STUDIES ON PULLING FORCE AS DROUGHT RESISTANCE SCREENING METHOD AND GENETICS OF UPLAND RICE ROOT CHARACTERISTICS*)

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Abstract

The main objective of this research is to develop pulling-force technique as an easy and simple drought resistance screening method for a large number of breeding lines in a relatively short period.

For this purpose, field experiments were conducted by planting several varieties and lines representing different degrees of drought resistance, i. e. MI 48, IR 1750 F5 B-5, C 22, IR 20, IR 26, IR 442-2-58, Salumpikit, OS4 and MGL 2 during the rainy season of 1976/1977 at Los Banos, Philippines and the rainy and dry seasons of 1980 and 1981 at Yogyakarta, Indonesia. Studies were made of on the relationship between pulling-force and drought resistance scale according to the IRRI standard evaluation system for rice, correlation between pulling-force and root characteristics, path coefficients of root characteristics to pulling-force and the determination of the appropriate time (age) of pulling-force and root characteristics measurement. Similar experiments and pot experiments using regosol and grumusol soil were also conducted to study the environmental effects on the pulling-force and root growth. Pulling-force technique evaluation was carried out by regressing drought resistance scale on pulling-force measurement using F4 and F5 breeding lines derived from crossings of the varieties mentioned, planted in the 1981 and 1982 rainy season and in the 1982 and 1983 dry season. The F1 and F2 generation of the crosses were used for studying the genetics of root characteristics.

The following are the results of the experiments.

There was a significant correlation between pulling-force and drought resistance scale, the heavier the drought stress the closer the relationship.

Pulling-force was directly and positively affected by the thick root number, but directly and negatively affected by the total root number. It means that thick root number should be strongly considered in drought resistance breeding.

Broad sense heritabilities of root characteristics increased hyperbolically with the age of plant, and became practically constant at the initiation of flower primordia. This suggests that the appropriate time of pulling-force and root characteristics measurements should be carried out at this growth stage.

Pulling-force and root characteristics were affected by the root growth environment. The non significant genotype x environmental interaction indicates that the rank of cultivars for pulling-force and root characteristics are constant over a wide range of environment.

The regression of drought resistance scale on pulling-force was not significant for F4 and F5 segregating breeding lines, eventhough the relationship tended to increase.

Total root number, thick root number, maximum root length and total root weight are quantitative characters, governed by polygene, varied from no dominance, partial dominance and over dominance depending on the type of parental crosses. The values of the broad sense heritability of these root characteristics ranged from 0.39 (medium) to 0.91 (high) depending also on the type of parental crosses.

From the results of these studies the following conclusions can be made.

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Pulling force technique can be applied in the screening of breeding material for the drought resistance. It can be applied under broad environmental conditions. This technique should be applied on homozygous breeding lines, under homogeneous field conditions, especially with regard to soil moisture. The most appropriate time for its application is at the age of about nine weeks, i. e. the period of initiation of flower primordia.

Considering the simplicity of the pulling force technique, screening of drought resistance lines, can be carried out even by middle personnel, provided a detailed written procedure could be made available to them.

Intisari

Tujuan utama penelitian ini ialah mengembangkan teknik gaya cabut sebagai metode penyaringan ketahanan terhadap kekeringan yang sederhana, mudah, dan mampu menyaring banyak galur pemuliaan dalam waktu singkat.

Untuk itu dibuat percobaan lapangan dengan menanam variestas dan galur yang berbeda-beda ketahanannya terhadap kekeringan, yaitu MI 48, IR 17 50 F 5 B-5, C 22, IR 20, IR 26, IR 442-2-58, Salumpikit, OS 4 dan MGL 2 pada musim penghujan tahun 1976/1977 di Los Banos, Filipina dan pada musim penghujan dan musim kemarau tahun 1980 dan 1981 di Yogyakarta, Indonesia. Percobaan ini bertujuan untuk mengaji hubungan antara gaya cabut dengan nilai ketahanan terhadap kekeringan menurut sistem penilaian baku untuk padi yang dibuat IRRI, korelasi antara gaya cabut dengan sifat perakaran, koefisien lintas sifat perakaran terhadap gaya cabut dan waktu (umur) yang tepat untuk pengamatan gaya cabut dan sifat perakaran. Percobaan yang sama dan percobaan pot dengan media tanah regosol dan grumusol digunakan untuk mengaji pengaruh lingkungan terhadap gaya cabut dan perakaran. Evaluasi metode gaya cabut sebagai metode penyaringan dilakukan dengan meregresikan gaya cabut dan nilai ketahanan terhadap kekeringan, menggunakan galur pemuliaan keturunan F4 dan F5 dari persilangan varietas tersebut. Evaluasi dilakukan pada musim penghujan tahun 1981 dan 1982, dan pada musim kemarau tahun 1982 dan 1983. Genetika sifat perakaran dikaji dari tertua, keturunan F1 dan F2 nya.

Rangkuman hasil percobaan tersebut adalah sebagai berikut.

Ada korelasi nyata antara gaya cabut dengan nilai ketahanan terhadap kekeringan, makin berat tekanan kekeringan makin erat hubungannya.

Gaya cabut dipengaruhi secara langsung dan positif oleh jumlah akar besar dan dipengaruhi secara langsung dan negatif oleh jumlah akar total. Ini berarti jumlah akar besar perlu mendapat perhatian utama dalam pemuliaan ketahanan terhadap kekeringan. Nilai heritabilitas dalam arti luas sifat perakaran meningkat menurut umur secara hiperbolik dan menjadi konstan pada fase pembentukan primordia bunga. Ini berarti bahwa waktu pengamatan gaya cabut dan sifat perakaran yang paling tepat ialah pada fase pertumbuhan tersebut. Pada fase pembentukan primordia tersebut variasi antar varietas terbesar, yang dicerminkan oleh nilai heritabilitas yang mendekati maksimum.

Besar gaya cabut dan sifat perakaran dipengaruhi oleh lingkungan tumbuh, tetapi interaksi genotipe dengan lingkungan tidak nyata. Artinya peringkat gaya cabut dan sifat perakaran antar varietas tidak berubah.

Hubungan gaya cabut dengan nilai ketahanan terhadap kekeringan pada galur pemuliaan yang masih mengalami segregasi (F4 dan F5) tidak nyata, tetapi ada kecenderungan meningkat.

Sifat jumlah akar total, jumlah akar besar, panjang akar maksimum dan berat akar total termasuk sifat kuantitatif, diatur oleh poligen yang tindak gennya berbeda-beda yaitu tidak ada dominansi, dominansi sebagian, dan dominansi lebih tergantung persilangan. Nilai heritabilitas dalam arti luas sifat perakaran tersebut juga berbeda-beda dari 0,39 (sedang) sampai 0,91 (tinggi) tergantung persilangan.

Hasil dari kajian penulis dapat disimpulkan sebagai berikut. Metode gaya cabut dapat diterapkan untuk menyaring galur pemuliaan yang tahan kering. Bahan pemuliaan yang disaring hendaknya sudah homosigot. Pelaksanaan penyaringan dapat dilakukan pada berbagai kondisi lingkungan, tetapi kondisi lapangan tempat tumbuh perlu diusahakan dalam keadaan seseragam mungkin, terutama lengas tanah. Waktu yang baik untuk penerapan gaya cabut ialah pada umur sekitar sembilan minggu, yaitu sekitar fase pembentukan primordia bunga.

Berdasarkan pertimbangan bahwa metode gaya cabut ini sangat sederhana, maka praktek penyaringan ketahanan terhadap kekeringan dengan menggunakan metode ini, dapat dilakukan oleh tenaga menengah, asal diberikan petunjuk tertulis yang jelas.

Introduction

The world upland rice crop covers about 10 percent or 14 million hectares of rice field. Among of these areas, approximately 1,202,747 hectares are located in Indonesia or about 12.8 percent of total rice field in this country. Recently, the average yield ranges from O.5 to 1.5 tons per hectare, while in Indonesia it is 1.416 tons per hectare. Considering that the total cropping upland rice are quite large, therefore yield increase per hectare would significantly contribute to the total rice production.

Less intensive cultural practices, including limited use of improved variety (which are high yielding, drought resistant, blast tolerant, and problem soil tolerant), are suspected to be the main factors affecting the low yield per hectare. At precent, the improved variety of upland rice in Indonesia are still rare.

It has been reported that a significant increase of rice production obtained from irrigated rice causes lack of interest to improve upland rice variety. On the other hand, less attention in improving upland rice variety may be partly due to the complexity of the problems in developing improved drought resistant variety and unavailability of a simple and practical screening method, particularly for handling a large number of breeding lines in relatively short time.

There are three adaptive mechanisms to drought stress, namely escape, avoidance, and tolerance. The first mechanism is pseudo-resistance while the other two are true resistance. Between the last two mechanism, avoidance seems to be more important in contributing drought resistance than tolerance mechanism.

Drought avoidance of a particular plant is due to morphological properties of cuticles, leaf characters and rooting system. Deep rooting system enables the plant to obtain more water, so that proper water balance can be maintained without diminishing transpiration.

Several authors found significant correlation between pulling force and tolerancy to root worm on maize. Other authors also found a siginificant correlation between drought resistance and thick, deep penetration, and dense of rooting system of several plants.

The objective of this study is to develop a simple, rapid method of screening for drought resistant breeding lines by measuring pulling force applies to individual plant (subsequently referred to pulling force method). The measured value of pulling force, then, was correlated with drought resistance characters of plants. Another related objective is to determine the appropriate time of measuring the pulling force which gives the most significant difference among cultivars.

To support drought resistance breeding program through rooting system improvement, the study also observed the most important components of rooting which directly affect pulling force. Beside this objective, genetics of the important root characteristics also studied.

Materials and Methods

To correlate pulling force with drought resistance, two experiments were carried out. The first experiment was conducted in the rainy season of 1976/1977 at IRRI, using six varieties and lines representing different degrees of drought resistance ($IR_{442-2-58}$, MI_{48}, $IR_{1750}F_5$-B-5, OS_4, C_{22}, IR_{20}). These cultivars were direct seeded under wet condition. The second experiment also used six varieties and lines (MGL_2, OS_4, Salumpikit, $IR_{442-2-58}$, IR_{26}, IR_{20}), which were direct seeded under rainfed condition in the 1980/1981 rainy season at Kalitirto, Yogyakarta. Pulling force measurement were conducted on those two experiments at six weeks after seeding (under wet condition) and at 60 days after seeding (under rainfed condition). The same varieties and lines also planted in the following dry season. Drought resistance scales were made on those cultivars in the dry season, after water stress treatment was applied, using IRRI method.

