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SEMI-ANNUAL SUBSTANTIVE REPORT No. 1

Contract No. AID/csd-834

For Research on Farm and Equipment Power Requirements for Production of Rice and Associated Food Crops in the Far East and South Asia.

(For the period ending December 31, 1965)

by

Loyd Johnson

Copies of this report have been filed with:

1. U. S. Agency for International Development, Washington, D. C., John R. Wilson, Office of Technical Cooperation and Research. (25 copies.)
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This report covers the period July through December 31, 1965. The The contract was signed June 28, 1965 and a work plan was submitted September 21 to cover the period September 15 to December 31, 1965.

The September 21, 1965 work plan was not implemented due to lack of available staff. Mr. Loyd Johnson was already committed to projects adequately supported by IRRI funds. Dr. William Chancellor was unable to obtain leave from the University of California to accept the position as Agricultural Engineer, and Mr. Thomas Weaver has not yet arrived to assist on the project as Agricultural Economist. Several other prospects have been and are being considered. Staffing efforts will continue both by the IRRI Director Dr. Robert F. Chandler, Jr. and Dr. Robert D. Osler of the Rockefeller Foundation.

Mr. Johnson visited Japan September 20 to 30 and Taiwan October 1 to 7, 1965, to learn of their latest developments in mechanization. The major emphasis was to visit manufacturers and machinery centers. At the Agricultural Economics Department of the Japanese Institute of Agricultural Sciences, Dr. T. Sawamura and associates are working on the Agricultural Structure Improvement program which has similar economic features to this contract. Several manufacturers expressed their desire to cooperate in future efforts and indicated that they might supply IRRI with samples of their best available equipment on a loan basis for testing, adaptation, and modification. A storage and display area is being completed at present to take full advantage of any lent equipment as this will reduce equipment expenditures. Some manufacturers are not willing to participate however, and when a certain piece of equipment seems particularly suitable, it will be necessary to purchase it.

Four-wheel drive articulated tr-ctors seem particularly suited for wet land preparation with a disc harrow. No manufacturer is yet marketing this equipment for rice farmers. The most suitable tractors are presently marketed for log skidding, cane loading, and for vegetable transport. One of these units should be purchased in 1966, a partial objective of which would be to demonstrate to manufacturers its potential use in rice land preparation.

The IRRI shop work continued on developing equipment fully supported by IRRI funds due to the limitation stated in Appendix B, Article I-B5 of this project.

> "5. Adapt, test and develop more suitable rice-producing equipment in those cases in which presently available equipment obviously does not perform efficiently. Conduct necessary tests and write preliminary design specifications. In addition to equipment adaptation, design and development in the Contractor's own shops, the Contractor shall make a continuing effort to interest and encourage manufacturers to design and develop the desired equipment. It is mutually understood and agreed by the parties to this contract that the work under this paragraph will not commence until <u>the second year of the contract term</u> and may require a two-year extension to the contract term in order to permit its completion."

The previous work carried out and reported in the 1965 IRRI Agricultural Engineering annual report would indicate that this restriction should be lifted to permit better use of the present staff and shop facilities. The wheels and rotary tiller developed in the IRRI shop in 1965 show considerable promise. The information and much of the equipment already available on anhydrous ammonia and drill row seeding indicate that a contractor unit to roto-till, apply anhydrous ammonia, and direct seed in drill rows is possible and probably practicable. The wider drill rows also indicate that a stripper harvester could be developed to harvest wet rice and thus bypass the problem of separating wet straw and grain, as the straw would be left standing in the field. Much of the economic advantage of machinery depends on low cost, timeliness, and efficiency. The bottleneck seems to be efficiency; thus better design is a keystone to economical machinery.

The attached 1964 and 1965 annual reports of the IRRI Agricultural Engineering Department are presented to indicate that enough work has been carried out to waive the limitation imposed by paragraph 5, Article I-B of Appendix B, Operational Plan. This will permit the agricultural engineering adaptation and design work to proceed. If approved, expenditures for further development of the rotary tiller, anhydrous ammonia applicator, drill row seeder, and stripper harvester will be charged to this project instead of to IRRI funds.

Permission to purchase one 60- to 80-rated horsepower four-wheel drive articulated tractor is also requested. The unit will cost about $9000. Full details will be presented in a separate letter if the above paragraph is approved.

Until staff members are available to further implement the project, the September 21, 1965 work plan will continue to guide our efforts in implementing the contract. Hopefully the staff and other positions will be filled by April, 1966, and from that date on, the project should progress as expected.

Loyd Johnson
Agricultural Engineer, IRRI

1964 ANNUAL REPORT, The International Rice Research Institute
Mailing Address: Manila Hotel, Manila, Philippines

Agricultural Engineering

A FOUR-WHEEL DRIVE TANDEM UNIT, made by joining two 8.5-Rhp standard tillers, helps eliminate bogging and keeps the operator from walking in the mud.

POWER EQUIPMENT FOR RICE PRODUCTION

FACTORS associated with the use of power equipment for rice production absorbed a major portion of the department's efforts this past year.

Most tropical areas presently produce only one crop a year, although temperature and other factors may favor continuous cropping. Rice harvesting and threshing take from 2 to 4 months, so that the land is bare (and dries out) during this period.

A second crop of rice, wheat, grain sorghum, corn, or pulses will require additional power for rapid harvest, transport, land preparation, planting, cultivation, and irrigation. The energy for transport and irrigation may be supplied either directly, as in trucks or pumps, or indirectly, as in the construction of roads, reservoirs, and canals.

In all cases, however, additional power must be supplied to complete one crop season before additional days of crop production are possible. This view emphasizes the shortage of productive power in Asia to utilize adequately the available land resources. It contradicts the generally accepted view of a lack of land resources and a surplus of farm labor.

These additional days of crop production use solar energy and available nutrients to produce 10 to 50 kilograms of palay (rough rice) per hectare-day. If properly used, this sunlight could not only produce enough rice to pay for the additional power required but also provide a surplus to develop resources further. Additional exploitation of the available solar energy should be encouraged and further exploitation of manual labor as a crude power supply, discouraged. This requires that adequate knowledge, energy, and materials be available in applicable forms. Man's role, then, would be to manage the plant to produce as much palay as possible on a hectare-day basis.

One missing factor is equipment for efficient land preparation and harvesting under wet soil conditions. Mechanical power is available at low cost in the form of engines and gear trains, but a design for effective application of this energy is lacking. More engineering effort must be concentrated on the selection and design of efficient power equipment to increase productive land time and decrease the cost of rice production.

A starting point is to provide data on some of the present uses and forms of power.

Harvesting

Time studies were made of hand harvesting of two crops of variety BPI-76 at the Institute. The rice, spaced at 25 x 25 cm, was harvested with a serrated sickle, stacked into bundles, and threshed manually. As detailed below, this method of harvest requires about 225 to 345 man-hours of labor per hectare and 68 to 116 man-hours per metric ton of dry palay. The 2-hectare family farm would thus have a full work load at harvest for several weeks.

	Man hours for operation	
Operation	Per hectare	Per metric ton palay
Cutting with serrated sickle	60–80	20–26
Carrying and stacking	25–45	8–20
Threshing, winnowing, sacking	140–220	40–70
Total	225–345	68–116

Threshers

The development of a thresher appears to be the logical first step in the mechanization of rice harvest. This is the part of the harvesting operation which has the greatest labor requirement. It is also the part of the operation where the problems of moving equipment over the field are at a minimum. For these reasons development continued on the cone thresher described in the 1963 Annual Report. A power take-off driven model with more power and more screen area for separation was built (Fig. 1). The 36-hp tractor stalled when the thresher was fed straw and grain at rates of 60 kg/min. The centrifugal nature of the cone thresher resulted in increased friction on the screen and drag on the drum, creating a high power requirement. Threshing was completed, but even a 50-square foot screen did not fully separate the grain from the straw. The development of a commercial thresher will require changes in these weak points.

Land Preparation

After harvesting and threshing are completed, the land must be prepared for the next crop. In the Philippines, carabaos are the major source of power for pulling plows and sleds, and a study was completed on the energy expenditure and work capacity of these work animals while pullings loads.

The test carabaos developed from 0.48 hp at a 40 kg load to 1.38 hp at a 100 kg load. Working under a high environmental stress for 2 hours did not affect significantly the animals' horsepower output.

Intensity of loading did not change significantly the speed of pulling. Speed ranged from 3.64 km/hr to 4 km/hr for loads ranging from 40 to 100 kg.

