root number	13	21	15	20	82	74	86	64
Thick root number	63	33	33	55	60	77	86	72
Root length	8	8	6	5	36	27	40	48
Root to shoot ratio	13	7	11	15	0	54	7	0
Root weight	14	21	19	20	68	62	57	29
Root branching	14	8	8	12	48	69	87	71

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Table 6. Correlation matrix between pulling force and root characteristics of the second observation.

	PF 7	RN 1	TRN 2	RL 3	R/S 4	RW 5	RB 6
PF 7	–	+ .128	+ .385	+ .187	– .087	+ .368	+ .416*
RN 1			– .559*	– .177	+ .295	+ .774**	+ .583**
TRN 2				+ .532**	– .261	– .097	– .185
RL 3					– .021	+ .054	+ .017
R/S 4						+ .405*	+ .308
RW 5							+ .584**
RB 6							–

PF : Pulling force
RN : Root number
TRN : Thick root number
RL : Root length
R/S : Root to shoot ratio
RW : Root weight
RB : Root branching
r .05 (22 df) : .404;
r .01 (22 df) : .515.

Table 7. Correlation matrix between pulling force and root characteristic of the third observation.

	PF 7	RN 1	TRN 2	RL 3	R/S 4	RW 5	RB 6
PF 7	–	+ .194	+ .348	+ .548**	+ .321	+ .463*	+ .372
RN 1			– .525**	– .046	+ .066	+ .672**	+ .780**
TRN 2				+ .101	+ .026	+ .009	– .229
RL 3					+ .395	+ .456*	+ .145
R/S 4						+ .447*	+ .093
RW 5							+ .609**
RB 6							

r .05 (22 df) : .404
r .01 (22 df) : .515

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