Attempting to study the relationship between pulling force and rooting components, two experiments were conducted in the rainy season of 1980/1981 and 1981/1982 respectively, using six cultivars representing different degrees of drought resistance. This experiments were arranged in randomized completely block design with four replications. The six cultivars used were IR_{20}, IR_{26} representing wet rice varieties, $IR_{442-2-58}$ representing deep water rice cultivars, and OS_4, MGL_2, Salumpikit representing upland rice varieties. Pulling force measurement and data on root characteristics were taken every week starting from the second up to the tenth week after seedling. Pulling force were measured from 10 randomly individual plant samples, using a spring balance equipped with a clamp accessory. The maximum capacity of the spring balance is 60 lbs, made by John Chatilon & Sons Inc. New York. Data on root characteristics was taken by careful tap water spraying and pulling out five randomly individual plant samples.

To determine the appropriate time for pulling force and root characteristics measurements, combined analysis of the two year experiments was performed for each week observation, and regression analysis of broad sense heritabilities of pulling force and root characteristics on age were calculated. Correlation coefficients between pulling force and root characteristics and among root characteristics were calculated using data observed at the appropriate week. The combined analysis was also used to detect interaction between genotype and year of planting. To determine the root characteristics which mostly affect the pulling force, path analysis was performed using data on the previous correlation coefficient.

Pot experiments were carried out in the green house to study on the effect of soil groups on root characteristics. In this experiment, the same six previous varieties were planted on light (regosol) soil and on heavy (grumusol) soil respectively. Factorial design with three replications used in this study.

In order to study pulling force on different soil groups, field experiments were carried out on these two soil groups (grumusol soil at Gading, Wonosari, and regosol soil at Kalitirto, Yogyakarta). The same six previous varieties and F_3 from several parental crosses (IR_{442} × Salumpikit, IR_{442} × OS_4, IR_{20} × MGL_2) were used in this study. Correlation of both data on pulling force is then calculated.

To study on genetics of root characteristics, four parentals (OS_4, MGL_2, IR_{442}, IR_{20}), F_1 and F_2 of their crosses, were planted under irrigated condition in isolated wire field in the 1980/1981 rainy season. Root characteristics measurements were taken around the initiation of flower primordia, by carefully pulling out all individual plants. Potent ratios and broad sense heritabilities were computed, and frequency distributions of F_2 were performed.

The last experiment was to evaluate the pulling force method by studying correlation between pulling force data from experiments in the 1981/1982 and 1982/1983 rainy season respectively, and drought resistance scales resulted from experiments conducted in the dry season of 1982 and 1983 respectively. Breeding lines of F_4 and F_5 generations were used in these experiments.

Result and Discussions

Results of the analysis are the following :

There was a significant correlations between pulling force and drought resistance scale. The heavier the drought stress the closer the relation. At soil matric potential of -2b (light drought stress), the correlation showed no significant. However, at soil matric potential of -4 and -8b, the correlation were significant. Trends of correlation were similar under rainfed and under irrigated condition; the higher the pulling force the higher its drought resistance (Figures 1 and 2). This phenomenon was due to the more thick root number, the longer, and deeper penetration of root would be. Drought resistance which is related to pulling force is an avoidance mechanism through rooting system.

Highly positive for both correlation coefficient and path coefficient between pulling force and thick root number showed a true positive relationship (r_{25} = + 0.90 and p_{25} = + 0.7991). On the other hand, highly negative correlation and moderately negative path coefficient between pulling force and total root number were observed (r_{15} = -0,986 and p_{15} = -0,6002). It indicates that the primarily factor influencing the magnitude of pulling force are the number of thick roots and the total root number.The bigger the pulling force the higher the number of thick roots, and the more resistant to drought. On the other hand, the smaller the pulling force the higher the total root number. Usually, rice cultivar with high thick root number, are low in its total root number. On the other hand, cultivars which its roots are mostly fine in size, are high in its total root number (Figure 8).

Highly positive correlation between pulling force and maximum root length undepicted the real relationship due to the negative value of their path coefficient (r_{35} = + 0,906 and P_{35} = -0,1682). The positive relationship between pulling force and the maximum root length could be due to its indirect effect through highly positive correlation between maximum root length and thick root number ($p_{25}r_{23}$ = + 0,8174). Similar result was observed on correlation between pulling force and total root weight (r_{45} = + 0,709 and p_{45} = -0,2749). This positive relationship between pulling force and total root weight could be due to its indirect effect through positive correlation between total root weight and thick root number ($p_{25}r_{24}$ = + 0,7560) (Figure 8).

Broad sense heritability which is the ratio between total genetic variance with phenotypic variance for pulling force, total root number, thick root number, and maximum root length were not consistent following the age of plant. The relationship between the magnitude of heritability and the age of plant fits in with the regression equation $Y = a - bx^{-1}$. This equation indicates that changing rate of heritability will be slower with advance growth of plant and approximately reached constant value at nine weeks after seeding (Table 2). This period corresponds with the flower primordia initiation stage. It means one cultivar differed most clearly from the other in this stage. Therefore, this stage is the appropriate time to measure pulling force and to observe root characteristics in relation with drought resistance. For early maturing variety of rice, it ranges from 60 to 70 days after seeding (Tables 1; 2 and Figures 3; 4; 5; 6).

The magnitude of pulling force and root characteristics were influenced by environmental factors such as soil group and year of planting. The root characteristics on grumusol soil was better than on regosol soil, and the root characteristics on 1981 experiment was better than on 1980 experiment. However, there was no interaction between genotype and environment namely, year of planting and soil group (Tables 3; 4 and Figures 7; 9). This result depicts that the rank of pulling force and root characteristics among cultivars are consistent. Therefore, the use of pulling force as a screening method for drought resistance may be carried out at any year of planting and soil group tested.

Using segregating material of F_4 and F_5 generation, no significant correlation was observed between pulling force and drought resistance. However, subsequent generation from F_4 to F_5 indicated higher coefficient of regression and correlation, which means that it tends to be more closely related (Figure 10).

Frequency distribution for root characteristics of F_2 resulting from several crosses showed normality. It means that root characteristics, such as maximum root length, total root number, thick root number, and total root weight are polygenically controlled (Figure 11 A, B, C, D; Figure 12 A, B, C; Figure 13 B). However, F_2 frequency distribution for thick root numbers resulting from segregation of $IR_{20} \times OS_4$ and $IR_{442} \times OS_4$ crosses indicated abnormality at $P = 0.01 — 0.001$ and showing bimodal distribution. Using genetic analysis by Powers, frequency distribution of F_2 from these crosses failed to perform the genetic ratio of 3 : 1 and 15 : 1. This means that there should be more than two genes controlling the thick root number of these crosses (Figure 13 A, C). Frequency distribution for total root weight of F_2 segregations resulting from crosse of $IR_{20} \times OS_4$ and $IR_{20} \times MGL_2$ showed abnormality ($P < 0.001$) and tended to lefty skewness. Therefore, it is still ambiguous to interpet the data (Figure 14 A, B).

There are different gene actions of the genes controlling root characteristics. It varied from no dominance, partial dominance, and overdominance depending on the type of parental crosses (Table 5). Information of this gene action should be taken in to account in implementing a breeding program, particularly in relation with the development of pure line or F_1 hybrid variety.

Broad sense heritability for root characteristics differed one from the other depending on the type of parental crosses. It ranged from 0.39 (medium) to 0.91 (high). The negative value of heritability were obtained on crosses of $IR_{442} \times OS_4$ for maximum root length and thick root number, and on cross of $IR_{20} \times OS_4$ for root weight. It is due to the existing F_1 outstanding individuals which contributed higher F_1 variance. The overdominance effect of those root characteristics on the two crosses has important role in the contribution. The magnitude of the heritability determines the appropriate method of selection, what generation lines to be selected, and selection intensity in order to get high estimate of response to selection.

Conclusions

The results of writer's studies lead to the following conclusions. Pulling force tec-nique can be applied in screening breeding material for the obtainment of drough resistance breeding lines. Pulling force technique can be applied under various en-vironmental conditions. Pulling force technique should be applied on homozygou: breeding lines, under homogeneous field conditions, especially with regard to soi moisture. The most appropriate time for the application of pulling force technique i: the age of nine weeks, i.e. the transition period between the vegetative and th generative phase or the period of initiation of flower primordia.

Considering the simplicity of the pulling force technique, it may be concluded that screening practice on the obtainment of drought resistance lines, can be carriec out even by middle personnel, and even at remote site, provided a detailed writter procedure could be made available to them.

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Daftar 1. **Koefisien regresi dan nilai r^2 dari persamaan regresi nilai heritabilitas dalam arti luas gaya cabut dan sifat perakaran atas umur (minggu).**

(Table 1. ***Regression coefficients and r^2 values of the regression equation of the broad sense heritabilities of pulling force and root characteristics on age, week).***

Persamaan (*Equation*)	Koefisien (*Coefficients*)	Gaya cabut (*Pulling force*)	Jumlah akar total (*Total root number*)	Jumlah akar besar (*Thick root number*)	Panjang akar maksimum (*Maximum root length*)
		Gaya cabut dan Sifat perakaran (*Pulling force and Root characteristics*)			
$Y=a+bx^{-1}$	a	0,965	1,223	1,250	1,168
	b	-0,222	-1,917	-0,057	-1,860
	r^2	0,580	0,670	0,765	0,698
Uji nyata (*Test of significance*)	F hitung (*Calculated F*)	11,01*	16,12**	25,65**	18,45**
	F 0,05(1;8)	5,32	5,32	5,32	5,32
	F 0,01(1;8)	11,26	11,26	11,26	11,26

Daftar 2. **Taksiran peningkatan nilai heritabilitas arti luas pada tiap minggu untuk gaya cabut dan sifat perakaran.**

(Table 2. ***Estimates of broad sense heritability increase on each week for pulling force and root characteristics).***

Minggu pengamatan *(Observation week)*	Gaya cabut dan sifat perakaran *(Pulling force and Root characteristics)*											
	Gaya cabut *(Pulling force)*			Jumlah akar total *(Total root number)*			Jumlah akar besar *(Thick root number)*			Panjang akar maksimum *(Maximum root length)*		
X	$Y_e = 0,965 - 0,222x^{-1}$			$Y_e = 1,223 - 1,917x^{-1}$			$Y_e = 1,250 - 2,057x^{-1}$			$Y_e = 1,168 - 1,860x^{-1}$		
X												
II	0,854			0,265			0,222			0,238		
		)0,037			)0,319			)0,342			)0,310	
III	0,891			0,584			0,564			0,548		
		)0,019			)0,160			)0,172			)0,155	
IV	0,910			0,744			0,736			0,703		
		)0,011			)0,096			)0,103			)0,093	
V	0,921			0,840			0,839			0,796		
		)0,007			)0,064			)0,068			)0,062	
VI	0,928			0,904			0,907			0,858		
		)0,005			)0,045			)0,049			)0,044	
VII	0,933		)0,007	0,949		)0,011	0,956		)0,012	0,902		)0,010
		)0,004			)0,034			)0,037			)0,034	
VIII	0,937		)0,001	0,983		)0,007	0,993		)0,009	0,936		)0,009
		)0,003			)0,027			)0,028			)0,025	
IX	0,940		)0,000	1,010		)0,006	1,021		)0,005	0,961		)0,004
		)0,003			)0,021			)0,023			)0,021	
X	0,943		)0,001	1,031		)0,004	1,044		)0,004	0,982		)0,004
		)0,002			)0,017			)0,019			)0,017	
XI	0,945			1,048			1,063			0,999		

Daftar 3. **Ringkasan analisis varians gaya cabut dan sifat perakaran tanaman percobaan tahun 1980 dan 1981, pengamatan pada minggu ke-sembilan sesudah tanam.**

(Table 3. Summary of the variance analysis of the pulling force and root characteristics. Experiment of the year 1980 and 1981 respectively. Observation on the ninth week after seedling.