The gross energy expenditure expressed in Cal/min varied linearly with horsepower output within 0.48 to 1.38 hp (Fig. 2). The relationship was described by the equation:

$$\text{Gross energy} = 8.04 + 39.18\ \text{hp}$$

The net energy in Cal/min was given by:

$$\text{Net energy} = -\ 0.54 + 39.6\ \text{hp}$$

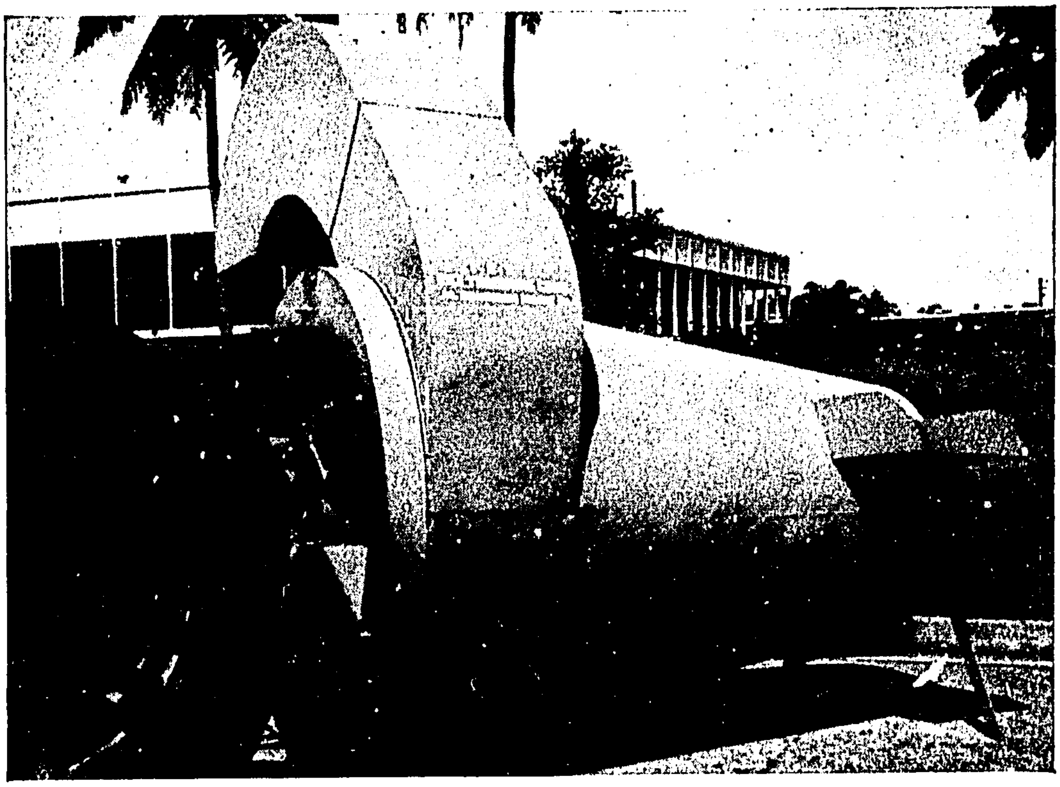


Fig. 1. A PTO-driven cone thresher.

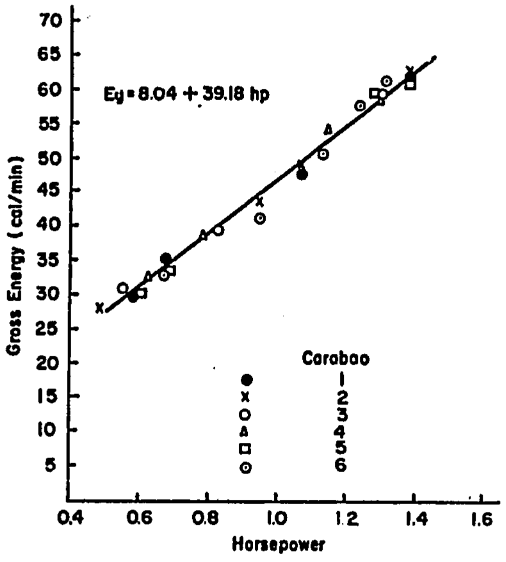


Fig. 2. Relation between energy and horsepower output of six carabaos pulling 40, 60, 80 and 100 kg loads under low environmental stress.

Gross efficiency increased at a decreasing rate with horsepower. The average maximum efficiency of 23.5 percent was attained at loads of 80 and 100 kg.

Net efficiency showed an average peak value of approximately 28.5 percent at horsepower ranging from 0.8 to 1.2 (Fig. 3).

Power Tillers

Studies of animal plowing and harrowing to prepare flooded rice soils indicate that 30 to 60 man- and animal-hours are required to plow and 40 to 60 hours to comb harrow. In the Philippines, the operator's wages and the rental value of the animal are about the same; therefore, the costs of land preparation are about the same as 140 to 240 man-hours of farm labor or 1 horsepower-hour plus operator costs about the same as 2 man-hours.

In Asia, the 5- to 10-horsepower tillers now compete with the animal. Time studies made on an 8.5-hp tiller indicate that this machine may be expected to prepare a hectare of land with 75 hp-hours plus 9 operator-hours (Table 1). Although its power requirements are about the same as those of the animal, it greatly reduces operator time and shortens the period during which the land is idle. The power tiller would seem more economical if each horsepower-hour costs less than 2 man-hours of farm labor.

The major advantage of these power tillers is their mobility in soft soils. This is achieved by light weight construction, special lug wheels, and special roto-tiller blades which slash the soil and also aid the forward movement of the tiller.

The major disadvantages of these tillers are the high cost per rated horsepower and the fact that the operator has to walk in the mud. Higher horsepower, four-wheel drive, articulated tractors seem to be the next step in wet land farming. A small four-wheel drive tandem unit was made by joining two 8.5-Rhp standard tillers. The unit lacked power and weighed too much in the rear. Improved designs of this type with more power, lighter weight, and better weight distribution should prove commercially feasible.

Work continued to develop design information for four-wheel articulated tractors. A hydraulic cylinder cable

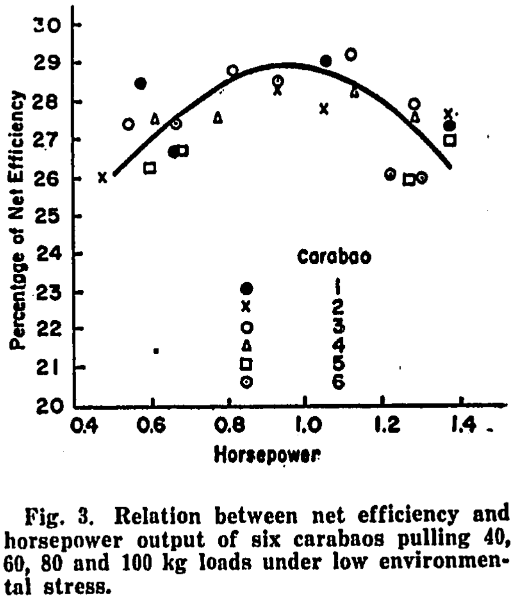


Fig. 3. Relation between net efficiency and horsepower output of six carabaos pulling 40, 60, 80 and 100 kg loads under low environmental stress.

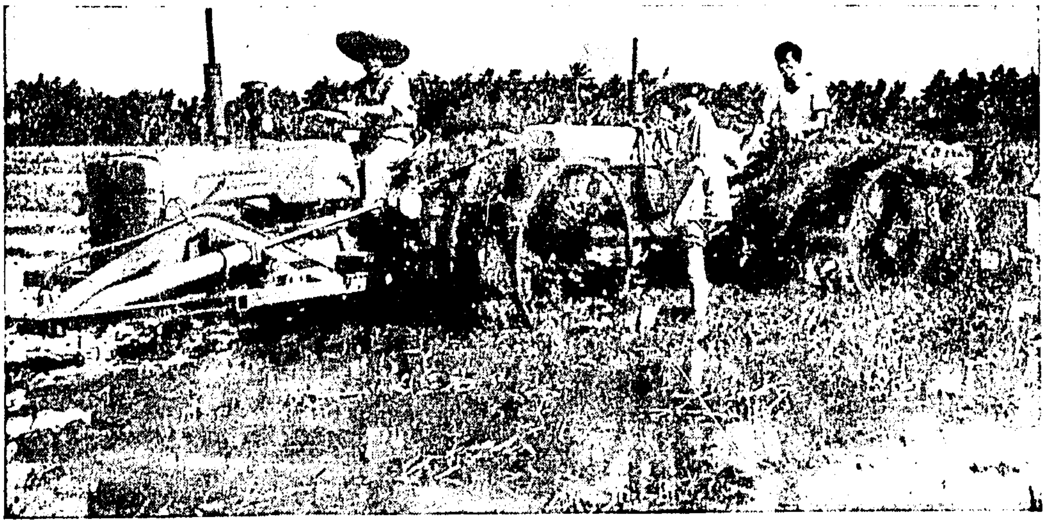


Fig. 4. A hydraulic cylinder cable arrangement for determining axle torque required to overcome rolling resistance and provide traction.