Sumber Variasi *(Source of variation)*	Derajat Kebebasan *(Degrees of Freedom)*	Varians berbagai sifat perakaran dan gaya cabut *(Variances of the root characteristics and pulling force)*				
		Gaya cabut *(Pulling force)*	Jumlah akar total *(Total root number)*	Jumlah akar besar *(Thick root number)*	Panjang akar maksimum *(Maksimum root length)*	Berat akar total *(Total root weight)*
Tahun (T) *(Year, Y)*	1	1,5650 **	1,2597 **	2,2903 **	0,0675 **	0,5959 **
Blok/T *(Block/T)*	6	0,0083	0,0053	0,0558	0,0008	0,0109
Genotipe *(Genotype, G)*	5	0,1724 **	0,1347 **	1,6612 **	0,0363 **	0,0263 **
G x T *G x T*	5	0,0068 TN	0,0039 TN	0,1091 TN	0,0029 TN	0,0031 TN
G x Blok/T *G x Block/T)*	30	0,0034	0,0036	0,0504	0,0023	0,0056

*) Berbeda nyata pada 0,05
(Significantly difference at 0.05)

**) Berbeda sangat nyata pada 0,01
(Highly significant difference at 0.01)

Daftar 4. **Ringkasan analisis varians sifat perakaran padi pada tanah Regosol dan Grumusol. Pengamatan sembilan minggu sesudah tanam (transformasi log (x + 1).**

(Table 4. Summary of the analysis of variance of the rice root characteristics planted on Regosol and Grumusol soil. Observation on the ninth week after seedling (log (x + 1) transformation).

Sumber Variasi (*Source of variation*)	Derajat Kebebasan (*Degrees of Freedom*)	Varians berbagai sifat perakaran (*Variances of the root characteristics*)			
		Jumlah akar total (*Total root number*)	Jumlah akar besar (*Thick root number*)	Panjang akar maksimum (*Maximum root length*)	Berat akar total (*Total root weight*)
Kombinasi Perlakuan (*Treatment combination*)	11				
Varietas (V) (*Variety*)	5	0,1210 **	0,9928 **	0,0597 **	0,0261 **
Tanah (T) (*Soil*)	1	1,1942 **	1,6417 **	0,0994 **	0,5701 **
V x T	5	0,0027 TN	0,0405 TN	0,0113 TN	0,0057 TN
Acak (*Error*)	24	0,0058	0,0289	0,0092	0,0051

TN = Tidak berbeda nyata
(Not significantly different)

*) = Berbeda nyata pada 0,05
(Significantly different at 0,05)

**) = Berbeda sangat nyata pada 0,01
(Highly significant different at 0,01)

Daftar 5. **Nilai tengah tetua ($\overline{MP}$), purata F1 ($\overline{F1}$) dan tetua yang lebih besar ukurannya ($\overline{HP}$) untuk sifat perakaran pada beberapa persilangan.**

*(Table 5. **Midparent ($\overline{MP}$), means of F1 ($\overline{F1}$) and higher parent ($\overline{HP}$) of root characteristics in several crosses).***

Persilangan *(Crossing)*	Sifat *(Characteristic)*				Keterangan pengaruh dominansi *(Interpretation of dominance effect)*
	$\overline{F_1}$	$\overline{MP}$	$\overline{HP}$	hp	
	Panjang akar maksimum *(Maximum root length)(cm)*				
IR_{20} x OS_4	29,6	22,7	26,1	2,03	Dominansi lebih *(Over dominance)*
IR_{20} x MGL_2	27,9	24,6	30,0	0,61	Dominansi sebagian *(Partial dominance)*
IR_{442} x OS_4	29,2	25,5	26,1	6,17	Dominansi lebih *(Over dominance)*
IR_{442} x MGL_2	31,7	27,4	30,0	1,65	Dominansi lebih *(Over dominance)*
	Jumlah akar total *(Total root number)*				
IR_{20} x OS_4	301,6	265,9	448,2	0,20	Tidak ada dominansi *(No dominance)*
IR_{20} x MGL_2	390,1	356,0	448,2	0,37	Dominansi sebagian *(Partial dominance)*
IR_{442} x MGL_2	308,2	246,9	263,7	3,65	Dominansi lebih *(Over dominance)*
	Jumlah akar besar *(Thick root number)*				
IR_{20} x OS_4	34,5	19,9	39,7	0,74	Dominansi sebagian *(Partial dominance)*
IR_{20} x MGL_2	27,6	39,1	78,2	-0,29	Dominansi sebagian *(Partial dominance)*
IR_{442} x OS_4	45,9	26,8	39,9	1,46	Dominansi lebih *(Over dominance)*
	Berat akar *(Root weight)(gram)*				
IR_{20} x OS_4	2,956	0,778	0,925	14,82	Dominansi lebih *(Over dominance)*
IR_{20} x MGL_2	2,560	2,272	3,619	0,21	Tidak ada dominansi *(No dominance)*

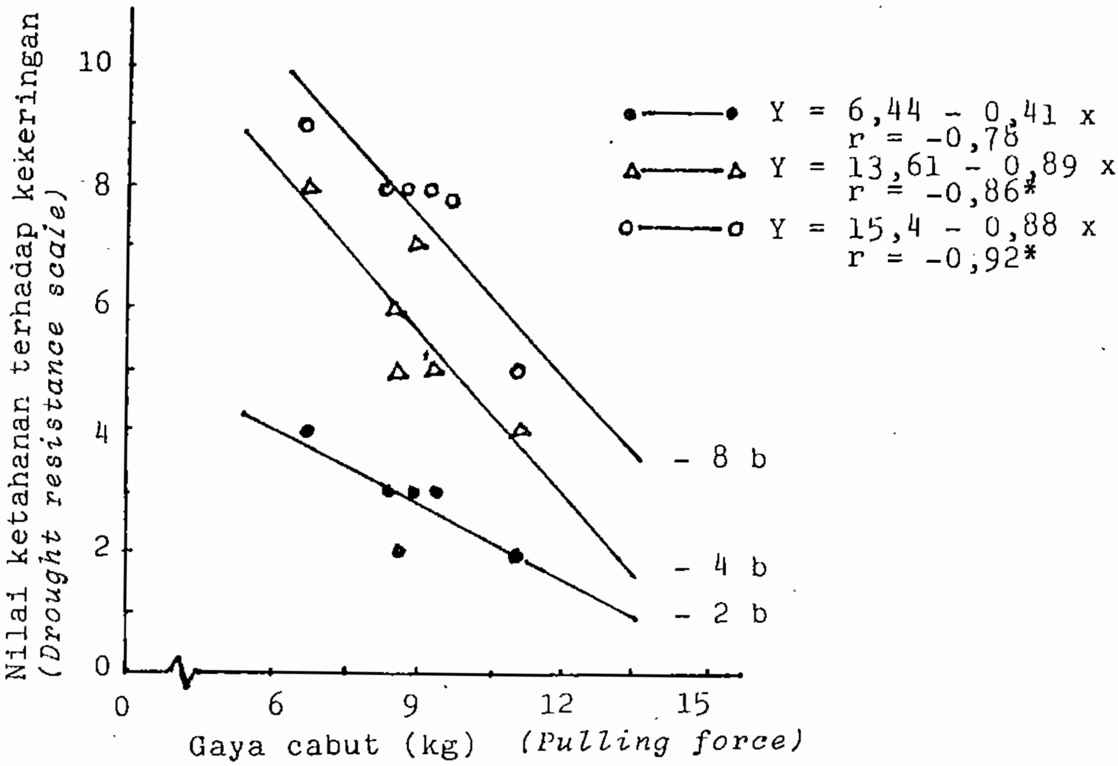
Daftar 6. Purata dan kisaran tetua, F1, dan F2, bentuk sebaran frekuensi F2, dan nilai heritabilitas dalam arti luas sifat perakaran pada beberapa persilangan.

(Table 6. Means and range of parents, F1 and F2, frequency distribution of F2, and broad sense heritabilities of root characteristics in several crosses).

Persilangan *(Crossing)*	Tetua Betina *(Female parent)* n	x ± SD	Kisaran *(Range)*	Tetua Jantan *(Male parent)* n	x ± SD	Kisaran *(Range)*
	Sifat panjang akar maksimum *(Maximum root length)*(cm)					
$IR_{20} \times OS_4$	10	19,2 ± 3,0	12,5/21,5	10	26,1 ± 4,6	19,0/32,1
$IR_{20} \times MGL_2$	10	19,2 ± 3,0	12,5/21,5	10	30,0 ± 4,3	24,5/38,0
$IR_{442} \times OS_4$	10	24,8 ± 4,3	14,5/28,0	10	26,1 ± 4,6	19,0/32,1
$IR_{442} \times MGL_2$	10	24,8 ± 4,3	14,5/28,0	10	30,0 ± 4,3	24,5/38,0
	Sifat Jumlah akar total *(Total root number)*					
$IR_{20} \times OS_4$	5	448 ± 37,4	418/509	8	84 ± 15,9	61/103
$IR_{20} \times MGL_2$	5	448 ± 37,4	418/509	9	264 ± 52,2	207/345
$IR_{442} \times MGL_2$	9	230 ± 51,1	142/290	9	264 ± 52,2	207/345
	Sifat Jumlah akar besar *(Thick root number)*					
$IR_{20} \times OS_4$	10	0	0/0	7	40 ± 9,5	24/53
$IR_{20} \times MGL_2$	10	0	0/0	9	78 ± 23,1	45/101
$IR_{442} \times OS_4$	10	0	14 ± 11,5	7	40 ± 9,5	24/53
	Sifat Berat akar total *(Total root weight)*(g)					
$IR_{20} \times OS_4$	10	0,925 ± 0,71	0,1/2,38	10	0,63 ± 0,41	0,19/1,20
$IR_{20} \times MGL_2$	10	0,925 ± 0,71	0,1/2,38	10	3,619 ± 1,64	1,35/5,47

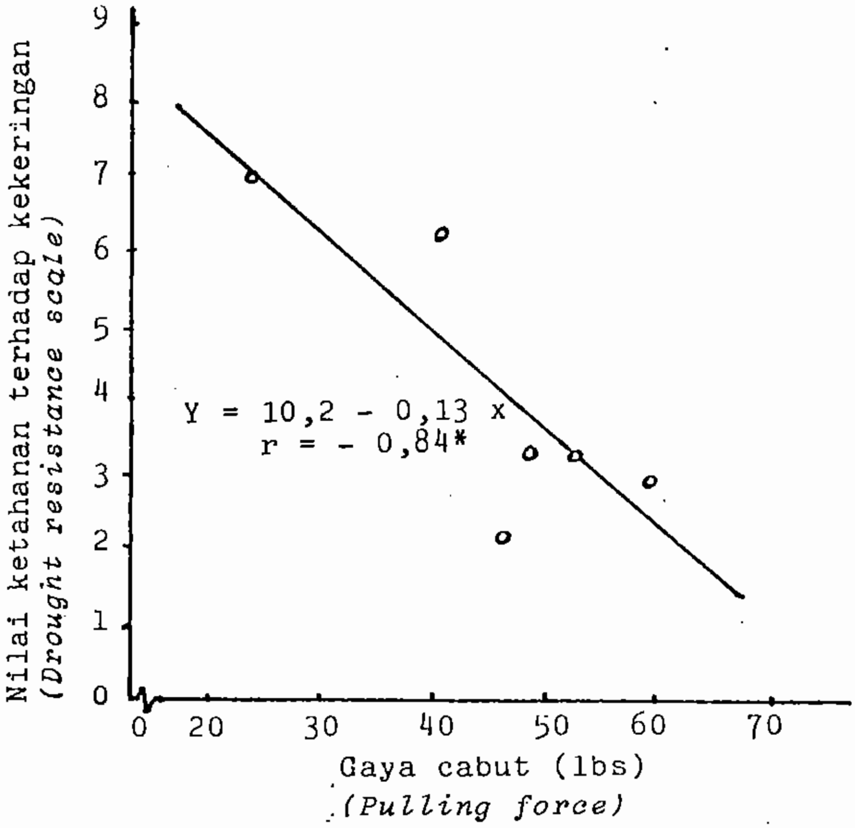
Persilangan *(Crossing)*	F_1 n	x ± SD	Kisaran *(Range)*	F_2 n	x ± SD	Kisaran *(Range)*
	Sifat Panjang akar maksimum *(Maximum root length)*(cm)					
$IR_{20} \times SO_4$	10	29,6 ± 2,9	24,0/33,5	108	21,6 ± 4,1	13,0/32,5
$IR_{20} \times MGL_2$	10	27,9 ± 1,3	25,4/30,0	110	22,2 ± 4,3	13,5/33,0
$IR_{442} \times OS_4$	14	29,2 ± 4,6	21,5/37,5	98	22,6 ± 4,5	12,5/33,5
$IR_{442} \times MGL_2$	13	31,7 ± 3,3	26,5/38,0	130	23,5 ± 4,9	9,0/36,5
	Sifat Jumlah akar total *(Total root number)*					
$IR_{20} \times OS_4$	10	302 ± 33,8	249/366	108	206 ± 76,3	23/460
$IR_{20} \times MGL_2$	11	390 ± 76,1	225/501	109	300 ± 101,0	120/565
$IR_{442} \times MGL_2$	13	308 ± 52,6	200/367	126	162 ± 67,4	42/358
	Sifat Jumlah akar besar *(Thick root number)*					
$IR_{20} \times OS_4$	8	35 ± 7,7	25/48	101	36 ± 25,2	0/98
$IR_{20} \times MGL_2$	10	28 ± 16,2	14/69	101	46 ± 24,7	0/100
$IR_{442} \times OS_4$	13	46 ± 21,1	11/79	96	22 ± 18,6	0/69
	Sifat Berat akar total *(Total root weight)*(g)					
$IR_{20} \times OS_4$	10	2,956 ± 0,67	2,11/3,93	100	0,890 ± 0,61	0,1/2,51
$IR_{20} \times MGL_2$	4	2,56 ± 0,58	2,09/3,39	112	1,51 ± 0,04	0,38/1,36

Persilangan *(Crossing)*	Bentuk sebaran F_2 *(F_2 Distribution)*	Uji kenormalan *(Test of normality)*	$V_{F2} - V_{F1}$ Varians Genetik *(Genetic Variances)*	$\frac{V_{F2} - V_{F1}}{V_{F2}}$ Heritabilitas arti luas *(Broad sense heritabilities)*
	Sifat Panjang akar maksimum *(Maximum root length)*(cm)			
$IR_{20} \times SO_4$	Normal	P = 0,70 - 0,8	8,4	0,50
$IR_{20} \times MGL_2$	Normal	P = 0,7 - 0,8	16,8	0,91
$IR_{442} \times OS_4$	Normal	P = 0,3 - 0,5	-0,91	-0,05
$IR_{442} \times MGL_2$	Normal	P = 0,5 - 0,7	11,07	0,55
	Sifat jumlah akar total *(Total root number)*			
$IR_{20} \times OS_4$	Normal	P = 0,5 - 0,7	4657,4	0,80
$IR_{20} \times MGL_2$	Normal	P = 0,3 - 0,5	4409,8	0,43
$IR_{442} \times MGL_2$	Normal	P = 0,2 - 0,3	1776,0	0,39
	Sifat jumlah akar besar *(Thick root number)*			
$IR_{20} \times OS_4$	Dua puncak	P = 0,01 - 0,001	575,8	0,91
$IR_{20} \times MGL_2$	Normal	P = 0,3 - 0,5	347,7	0,57
$IR_{442} \times OS_4$	Dua puncak	P = 0,001-0,001	-107,7	-0,31
	Sifat Berat akar total *(Total root weight)*(g)			
$IR_{20} \times OS_4$	Condong ke kiri	P 0,001	-0,077	-0,21
$IR_{20} \times MGL_2$	Condong ke kiri	P 0,001	0,369	0,52



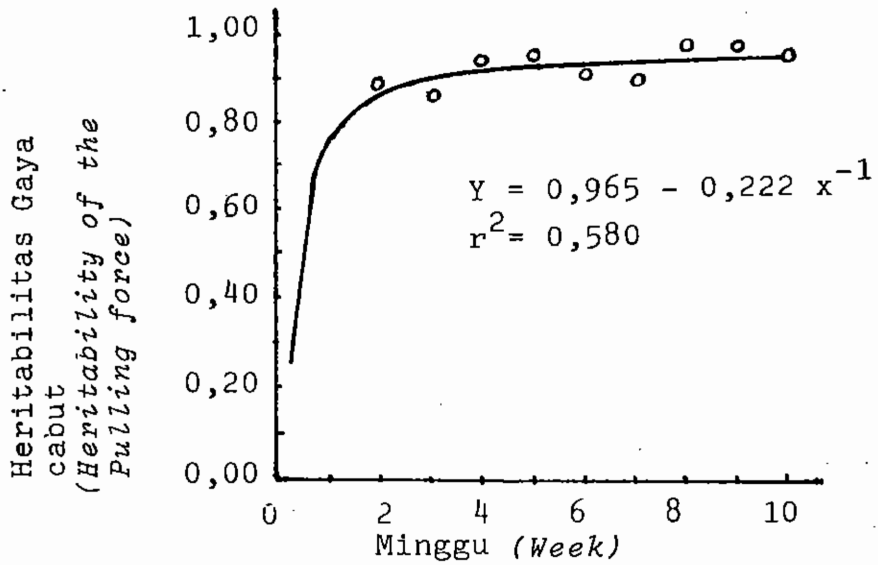
Gambar 1. **Hubungan antara gaya cabut pada kondisi sawah dengan nilai ketahanan terhadap kekeringan pada tiga tingkat potensial matrik tanah.**

(Figure 1. ***Relationship between pulling force under wet condition and drought resistance scale at three progressively soil matric potentials).***



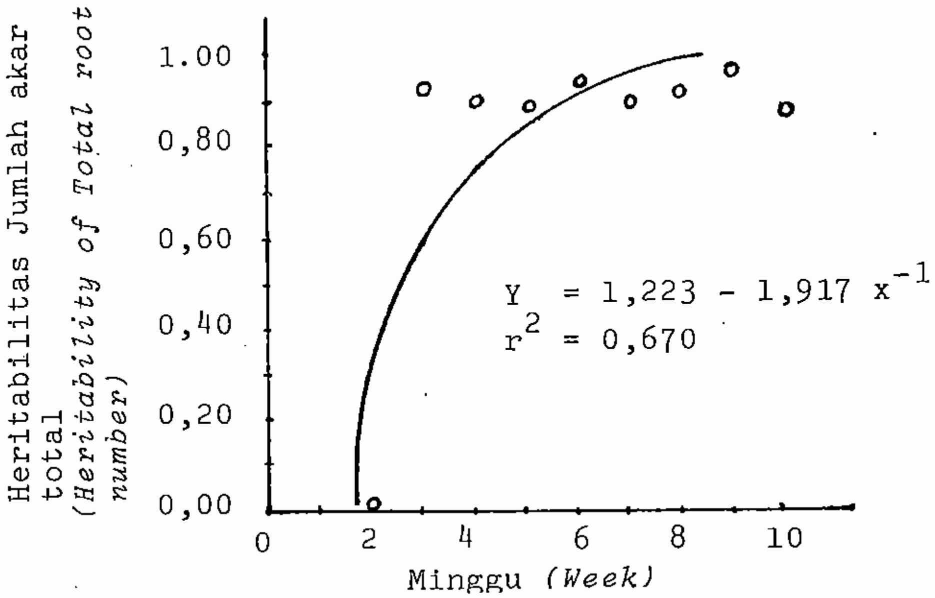
Gambar 2. **Hubungan antara gaya cabut pada kondisi kering dengan nilai ketahanan terhadap kekeringan pada kandungan lengas tanah 2 — 4,4%.**

(Figure 2. Relationship between pulling force under rainfed condition and drought resistance scale at 2 — 4.4% soil moisture content).