TABLE 1. Field performance of Iseki Model KF–850 8.5-Hp tiller while rotary tilling flooded clay soils.[a]

	Range	Average
Plot size, sq m	312 – 2500	312
Soil plasticity index	25 – 38	32
Penetrometer cone index at 9" depth, psi	8 – 70	20
Depth of tillage, cm	9 – 28	18
Width of tillage rotor, cm		60
RPM of rotor		267
Velocity of forward travel, meters/min	25 – 45	36
Time for 90° turn, seconds		4.6
Area, sq m, tilled per RHp-hr	100 – 162	134
RHp-hr/hectare	62 – 100	75
Operator hours/hectare	8 – 12	9
Diesel fuel, liters/ha	10.7 – 21.6	15.4

[a] 44 trials.

arrangement was designed to determine the torque required to overcome rolling resistance and to provide traction under flooded field conditions (Fig. 4). This device should help in evaluating the effect of sinkage, slippage, and wheel loads on the performance of various cage wheel and tire combinations (Fig. 5).

The larger tractors offer lower cost per horsepower-hour and per hectare of land preparation. Ultimately the cost per hectare is most important. Contractors may prepare land more rapidly and at lower cost through the use of larger, more efficient units than any one small farmer can justify for

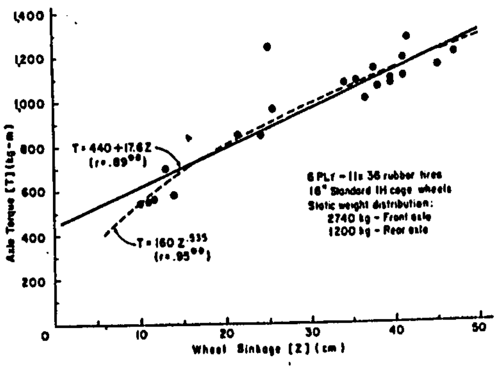


Fig. 5. Axle torque to overcome rolling resistance of a tandem tractor against sinkage of front wheels on flooded soils.

his own needs. Presently, preparing 2 hectares of land with one animal takes at least a month. The farmer and his animal cannot speed up land preparation. The production lost from the land is worth more than the cost of preparing land with power equipment.

Other special projects on land preparation included the fabrication of a set of special auger wheels for a 5-hp tractive type tiller (Fig. 6).

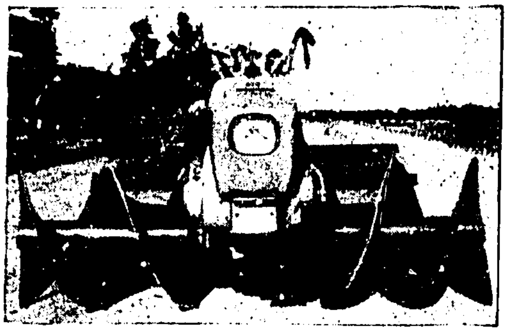


Fig. 6. A 5-hp tiller with special auger wheels.

SOIL DEPTH EFFECT ON RICE UNDER LOWLAND CONDITIONS

The literature on tillage indicates that rice yields are enhanced by plowing deeper than the conventional depth. An experiment comparing nine depths was initiated in July to gain basic information on the subject. Figure 7 and Table 2 show the relationship of grain yield per hill of Tainan 3 at the various depths. The available nitrogen at shallow soil depths apparently was inadequate for optimum growth and grain production. The soil, straw, and grain will be analyzed to determine the amount of nitrogen withdrawn by the plant.

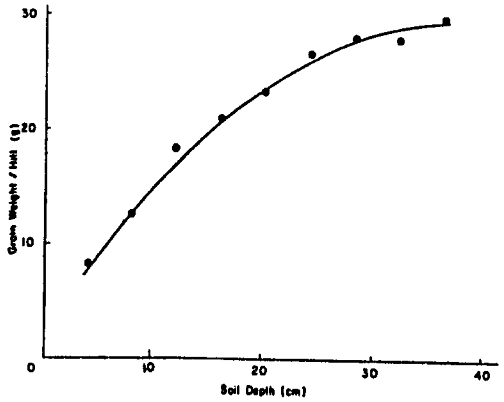


Fig. 7. Effect of soil depth on yield per hill of Tainan 3 spaced at 30 x 30 cm.

TABLE 2. Effect of soil depth on yield per hill of Tainan-3 variety, IRRI, 1964 wet season.

Soil depth (cm)	Ave. height of straw (cm)	Weight of straw (g)	Number of tillers	Number of mature panicles	Grain weight (g)
4	65.6	5.8	5.2	3.4	8.2
8	67.7	11.6	6.1	5.0	12.4
12	70.2	13.7	7.5	6.4	18.2
16	72.4	18.5	9.9	6.4	20.8
20	74.2	22.1	10.9	6.9	23.2
24	76.8	23.8	11.6	7.8	26.4
28	78.8	27.9	12.7	8.1	27.9
32	78.8	30.2	13.1	7.4	26.8
36	79.5	29.9	13.7	8.3	29.8

PLANTING

Development of equipment for planting rice requires more basic data on how the rice plant responds to various hill and row spacings. An experiment was conducted on row spacing of upland rice and two others on spacing of transplanted rice.

Row Spacing of Upland Rice

Six rice varieties were planted at nine row spacings ranging from 30 to 110 cm apart. The seed rate was approximately 100 seeds per linear meter of row, and germination was 50 by two applications of DPA and two to 90 percent. Weeds were controlled hand weedings.

Yield declined with increased spacing over 30 cm at the rate of 5 percent for each increase of 10 cm as shown in Fig. 8. Figure 9 shows the effect

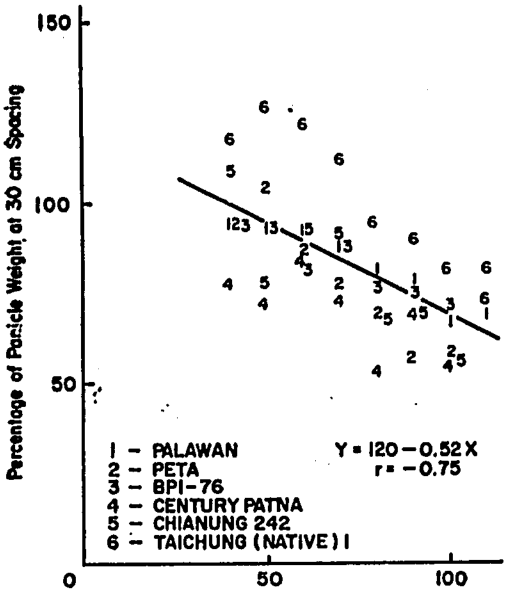


Fig. 8. The percentage of yield decreased as row spacing increased from 30 to 110 cm.

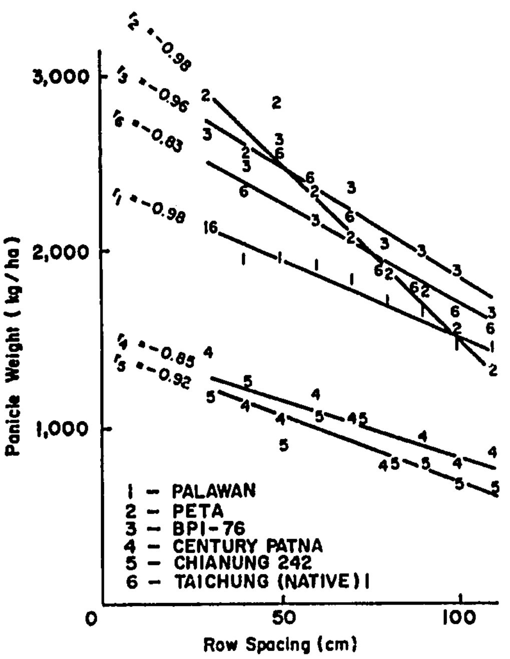


Fig. 9. Yield (kg/ha) decreased as row spacing increased from 30 to 110 cm.

in terms of yield in kilograms per hectare. The data support the hypothesis that row spacings greater than 30 cm decrease yields.