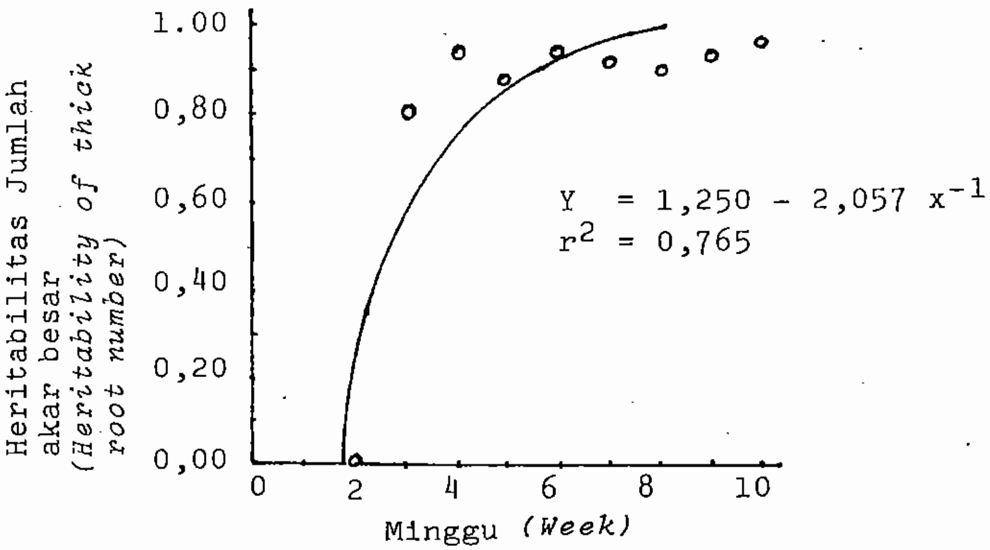
Gambar 3. **Regresi nilai heritabilitas dalam arti luas gaya cabut atas umur (minggu).**

(Figure 3. Regression of broad sense heritability of the pulling force on age, week).



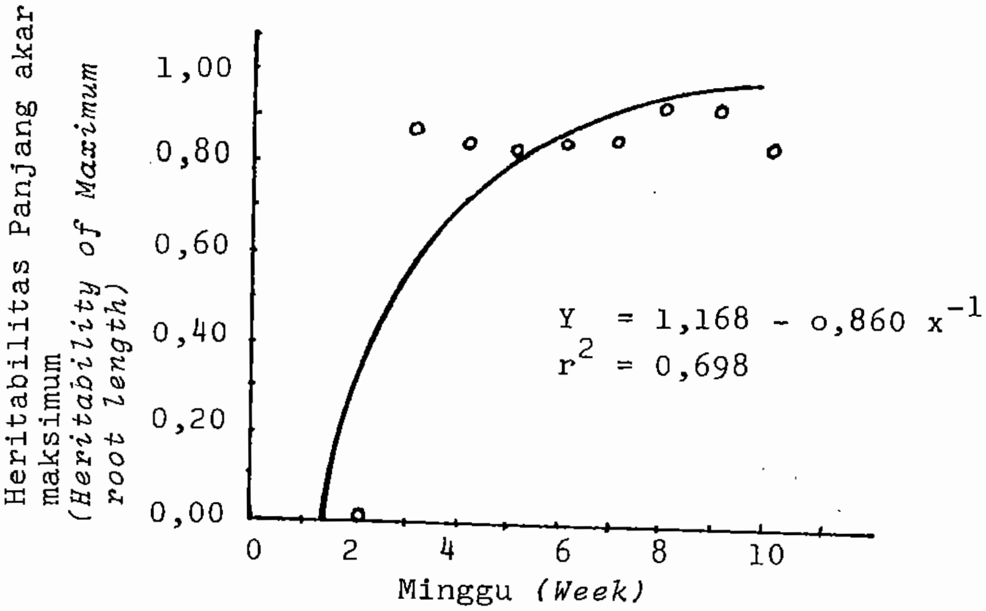
Gambar 4. **Regresi nilai heritabilitas dalam arti luas jumlah akar total atas umur (minggu).**

(Figure 4. ***Regression of broad sense heritability of total root number on age, week).***



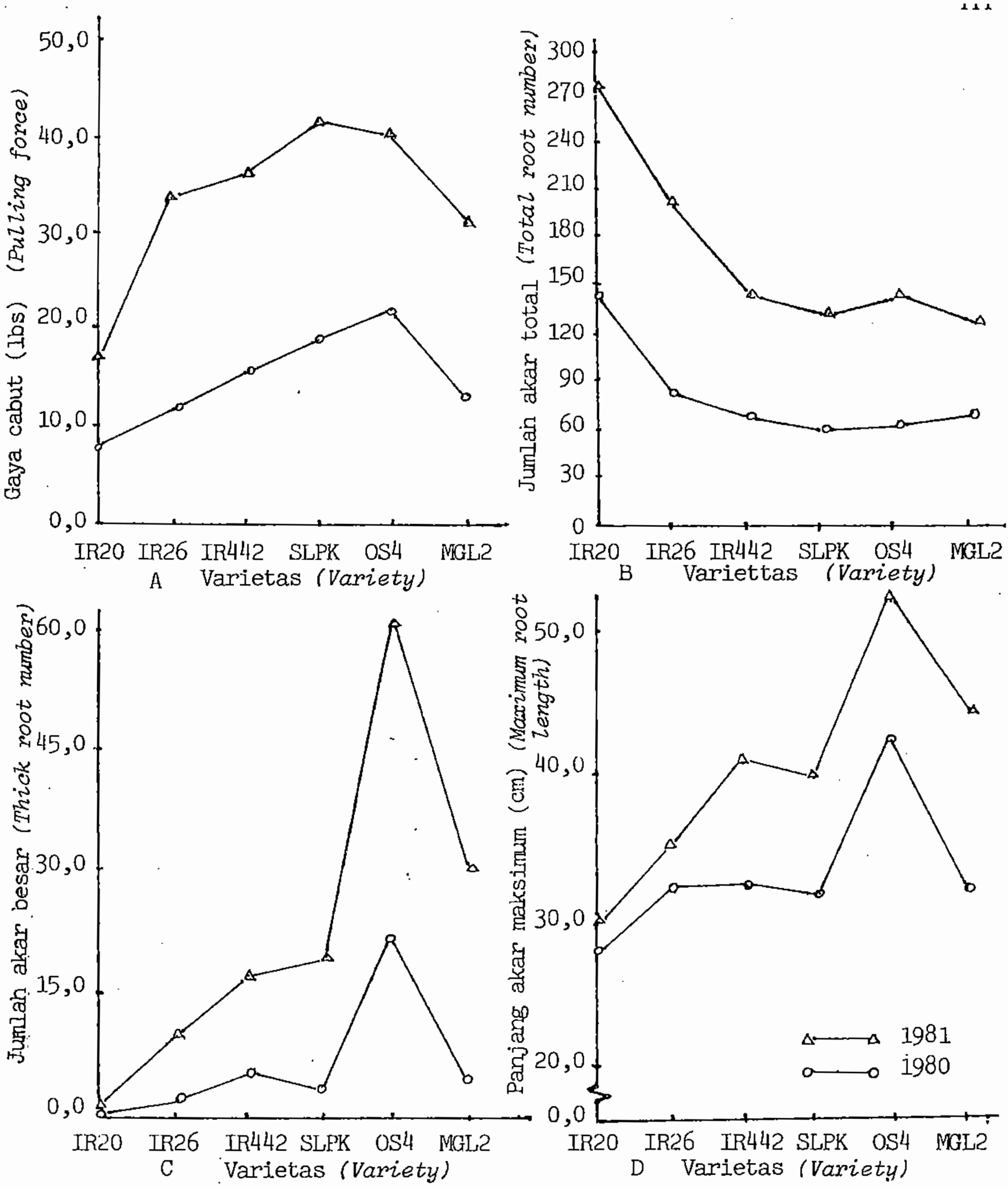
Gambar 5. **Regresi nilai heritabilitas dalam arti luas jumlah akar besar atas umur (minggu).**

(Figure 5. ***Regression of broad sense heritability of thick root number on age, week).***



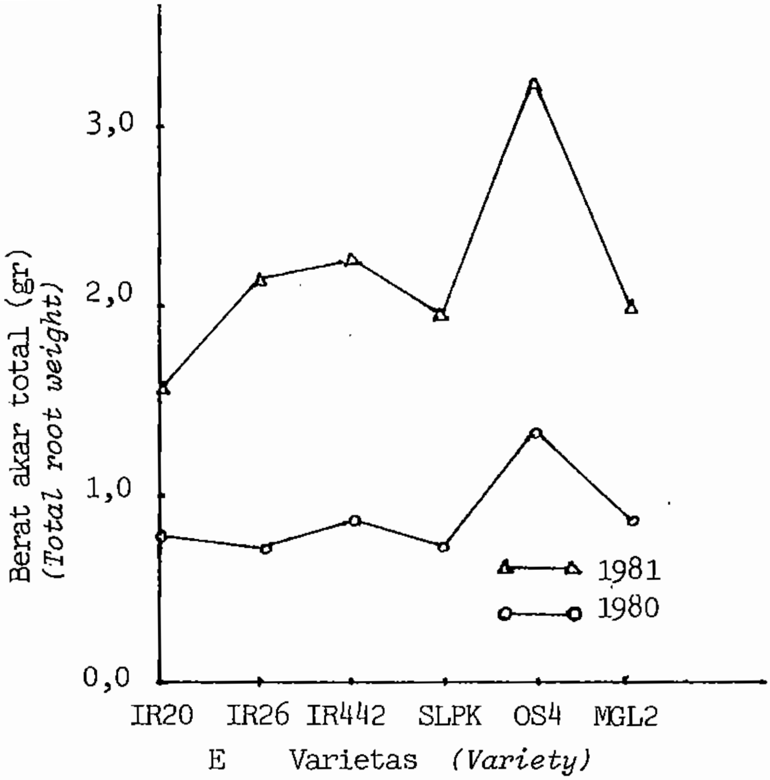
Gambar 6. **Regresi nilai heritabilitas dalam arti luas panjang akar maksimum atas umur (minggu).**

(Figure 6. Regression of broad sense heritability of maximum root length on age, week).

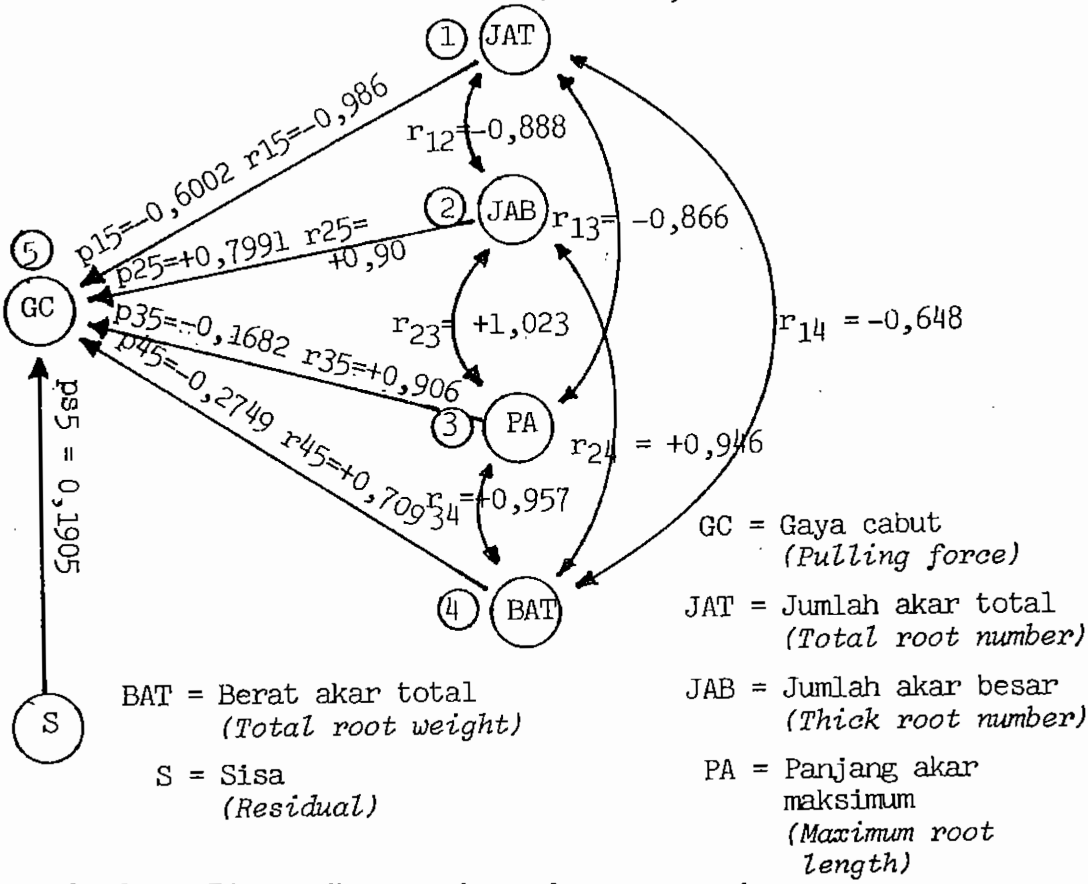


Gambar 7. **Peringkat gaya cabut dan sifat perakaran beberapa varietas yang mewakili berbagai tingkat ketahanan terhadap kekeringan pada percobaan tahun 1980 dan 1981. (Gaya cabut (A), jumlah akar total (B), jumlah akar besar (C), panjang akar maksimum (D) dan berat akar total (E).**

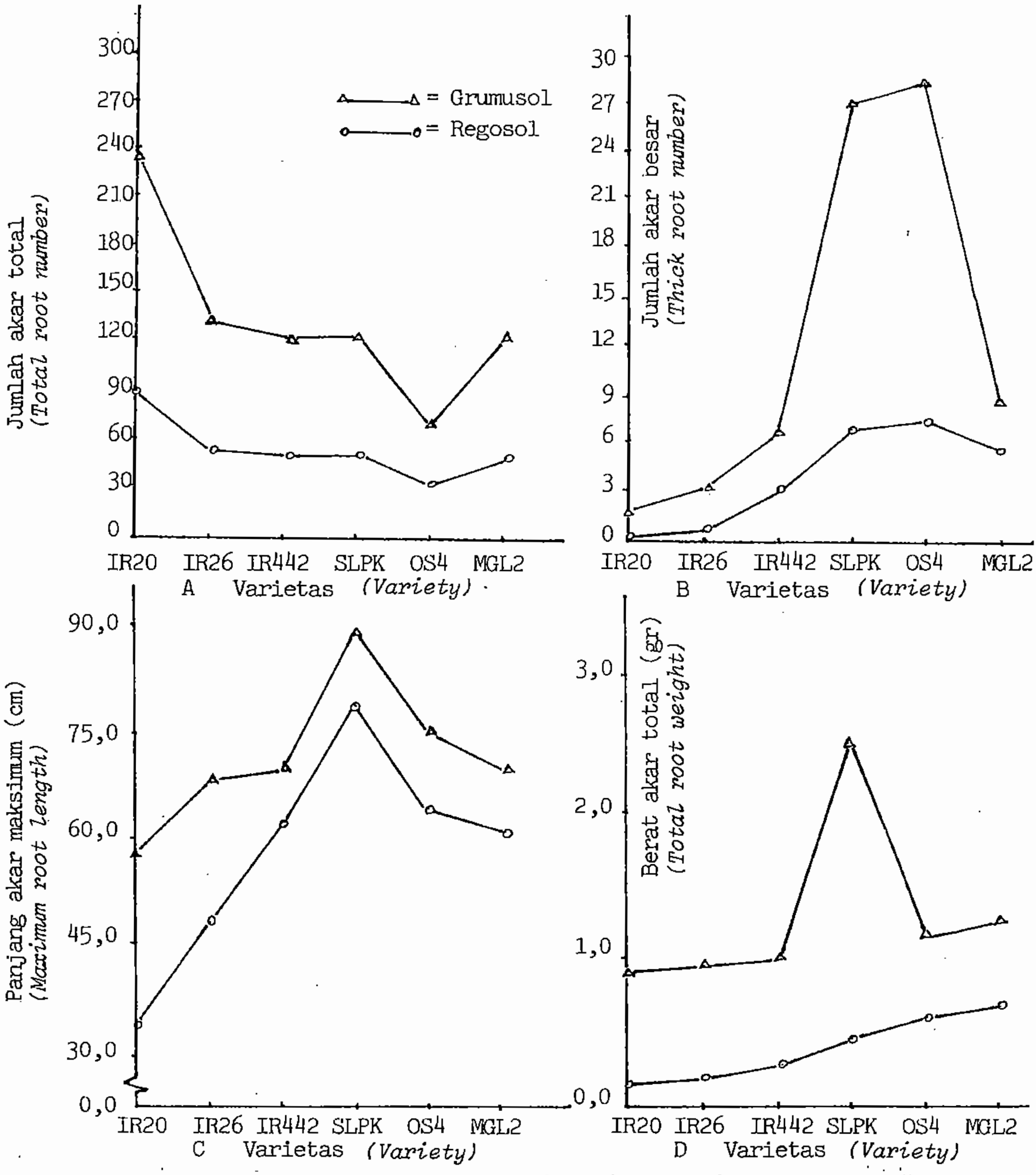
(Figure 7. ***Pulling force and root characteristics rank of several varieties representing various degrees of drought resistance in the 1980 and 1981's experiment respectively. Pulling force (A), total root number (B), thick root number (C), maximum root length (D) and total root weight (E).***



Gambar 7. **(lanjutan).**
(Figure 7. ***(continued).***

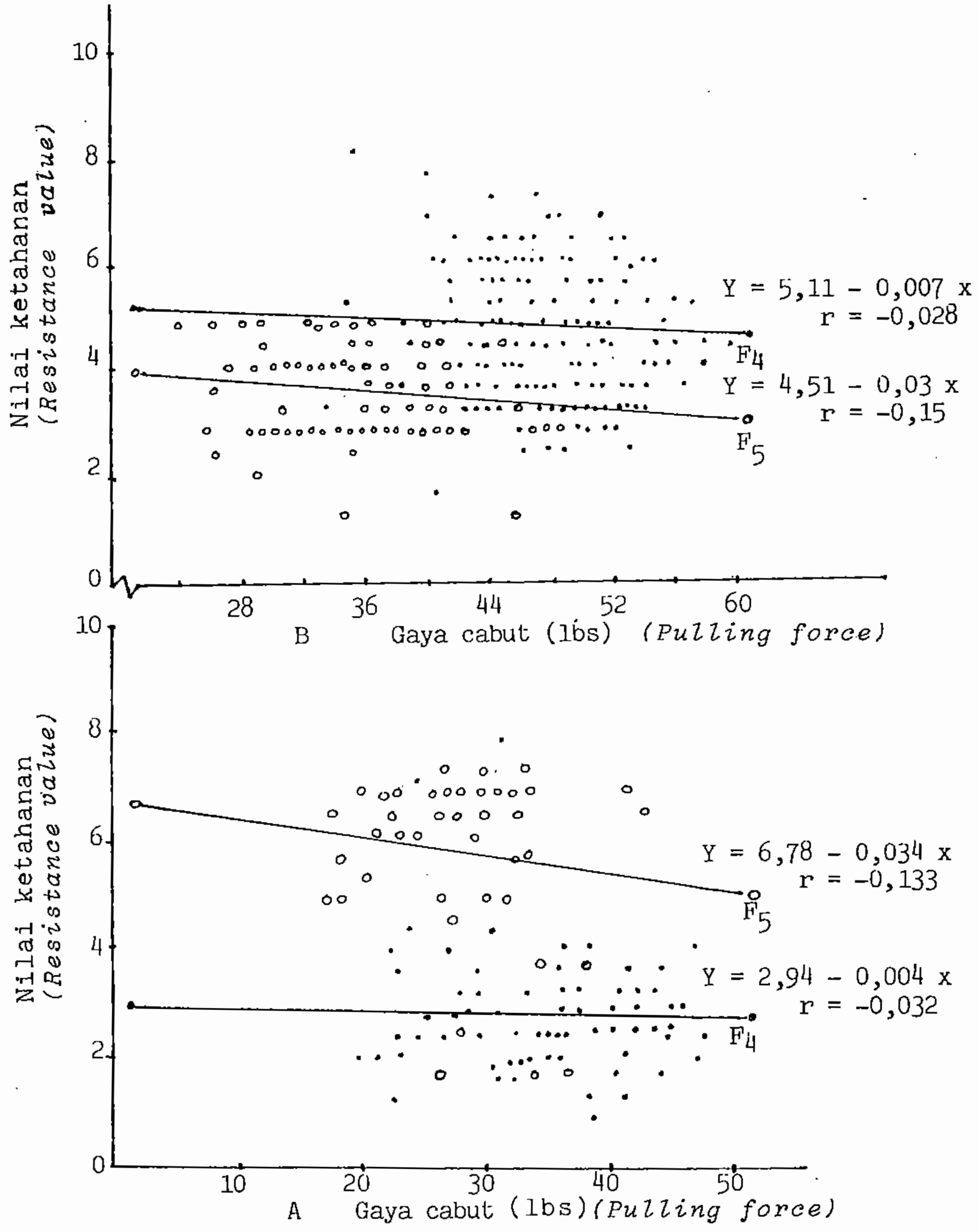


Gambar 8. **Diagram lintas perakaran dengan gaya cabut.**
(Figure 8. ***Path diagram of the root characteristics and pulling force).***