Peta lodged severely at the 30 cm spacing. Lodging gradually decreased with increased spacing. The stem height and diameter of both lodged and non-lodged plants were measured. A slender-column formula was used to compute the straw strength. The formula was simplified to

$$P_1/E = \frac{0.121 \times (d_2{}^4 - d_1{}^4)}{L^2} \text{ and } P_2/E = \frac{0.121 \times (d_3{}^4 - d_1{}^4)}{L^2}$$

in which d_1 is the inside stem diameter, d_2 the outside stem diameter, d_3 the diameter of the stem including the leaf sheaf, and L the stem length. Table 3 lists the average values of straw strength P_1/E and P_2/E for 60 lodged and non-lodged Peta plants for each spacing.

The five other varieties did not lodge but the closer spacing P/E values were always lower than the wider spacing values. This supports the observation that wider spacing decreases lodging.

Hill Spacing of Transplanted Seedlings

Methods of planting on lowland puddled soil should receive immediate attention as the 160 to 200 man-hours necessary to transplant a hectare is a major labor requirement, while broadcast seeding requires only about 3 man-hours per hectare. The value of production and labor must be balanced to decide which method is best.

Transplanting is normally at spacings of 15 to 50 cm or 4 to 50 plants per square meter, and broadcast rates are usually adjusted to obtain 100 to 200 plants per square meter. A broad range of spacing is indicated if the yield gradient due to spacing is to be identified.

TABLE 3. Average straw strength values of lodged and non-lodged plants of Peta variety for nine row spacings, IRRI.

Row spacing (cm)	Lodged (%)	Non-lodged plants[a] P_1/E	Non-lodged plants[a] P_2/E	Lodged plants[a] P_1/E	Lodged plants[a] P_2/E
		$mm^2 \times 10^{-6}$		$mm^2 \times 10^{-6}$	
30	96	3.3	11.2	2.8	7.5
40	93	4.2	14.3	2.8	8.3
50	85	4.6	14.1	3.1	8.2
60	66	5.3	15.6	3.7	9.0
70	46	5.9	16.6	3.9	9.4
80	38	6.0	16.9	5.1	12.3
90	22	6.2	18.2	4.0	10.3
100	20	6.0	17.2	5.1	11.6
110	8	6.3	19.0	4.5	10.7

[a] Each P/E value was computed from the average of 60 stem measurements.

In a preliminary experiment, 22-day seedlings of variety PI 215936 were transplanted at 37 spacings ranging from 7 to 100 cm between plants or 1 to 200 plants per square meter (Fig. 10, top). Light intensity measurements, taken October 28 at flower initiation (Fig. 10, middle), showed that the percentage of light penetration declined rapidly with populations up to six plants per square meter (Table 4) or until about 82 percent of the light was absorbed by the plants.

Plants began to lodge on November 2 at stand densities of 70 to 200 plants per square meter. By November 9, the plants at densities of from 12.5 to 200 plants per square meter were lodged after a heavy rain. On November 12, the lodging extended to the six plants per square meter (Fig. 10, bottom) after a heavy rain. No further lodging occurred; the plots were harvested December 1 to 4.

Data are summarized in Table 4 for total tillers, panicles, and grain weight per plant. Grain yield per plant vs. spacing followed a sigmoid curve, approaching the maximum plant weight of 128 grams at an 85 cm spacing (Fig. 11A). The same data converted to grain yield per hectare (Fig. 11B) show yields to increase rapidly with closer spacing from 100 cm down to 28 cm between plants. Spacings from 28 down to 7 cm gave approximately the same yield per hectare although lodging was more severe and earlier at the closer spacings. The data would indicate that transplanted rice may be spaced up to 35 cm between hills without seriously affecting yields and that broadcast seeding up to 200 plants per square meter should not reduce yields.

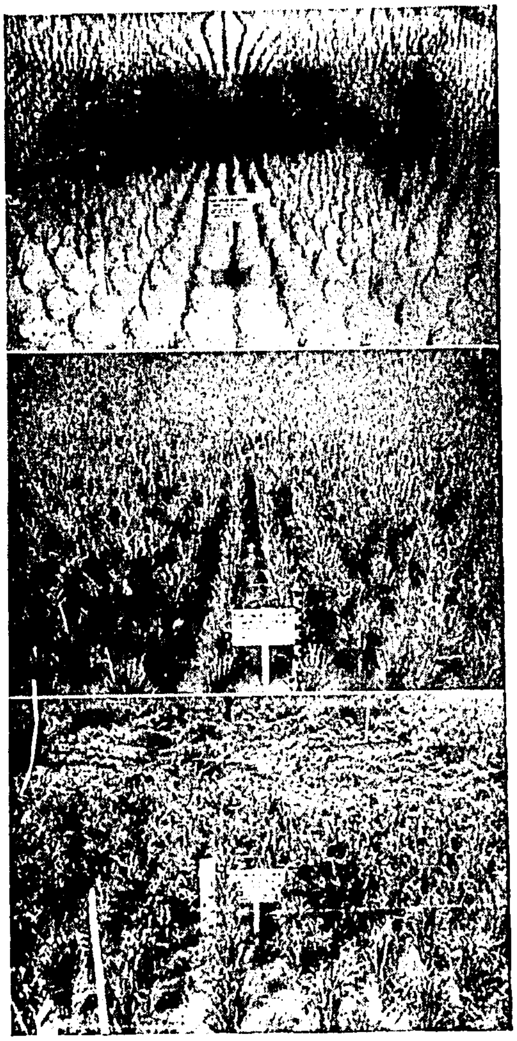


Fig. 10. Changes in appearance with age of rice variety PI 215936 transplanted at 37 spacings with 1 to 200 plants per square meter.

In Fig. 11B, the solid curve shows the theoretical yield per hectare vs. spacing from 7 to 100 cm between plants. The dotted line indicates that spacing below 7 cm would seriously reduce yields if the theoretical sigmoid curve values are extrapolated to cover the range of 200 to 1,000 plants per square meter. In field practice, how-

TABLE 4. Data on spacing experiment with variety PI 215936 transplanted August 20–23 and harvested December 1-4, 1964, IRRI.

No. of plant per m²	Distance between plants (cm)	Total tillers per plant	Panicles per plant	Grain weight per plant (g)	Grain weight (kg/ha)	Light transmission ratio at flowering (%)
1.00	100.00	47.8	47.5	128.2	1282	60.2
1.25	89.44	45.5	46.2	125.5	1569	59.3
1.50	81.64	43.6	44.4	120.6	1809	54.9
1.75	75.59	42.3	42.4	116.7	2042	51.7
2.00	70.71	40.0	40.1	109.3	2186	46.5
2.5	63.25	37.8	38.0	103.0	2575	42.7
3.0	57.74	35.6	36.0	95.1	2853	37.4
3.5	53.45	32.9	33.5	87.9	3076	33.1
4.0	50.00	31.5	31.6	81.0	3240	29.6
4.5	47.14	28.7	28.8	72.9	3280	25.8
5.0	44.72	27.4	27.5	65.7	3285	22.8
5.5	42.64	25.3	25.4	61.9	3404	21.4
6.0	40.82	24.0	23.9	55.8	3348	18.2
7.0	37.79	21.6	21.3	48.8	3416	17.1
8.0	35.36	20.2	20.1	47.1	3768	13.7
9.0	33.33	17.8	17.5	40.2	3618	12.5
10.0	31.62	16.0	15.8	35.6	3560	12.4
12.5	28.28	14.4	14.2	31.8	3975	12.1
15.0	25.82	12.2	11.9	25.8	3870	10.6
17.5	23.9	10.4	10.2	22.1	3867	9.6
20.0	22.36	9.5	9.0	17.9	3580	7.8
25	20.00	8.1	7.7	14.4	3600	7.5
30	18.25	7.1	7.0	11.1	3330	6.9
35	16.91	6.6	6.5	10.2	3570	5.6
40	15.81	6.1	5.9	9.5	3800	5.4
45	14.90	5.1	4.8	7.7	3465	4.1
50	14.14	4.9	4.7	7.4	3700	4.1
55	13.49	4.1	8	6.1	3355	4.1
60	12.92	4.0	3.7	5.7	3420	3.8
70	11.96	3.5	3.1	5.1	3570	3.2
80	11.18	3.2	3.0	5.1	4080	2.9
90	10.50	2.8	7	4.5	4050	2.5
100	10.00	2.6	2.3	3.6	3600	2.2
125	8.94	2.4	2.1	2.8	3500	1.9
150	8.16	2.2	1.8	2.3	3450	1.7
175	7.56	1.9	6	2.2	3850	1.6
200	7.07	2.0	5	1.8	3600	1.5

ever, excessively heavy seed rates and a high percentage of germination would be necessary to obtain more than 200 plants per square meter.

The dashed line in Fig. 11B indicates that the yield would decrease at a decreasing rate as spacing increases. The yield at 200 cm spacing would be 25 percent of the 100 cm yield. Zero yield would only occur at infinite spacing. The sigmoid equation thus provides a good fit for the 7 to 100 cm range investigated and also reasonable values when extrapolated to the extreme values of zero and infinity.

FIELD MEASUREMENT OF EVAPOTRANSPIRATION

Water is depleted in the rice paddy through seepage, percolation and evapotranspiration. Evapotranspiration was measured under field conditions from August 14 to December 2, 1964 on a 400-sq m plot prepared to keep seepage and percolation losses at a minimum. Near zero seepage losses were achieved through the use of multiple metal levees. Previous percolation readings made on the same plot were very low.

Water depth inside the plot was maintained at 50 to 90 mm. This level was recorded continuously with "Belfort" water level recorders modified to

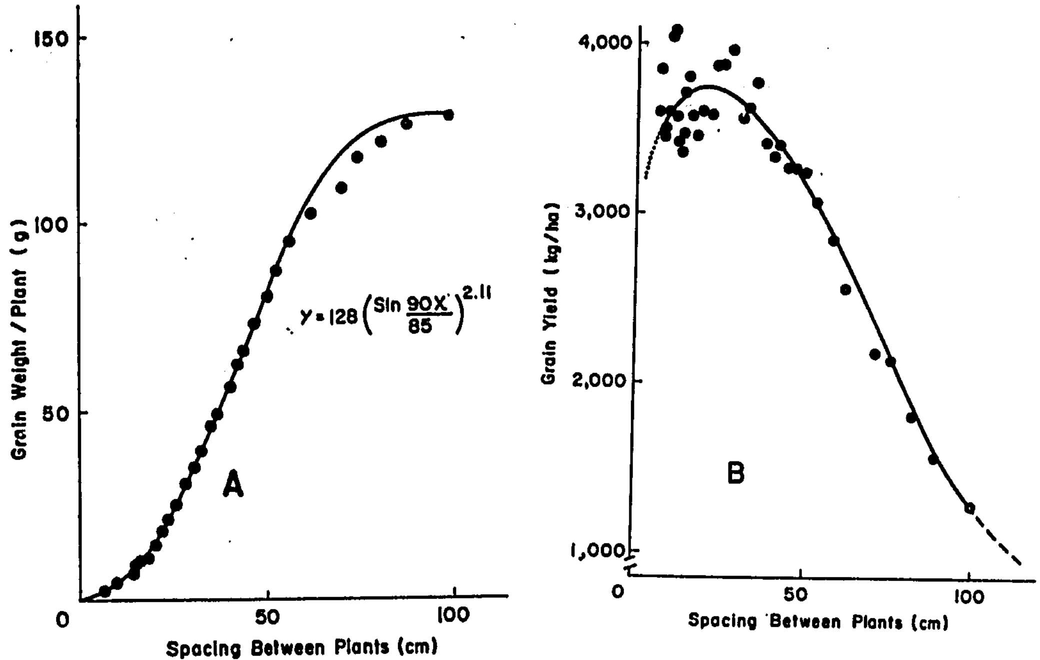


Fig. 11. Grain yield per plant (A) and grain yield per hectare (B) of PI215936 at spacings from 7 to 100 cm.

measure to 0.1 mm. In calculating evapotranspiration, data for days with more than 5 mm rainfall were discarded. Thus evapotranspiration was estimated on 49 days during the vegetative period and 18 days during the flowering period.

Solar radiation was measured by an Eppley pyrheliometer installed by the Agronomy department atop the laboratory building of the Institute. The values of solar radiation and water loss for both vegetative and reproductive stages are shown in Fig. 12. There were no apparent differences between growth stages. The data for both stages were combined to give the following regression equation:

$$Y = 0.15 + 0.01072X$$

The average values of solar radiation and water losses were 357 gm-cal/-cm^2/day and 4 mm per day, respectively. The 4 mm per day value for evapotranspiration is approximately the same water use that might be expected from upland crops with the same solar radiation.

The Y-intercept, 0.15 mm, may be considered as the average value of seepage and percolation. Under most field conditions losses through seepage and percolation exceed evapotranspiration. The measurement and control of levee seepage remains an important and difficult problem which will receive more attention in 1965.

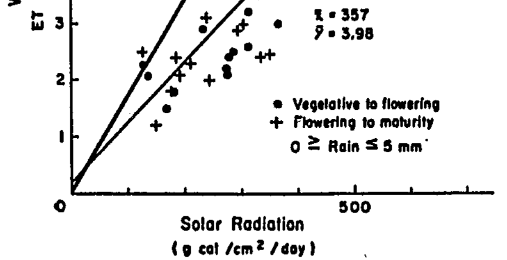
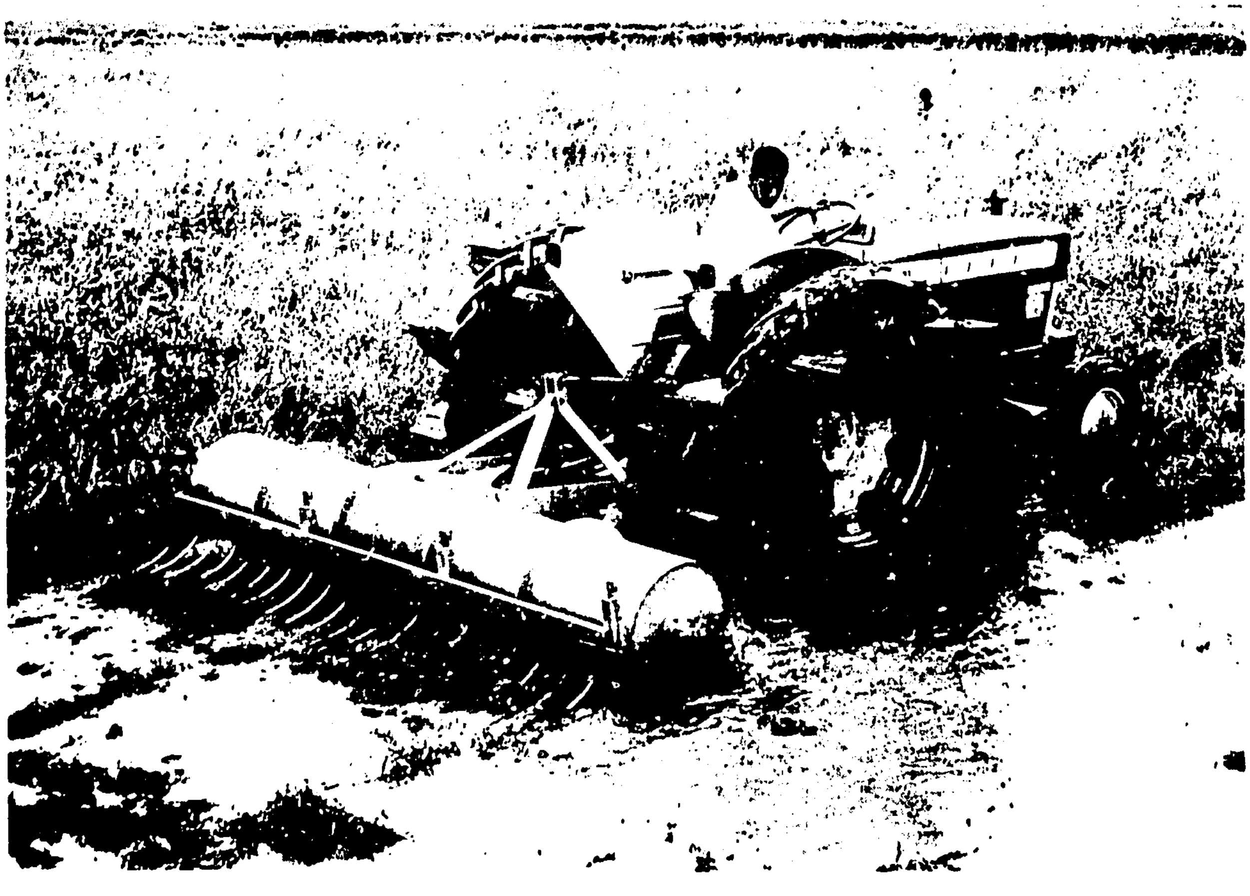


Fig. 12. The relationship of evapotranspiration to solar radiation.