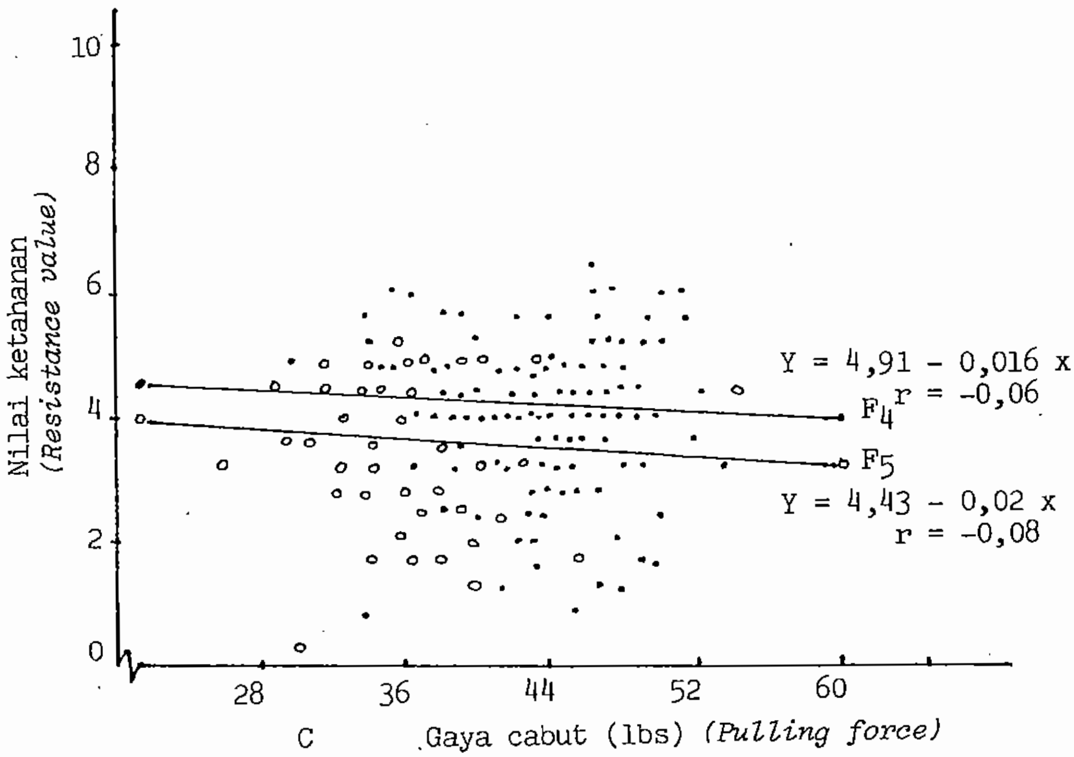
Gambar 9. **Peringkat sifat perakaran dari beberapa varietas yang mewakili berbagai tingkat ketahanan terhadap kekeringan, ditanam pada tanah berat (grumusol) dan tanah ringan (regosol). Jumlah akar total (A), jumlah akar besar (B), panjang akar maksimum (C) dan berat akar total (D).**

(Figure 9. ***Root characteristics rank of several varieties representing various degrees of drought resistance, planted on heavy soil (grumusol) and on light soil regosol) respectively. Total root number (A), thick root number (B), maximum root length (C) and total root weight (D).***

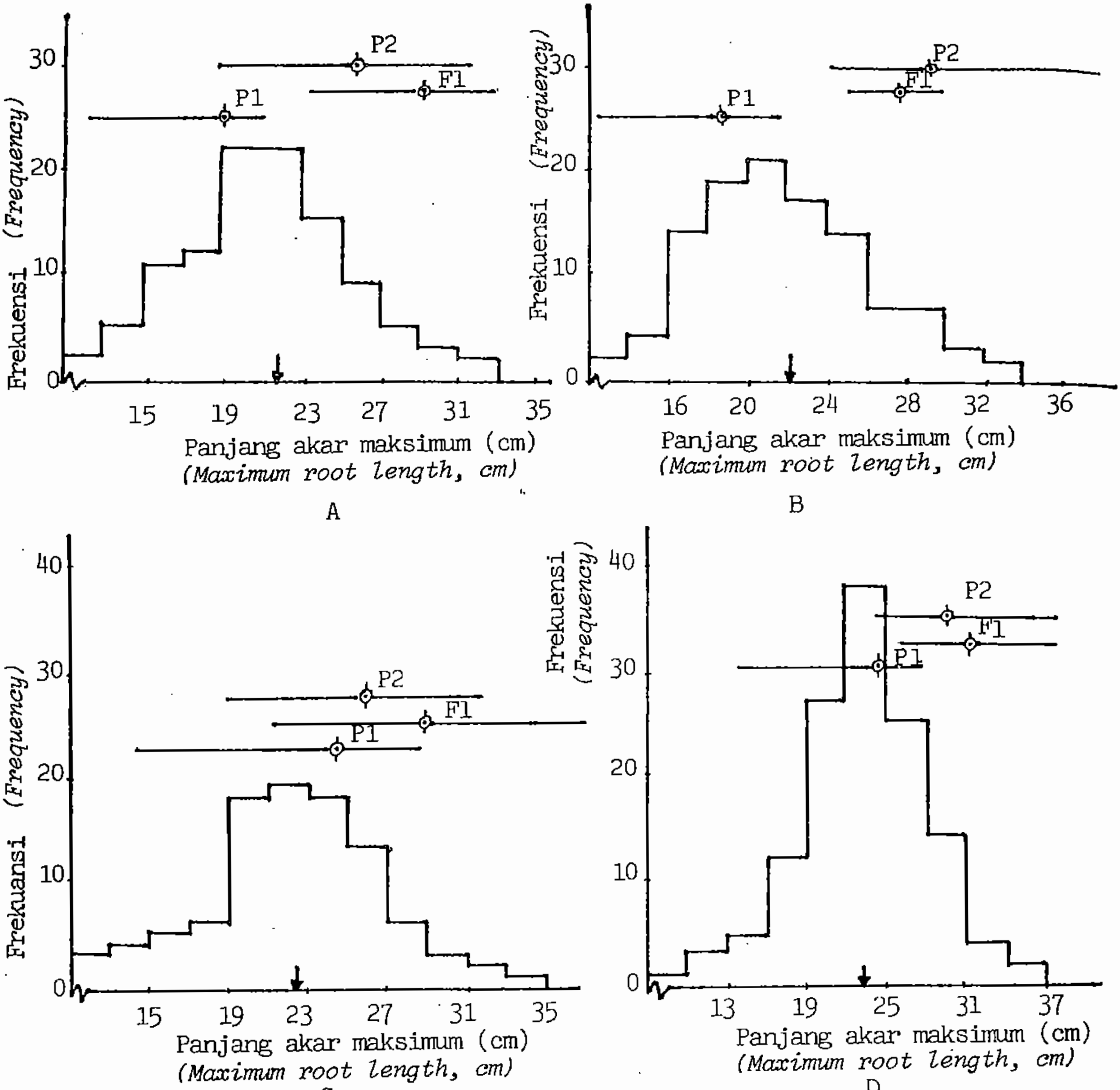


Gambar 10. **Hubungan antara nilai ketahanan terhadap kekeringan dengan gaya cabut pada tiga persilangan keturunan F_4 dan F_5. (A) keturunan IR_{20} × OS_4, (B) keturunan IR_{26} × MGL_2 dan (C) keturunan IR_{442} × MGL_2.**

(Figure 10. Relationship between drought resistance scale and pulling force of F_4 and F_5 generation of three crosses. (A) offspring of IR_{20} × OS_4, (B) offspring of IR_{26} × MGL_2 and (C) offspring of IR_{442} × MGL_2).