1965 ANNUAL REPORT

of the

Agricultural Engineering Department, IRRI



Engineering is the design of components into a system to adequately serve a need with minimum expenditure of energy and materials. Although increased rice production is a pressing need to meet the increased human energy requirements of Asia, an overall decrease in human energy used in rice production is also necessary if the rice is to be sold at a price acceptable to the consumer and be profitable to the grower. Applied scientific research should fill the gaps in our knowledge of rice production. Agronomic and engineering design techniques may then be used to apply the knowledge. In the absence of integrated knowledge, agronomists, engineers, and farmers must rely on ART rather than SCIENCE. The results are low production and high cost due to a shortage of talented practicing artists (good farmers). This shortage is due to the difficulty of learning the necessary operations which are not expressed explicitly or quantitatively.

Engineering design and economic and engineering systems analysis should be combined with the applied biology of the agronomists to make the best use of the present climate, land, labor, capital, and material resources of the rice farmer. At the same time future systems of production that offer maximum production and minimum costs must be explored.

In 1965, a contract was initiated with the United States Agency for International Development to investigate the farm and equipment power requirements for production of rice and associated food crops in the Far East and South Asia. This project will permit the present agricultural engineering program to be expanded to secure and integrate research knowledge into a system physically capable of increasing the production of rice and other food crops. The expanded program will employ one person for operations research and one for engineering design.

The AID project was not implemented during 1965 due to lack of staff to implement the program and continue the projects already undertaken. Thus, the general engineering program already in progress was continued in the fields of farm machinery, irrigation, and bio-engineering to obtain knowledge on factors influencing land preparation, fertilization, planting, irrigation, and harvesting of rice. Drying, storage, and processing were not considered due to lack of available staff. The search for personnel continues to fully implement the AID project and permit expansion of the present program.

LAND PREPARATION

Animal Power

Land preparation is the major user of animal power; quality and timeliness of land preparation largely depends on adequate power. Animal power is limited by the size of the power unit that one man can handle -- one or two animals -- and the available fuel supply, which is pasture or straw. In areas where land is limiting, the animals compete directly with man for food. The straw or roughage used to maintain the muscle power of mature animals coul be equally well utilized for growing younger animals or producing milk. The need for a complete analysis of the alternate use of present man labor, and the possibilities of using roughage for livestock production rather than work-animal maintenance, must be brought to the attention of specialists in animal husbandry, economics, and policy planning groups. From an engineering point of view the present animal power is inadequate and expensive, yet farmers and policy makers are reluctant to consider machines which require money instead of labor and straw.

Standard Tractors

Previous work reported in the 1963 and 1964 Annual Reports indicated that about 70 to 140 Rhp-hrs of work were required for wet land preparation, equivalent to one rotary tiller pass, or two passes with a disc harrow. The cost of land preparation thus depends on the efficiency and cost of the tillage power and equipment. The animal and small tiller units are fairly efficient, but their original and operation costs are high per horsepower and difficult to improve. Larger 40- to 50-hp tractors offer the opposite choice: their original and operation costs are low per horsepower but their efficiency is also low at the present time. The major problem with the larger tractor is to obtain mobility while providing power to a soil-working tool. Since these tractors and their equipment were designed for dry land preparation, there have been more failures than successes encountered in their use in wet land preparation. However, design and development to improve the performance of these tractors seem more promising than attempts to lower the cost of the small tillers.

During 1965, work was concentrated on developing lug wheels and a rotary tiller for the 40-hp tractor size. Fig. 1 shows a tractor with special lug wheels mounted both inside and outside the tire. These wheels and an offset rotary tiller were tested at Maligaya Rice Research and Training Center. Table 1 lists the average results of 10 tests covering a total area of 3.5 hectares. The area was a clay loam which had been flooded for one crop season. Straw and weeds from the crop were still on the plots. The tractor was used at maximum speed possible, 10th notch of 3rd gear, to average about 68 meters/minute forward speed. The narrow rotary tiller width of 150 cm loaded the tractor at this speed. The results were 84 Rhp-hr and 13 liters of diesel fuel per hectare. Test of the 8.5-Rhp Japanese tiller, reported in the 1964 tests, were 75 Rhp-hr and 15.4 liters of diesel fuel per hectare. The 8.5-Rhp tiller operated at a slower, 36 meters per minute, speed with a 60-cm wide rotary tiller. For ease of handling and efficient operation, the larger tractor should also be equipped with a wider rotary tiller up to about 8 cm width per rated horsepower, and be operated at a slower forward speed of 15 to 35 meters per minute.

Fabrication has been completed on a 300 cm rotary tiller (Fig. 2) which uses Japanese rotary tiller blades and design features. Japanese tiller blades are spiral mounted individually along the shaft with a distance of 3.5 cm and an angle of 150 degrees between blades, while for most dry land tillers 3 to 6 blades are mounted on a hub and the hubs are 15 to 25 cm apart. The cutting pattern of the Japanese blade results in narrow 3.5 cm wide slices 10 to 20 cm long, whereas the other pattern results in slices 15 to 25 cm wide and 3.5 to 7.0 cm long. These differences are significant when one considers that in wet soil the slice resultant force may be used to provide flotation and traction while pressing under straw and puddling the mud. Manufacturers of larger rotary tillers have been encouraged to develop equipment for flooded soils utilizing the Japanese design criteria.

The mobility of larger tractors increases with the use of rotary tillers which provide push and some flotation. However, when the tiller is raised, the tractor must be mobile enough to cross ditches and levees with the traction developed by the wheels alone. Ten types of wheels have been fabricated and tested in an empirical effort to improve the performance of tractors in flooded fields. Figs. 1 and 2 show lug wheels which provide both flotation and traction. The wheel lugs are rubber tipped and extend the full tire diameter for better traction. Cut-out 45° triangle-shaped box lugs provide flotation, yet permit the mud to escape between the lugs. (Wide solid wheels create a wave of mud.) When mounted on both sides of a standard tire, the lugs provide aggressive action for crossing or straddling levees. Lugs are rubber tipped and mounted on the tire rim with a rubber pad to reduce shock loads.

Four-Wheel Drive Articulated Tractors

Further efforts were made to interest manufacturers in the four-wheel drive articulated tractor, as this unit with a disc harrow should be competitive or superior to the rotary tiller and two-wheel drive tractor. Studies were completed on the tractive performance of a 72-hp tandem tractor equipped with 11 x 36 rubber tires and 16" x 48" diameter cagewheels. Cantilevered weights were mounted at the rear to vary the front and rear axleloads. A tractor-mounted, hydraulic cylinder-cable device was used for slow application and simple measurement of axletorque. Drawbar load was provided by a D-4 tracklayer.

The torque required to steer the tandem tractor was also measured on the same soil by using pressure gauges connected to the hydraulic circuit of the steering cylinders.

Towing tests also were conducted. The rolling resistance (towing resistance) of the tandem tractor was found equal to 1.58 times the self-propelled axletorque of the four wheels, or the effective wheel radius was 1/1.58 or 0.63 meter.

The results of traction tests were expressed by multiple regression equations based on data for two tires with cagewheels corresponding to either the front or rear wheels of the tandem tractor.

$$T_s = 487 + 0.206\ W - 3.16\ (C.I.)$$

$$T_m = 429 + 0.357\ W - 1.62\ (C.I.)$$

$$P_m = -291 + 0.377\ W + 2.50\ (C.I.)$$

$$P_c = -90 + 0.239\ W + 2.44\ (C.I.)$$

where T_s = self-propelled axletorque, kg-m

T_m = maximum (full slip) axletorque, kg-m

P_m = maximum, net tractive effort (measured), kg

P_c = maximum, net tractive effort (computed as $T_m - T_s$ divided by 0.63 meter), kg

W = axleload for two wheels (1290 to 2740 kg)

C.I. = soil cone index (96 to 169 psi at 12" depth)

A highly significant increase of T_s, T_m, P_m, and P_c with axleload or weight indicates that the test soil has a pronounced frictional property and that weight may be important in securing traction on flooded soils. This contradicts earlier beliefs that on flooded soils with deep mud, adding weight to the tractor would not increase net traction.

Self-propelled axletorque (rolling resistance) varied inversely with soil cone index. At low cone index greater sinkage was encountered resulting in increased compaction and bulldozing resistance.

Maximum axletorque also was inversely related to cone index. At low cone index the decrease in soil strength was offset by an increase in soil-wheel contact area due to sinkage.

Net tractive effort increased with cone index. On firm soils (high cone index) conversion of axletorque into tractive effort was more efficient as soil reactions were mostly horizontal.

The instantaneous torque to steer the tandem tractor increased with sinkage and steer angle. Peak values of 850 kg-m, 950 kg-m, and 1000 kg-m were obtained at sinkages of 20 to 25 cm, 25 to 30 cm, and 30 to 35 cm, respectively. Corresponding maximum steer angles were 45°, 35°, and 25°, respectively.

SIZES AND SHAPES OF FIELDS

Generally the field sizes and shapes of lowland rice farms in the Philippines were decided upon without foresight for the introduction of farm machinery. Farmers made small-sized fields, especially on lands with high slopes and oriented them to incur the least earth work for leveling, which was performed with carabaos and ordinary implements.

Farmers are now realizing that farms with larger fields with appropriate shapes are more accessible to farm implements and more suitable for operations such as plowing, harrowing, and applying irrigation water.

Yet many still hesitate to reconstruct their farms due to the large volume and cost of the earthwork required. The present sizes and shapes of fields are limiting the use of farm machinery on flooded rice farms; mechanization can be effectively implemented only if the sizes and shapes of the fields and other conditions permit the tractor to have easy access within the field, from field to field, and from farm to farm. Information on the existing field conditions of lowland rice farms, such as sizes and shapes, levee dimensions, and cone index values will help solve problems of using farm machinery and implements.

During 1965, eleven rice farms around Calauan, Laguna, were surveyed by the plane table method. Maps (scale 1:1000) were prepared of each farm layout showing the shape of each field. Dimensions and areas of the fields were measured from the scaled farm map. Later, fifty levee dimensions and field elevations were measured in the field with an improvised measuring device and a dumpy level; the top and bottom width of the levees and their heights at the upper and lower fields were measured, and the cone index of the 50 fields on each farm at 6-, 9-, 12-, and 15-inch depths were determined with a cone penetrometer. Percent slope of land was measured approximately by measuring distances between contour intervals.

The average field size was found to be 585 sq m. Field dimensions of the eleven farms ranged from 13 to 22.1 m wide and 20.3 to 39.4 m long. Average dimensions were 19.14 m wide by 29.4 m long.

There was no definite pattern followed in laying out the fields with respect to the slope of the land. However, in many cases the contour lines were diagonal to the rectangular fields, and the length of the field was thus controlled to some extent, whereas with contour levees the length could be several times the width. (Fig. 3.)

Average levee dimensions were 19 cm top width, 33 cm bottom width, 18 cm levee height on upper field side, 29 cm levee height on lower field side, and an average difference of 12 cm between fields. In general, the means varied only ±3 cm. Farmers on the 11 farms followed a similar pattern in making the levees, with little regard to slope or field size. The average levee base width and elevation difference would form a hydraulic gradient of 0.33 slope with zero water depth to almost 1.0 when fully flooded. Average levee areas would be about 6 cubic meters per 100 lin m so that earth work to build levees is a minimum. The major problem in reshaping the field size will be to cut and fill to combine adjacent fields. The average field size of 585 square meters, and elevation difference of 12 cm, would require about 600 cu m cut and fill per ha to combine adjacent fields and to double field size.

Soil bearing pressures were measured at 50 sites on each farm by taking penetrometer readings at 6-, 9-, 12-, 15-, and 18-inch depths. Using a cone index reading of over 35 psi at 15 inches as a criterion, approximately 84 percent of the farm area surveyed would permit mechanical land preparation.

SOIL DEPTH

The use of tractors instead of animals in land preparation usually results in a deeper soil profile over a period of years. The merits of this deeper soil are not clearly understood as the mixing of infertile subsoil with a fertile topsoil usually results in yield reduction for several crops. Yet, with deep plowing and the addition of fertilizer, the entire soil profile may be improved and brought to a new state of equilibrium. Deeper soils offer a greater reserve or holding capacity for water and nutrients. The management or timeliness of water or fertilizer applications are obviously not as critical in a soil 50 cm deep, as in one only 10 cm deep. However, the relative importance of the various intermediate depths is not as clear.

Grain and straw of the Tainan 3 variety, grown in the 1964 wet season experiment on soil depth, were analyzed for nitrogen content. During the 1965 dry season, the soil was again thoroughly mixed and placed on the sloping floors to provide depths of 6 to 40 cm. Variety PI 215936 responded to the soil depth; plants in the deeper center rows were taller, greener, and yielded more. (Fig. 4.)

Sloping concrete floors were placed in two additional 5.4 x 8.4 meter plots to provide depths ranging from 0 to 72 cm in each plot. Thoroughly mixed Maahas clay soil was added to each plot, and each plot was split: one half fertilized (50 kg of N per ha) and the other not fertilized. The fertilized plots showed a dramatic response in vegetative growth at all soil depths from 0 to 70 cm. However, the grain yield increased in only the 0 to 40 cm depths.

Grain and straw yield increased with increased soil depth in the form of a modified exponential equation of the form, $y = k + ab^x$. (Fig. 5.) However, total nitrogen recovered from the grain and straw showed a linear trend with a sharp break at a soil depth of 40 cm. (Fig. 6.) The slope of the N regression lines indicates that 32 gm of N were extracted per cu m of soil in the 0 to 40 cm range. From 40 to 70 cm soil depths the extracted N averaged only 6 gm per cu m of soil. Total soil nitrogen recovered from the straw and grain was apparently the same in both the fertilized and non-fertilized plots. The additional 50 kg of N per ha shifted the regression lines equivalent to a recovery of 40.7 kg of N in the grain and straw. The fertilizer application was thus equivalent to an additional soil depth of $\frac{40.7}{32} = 12.7$ cm. Grain yields of the two plots show a similar shift as if soil depth were increased by the nitrogen. Straw yields, however, show an upward shift due to the added N. Additional experiments on the interaction between applied N, soil depth, and time and depth of application should be conducted to allow one to predict at what depth and time nitrogen should be added, and to what depth land preparation should incorporate straw and fertilizer to form a deeper profile.

The results to date indicate that applied N is largely reflected in straw weight. Yield increases of grain and straw are more pronounced in soils less than 30 cm deep. Fertile soil depths up to 40 cm definitely increase yields. Soil depths of less than 40 cm respond more to fertilizer applications. For uniformly mixed soil less than 40 cm deep, the yield response is almost linear while on deeper soils the modified exponential trend becomes apparent.

Data in Tables 2, 3, and 4 demonstrate the full implications of soil depth. The values of k, a, b, and x of the equation $y = k + ab^x$ are given as well as the solution of the equation for soil depths representing 90 and 95 per cent of maximum yield k. The value, k, may be due to either solar radiation or a limited supply of N. Native soil nitrogen taken into the plant varied from 21.4 gm to 32 gm per cu m. Thus, Maahas clay supplied the equivalent of 86 to 128 kg N/ha from the top 40 cm of soil. Soil profiles of 40 cm and over may be impracticable because depth limits the movement of men and machines. However, depths up to 30 cm are not a problem. The present animal land preparation has created a plow sole at depths of 10 to 15 cm which will undoubtedly be too shallow for the most efficient utilization of fertilizer, machines, and land in the future.

FERTILIZER APPLICATION

Anhydrous ammonia (82% N) is a promising fertilizer material for flooded fields as it is low in cost and readily held in the wet soil. The positive pressure and gaseous or liquid form allow precise metering and placement of the nitrogen at any desired depth in the mud.

The Agricultural Engineering Department fabricated a knapsack anhydrous applicator for use by the Agronomy Department on wet, puddled soils. (Fig. 7). This unit will contain 10 kg of N and permit placement of the N at 0 to 20 cm depths at rates of from 0 to 240 kg per ha. Depth control is by means of a plate, and rate is controlled by a pressure regulator, orifice, and by ground speed. Details of fabrication and calibration are available to interested persons.