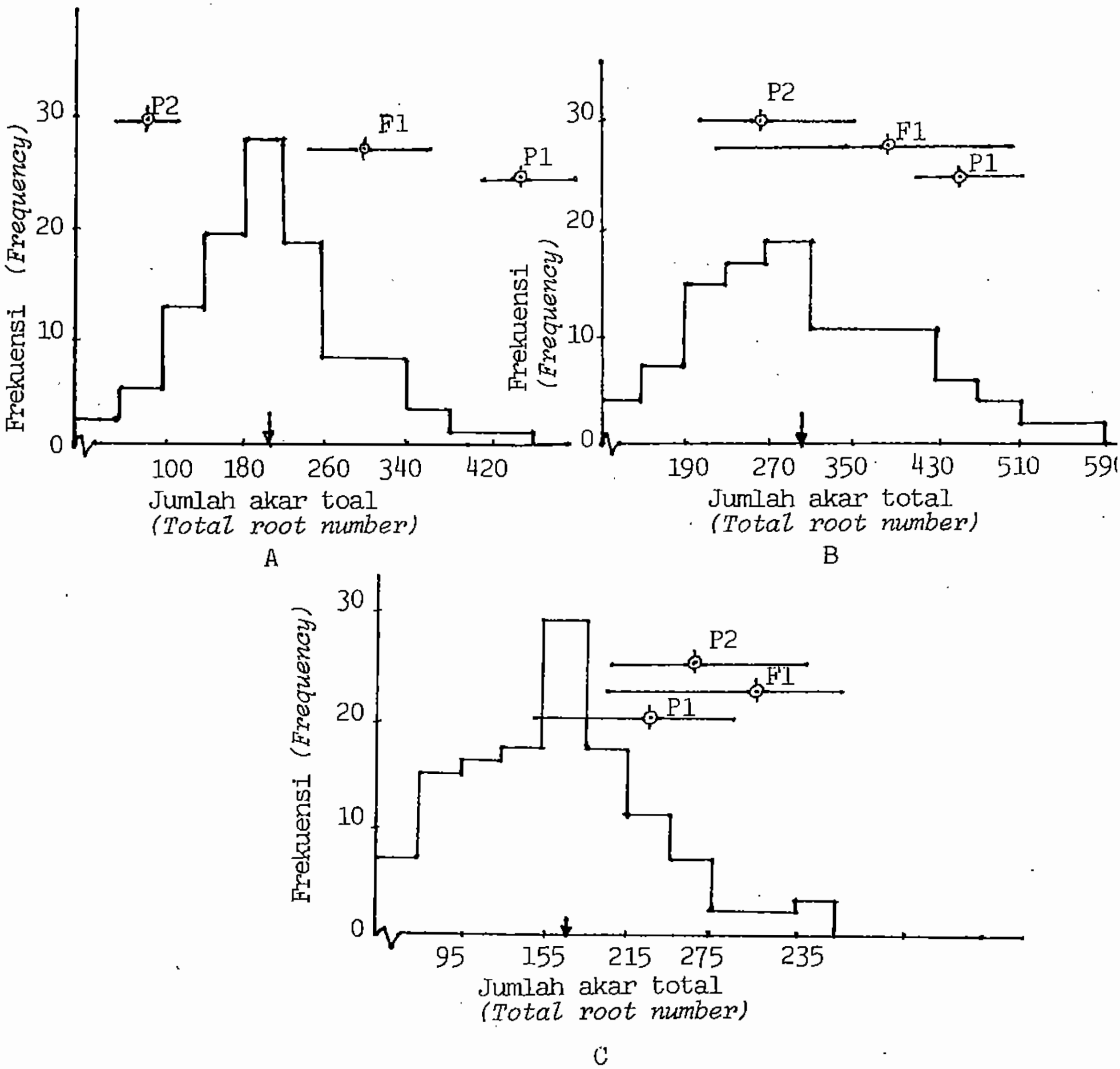


Gambar 10. **(lanjutan)**
(Figure 10. ***(continued).***



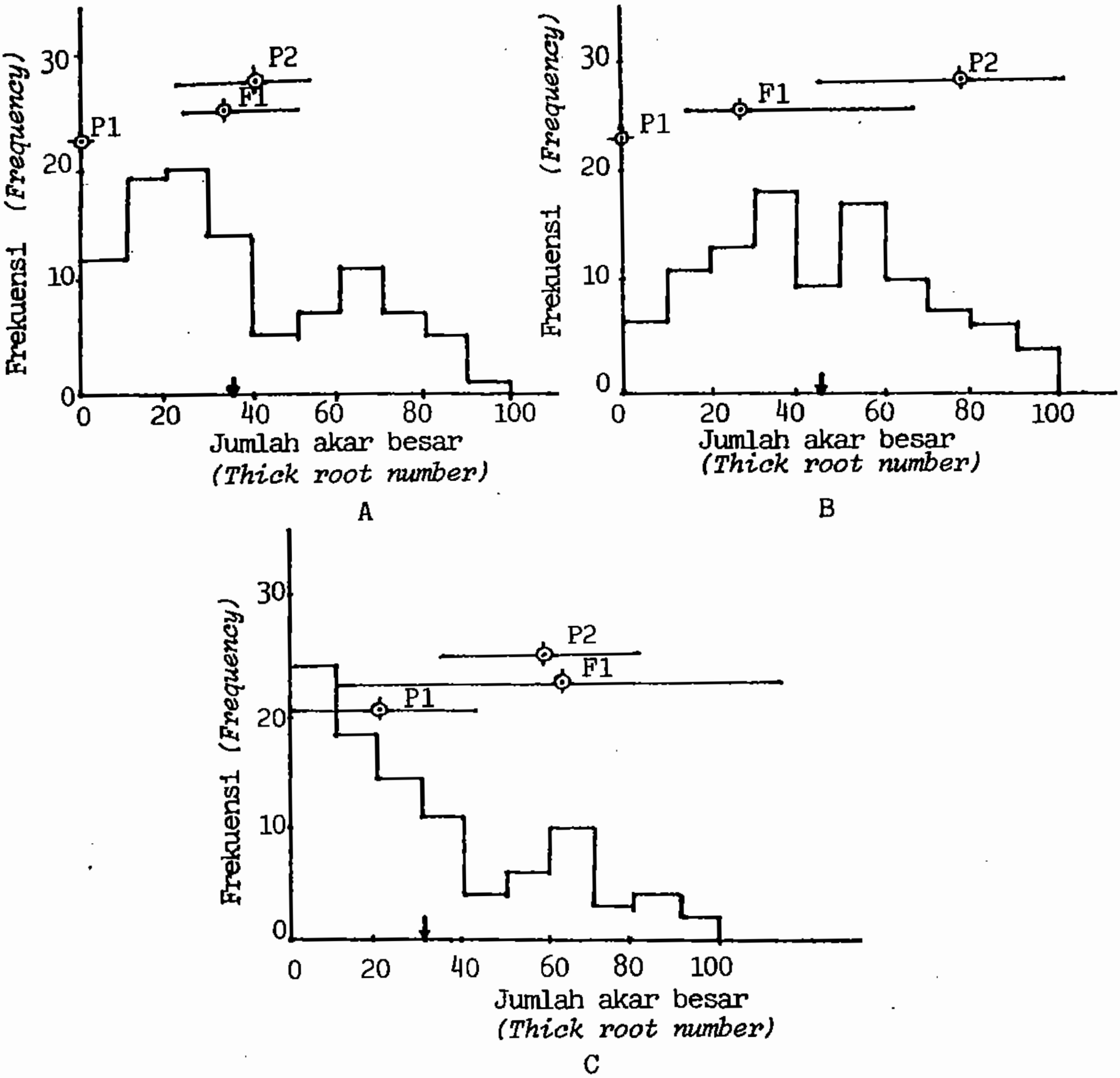
Gambar 11. **Sebaran dan purata tetua, F_1, dan F_2 untuk sifat panjang akar maksimum pada persilangan IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B); IR_{442} (P_1) × OS_4 (P_2) (C) dan IR_{442} (P_1) × MGL_2 (P_2) (D). Garis mendatar menunjukkan kisaran F_1 dan tetua terhadap puratanya.**

(Figure 11. Distributions and means of parents, F_1 and F_2 for maximum root lenghth in the crosses of IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B); IR_{442} (P_1) × OS_4 (P_2) (C) and IR_{442} (P_1) × MGL_2 (P_2) (D). Horizontal lines show the range of parents and F_1 about the means, dotted circle).



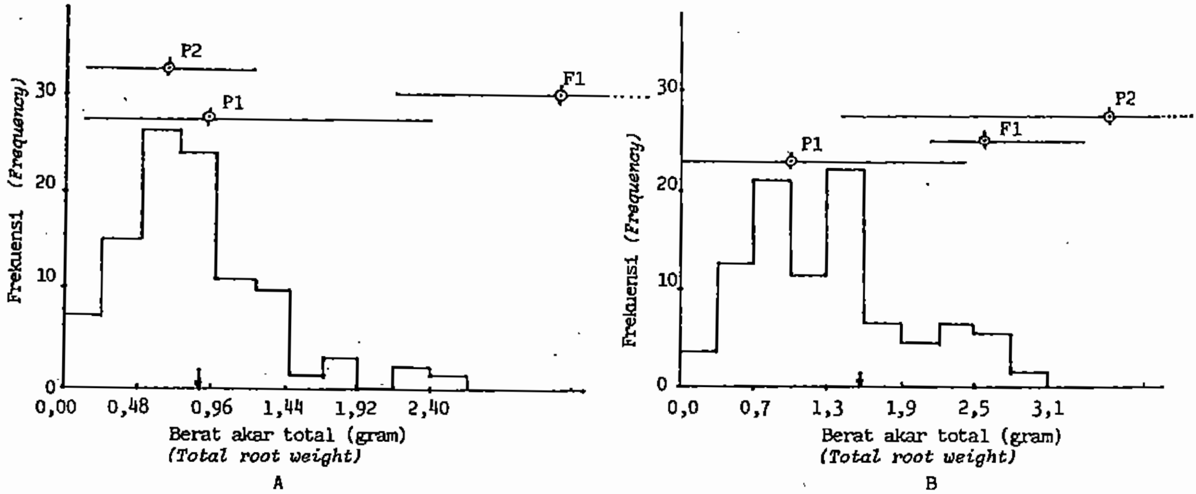
Gambar 12. **Sebaran dan purata tetua, F_1, dan F_2 untuk sifat jumlah akar total pada persilangan IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B) dan IR_{442} (P_1) × MGL_2 (P_2) (C). Garis mendatar menunjukkan kisaran tetua dan F_1 terhadap puratanya.**

(Figure 12. ***Distributions and means of parents, F_1 and F_2 for total-root number in the crosses of IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B) and IR_{442} (P_1) × MGL_2 (P_2) (C). Horizontal lines show the range of parents and F_1 about the means, dotted circle).***



Gambar 13. **Sebaran dan purata tetua, F_1, dan F_2 untuk sifat jumlah akar besar pada persilangan IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B) dan IR_{442} (P_1) × OS_4 (P_2) (C). Garis horizontal menunjukkan kisaran tetua dan F_1 terhadap puratanya.**

(Figure 13. Distributions and means of parents, F_1 and F_2 for thick root number in the crosses of IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B) and IR_{442} (P_1) OS_4 (P_2) (C). Horizontal lines show the range of parents and F_1 about the means, dotted circle).



Gambar 14. **Sebaran dan purata tetua, F_1, dan F_2 untuk sifat berat akar total pada persilangan IR_{20} (P_1) × OS_4 (P_2) (A); dan IR_{20} (P_1) × MGL_2 (P_2) (B). Garis horizontal menunjukkan kisaran tetua dan F_1 terhadap puratanya.**

(Figure 14. ***Distributions and means of parents, F_1 and F_2 for total root weight in the crosses of IR_{20} (P_1) × OS_4 (P_2) (A); IR_{20} (P_1) × MGL_2 (P_2) (B). Horizontal lines show the range of parents and F_1 about the means. dotted circle).***