An experiment was carried out in which the speed was maintained constant and the pressure was changed to obtain varying rates of N from 10 to 240 kg/ha. Variety PI-215936 was transplanted at 5 x 45 cm spacing on August 16-17, 1965. Three replicates were fertilized on September 22-23 at rates which were varied in 10 kg/ha increments between rows. The plants reacted visually to the application rate. Lodging started and was most severe at rates over 80 kg but occurred at rates as low as 35 kg in one replicate. Yield of grain and straw approached a maximum at 65 kg N/ha and gradually declined at higher levels of N. (Table 5). The solar radiation, rather than nitrogen, limited yields. The plants were a healthy green and showed promise of maximum yield if adequate sunshine had been available.

There should be a use for the backpack applicator in applying anhydrous ammonia to extensive field demonstration plots. Farmers can observe the variable rate and decide reasonably well at which point N application ceases to be important. A commercial model could also be made for backpack use and supplied by the fertilizer dealer on a rental arrangement.

SPACING

Mathematical equations to predict the effect of plant spacing and sunlight on yield are necessary to make a final decision on the method of planting to use, and the means to accomplish the operation. Adjustments in the method of planting should improve either yields or labor productivity if the results are even approximately predictable. High plant populations of over 50 plants per sq m are best achieved by direct seeding either by broadcast or drill rows. Transplanting may be square or in drill rows but transplanting at more than 25 plants per square meter is prohibitive in labor requirements.

Rice yields should be proportional to the solar radiation intercepted by the plant and converted to grain. Plant population or spacing is an important variable influencing panicle number and the interception of solar radiation. Sparsely spaced plants do not fully tiller to utilize the sunlight, whereas overpopulation results in light-weight panicles, death of the lower leaves, and excessive and early lodging of plants. Prior knowledge of the rice plant's reaction to spacing would permit adjustments to prevent excessive lodging yet adsorb 80 to 95 percent of the sunlight to obtain 80 to 95 percent of theoretical maximum yields.

Square Transplanted

The results of the 1964 spacing experiment No. 1 were used to design the dry season, 1965, experiments No. 2a and 2b. (Figs. 8 and 9). Replications were increased in No. 2a to increase precision at close spacings. Plant density was increased to cover the range of 200 to 400 plants per square meter. Forty-one spacings were used ranging from 1 to 400 plants per square meter. Experiment No. 2b was a row planting versus square arrangement in which plants were transplanted 5 cm apart in a drill row, and 16 rows were spaced at distances ranging from 5 to 144 cm. Transplants were also spaced with the same row distances and a plant distance in the row equal to the row distance to form a square pattern. Several additional experiments No. 3, 4, 5, 6, and 7 were made at intervals throughout the 1965 wet season to gain information on yield in relation to solar radiation, and to compare transplanting with direct seeding by broadcast and drill row methods. The percent of light penetrating to ground level, or the light transmission ratio (LTR), was taken at flowering time to estimate the effect of solar radiation adsorption on yield. The theoretical maximum yield for any one planting would depend on the solar radiation during the last few weeks prior to harvest and the efficiency of conversion. Maximum yields for all spacings within an experiment may be estimated by a regression equation of $y = a + b(LTR)$, in which a is maximum yield if all sunlight were intercepted and used as efficiently as it is used by widely spaced plants. Maximum yields seldom occur as the yield curve breaks at LTR values of 5 to 20 percent, when mutual shading and lodging becomes excessive. The a intercept and the (-100b) of the equation should be equal if the LTR is taken precisely, as at LTR = 100, no light is intercepted. In practice, however, the adjustments of the light meters and shadows cause the LTR values to be variable at wide spacings. Thus the a value is a better estimate of maximum yields and the -b value is the rate of change from maximum yields as LTR decreases.

Summary tables 6 to 15 are presented rather than numerous figures as persons interested in bio-mathematics can plot and compute for many combinations of spacing, panicle number, panicle weight, LTR, lodging index, and leaf area index, and attempt to find the best prediction equations. Adequate data are not yet available for a thorough analysis of the various relationships, but the following statements seem to be justifiable simplications based on the present experimental data:

1. Lodging occurs when the LTR is less than 5 to 10 percent in bright clear weather and 10 to 20 percent in cloudy weather.
2. Panicle number and leaf area index (LAI) determine LTR; yields thus vary directly with panicle number until excessive competition occurs.
3. Average individual panicle weight is almost constant at wide spacings and is probably genetically determined, while at close spacings the individual average panicle weight is reduced in direct proportion to the area available per panicle and the solar radiation. Individual PI 215936 panicles require 40 to 60 sq cm for full development; while PI 215936 x CI 9214 panicles require about 45 sq cm; and Fujisaka #5 panicles about 25 sq cm.
4. Panicle weight per sq m is determined by panicle number and

average panicle weight. Panicle number per sq m increases rapidly with plant population from 1 to 10 plants per sq m in the form of a modified exponential equation:

$$Y_1 \text{ Panicles/m}^2 = k + ab^x = k(1-b^x)$$

in which $k = -a$ and is the maximum fully developed panicle number per sq m, and x is the number of plants per sq m. The two equations, $Y = a + b(\text{LTR})$ and $k + ab^x$ give about the same results.

The approximate genetic maximum panicle size, and leaf area per panicle, should be reflected in the square centimeters required for full development of a panicle, while tillering ability of the plant is reflected in b^x; theoretically, when $x = 1$, then $b^x = b$. Tables 14 and 15 list prediction equations for panicle number and yield in panicle weight per sq m. Yield may be converted to clean grain weight by multiplying by a factor of 0.85 to 0.90. Note that in Table 14, the k value approximately equals the a value, especially for panicle number.

Drill Rows

The results from experiments No. 2b, 4, and 5 indicate that row spacings may be wider than hill spacings. Tentative prediction equations are proposed with the following forms:

$$\text{square transplant } Y = k(1 - b^x)$$

$$\text{drill row } Y = k\sqrt{1 - b^{2x}}$$

These are based on the yield results of experiment No. $2b_1$ and $2b_2$ and the observed lodging pattern. Drill rows spaced 45 to 60 cm apart are probably similar in mutual shading to hills spaced 25 to 33 cm apart. Yield of drill rows from 20 to 95 cm was almost equal in experiments 2b, 4, and 5. (Fig. 10).

Yield was apparently best near the last row lodged which ranged from 45 to 75 cm. However, yield was about the same at 85 and 95 cm row spacings. Additional information from rows spaced 100 to 200 cm will be necessary to predict the decline of yield at wide spacings on fertile soils.

Land preparation, fertilizer application, and direct seeding in rows could be completed in one operation if drill rows are 50 to 100 cm apart, while stripper harvesting from standing plants would eliminate the problem of separating wet grain and straw. Additional investigation of yield response of varieties direct seeded in drill rows would enable the machine designer to take advantage of the plant's inherent ability to compensate for spacing.

Individual Plants

An experiment was initiated to observe the plant's ability to compensate for spacing. Seven widely different varieties were selected and interspaced hexagonally with one square meter per plant. Approximately 150 plants of each variety were grown in this manner so that each was a replicate. Twenty-five healthy plants (25 replicates) were measured at harvest and the data, summarized in Table 13 and Fig. 11, indicate that the product of leaf area and growth period is closely related to yield. This relationship could be explored further to enable estimates of field production to be made from greenhouse experiments.

The leaf spread at the top of the plant is 80 to 128 cm, indicating that row spacing could be in this range before serious yield reduction occurred.

LODGING

Work continued on the use of the Euler slender column formula to correlate inner and outer diameters and length of straw with its strength. Excessive lodging often occurs for no apparent reason in production plots grown under uniform conditions. In order to test the sensitivity of the formula, 60 paired sample plants were taken from lodged areas in production plots of two varieties, Peta and Tainan 3. The largest tillers were selected from lodged plants and adjacent non-lodged plants; inner stem diameter, outer stem diameter, leaf sheath diameter, and straw length were measured, and the P/E values computed by the method reported in the 1963 and 1964 Annual Reports. Table 16 shows the average values, standard error of the mean $s_{\bar{x}}$ and coefficient of variability. The mixture of strong and weak straws in the two plant populations accounts for the great variability. The non-lodged plant population had the higher P/E values but a large number of samples would be required to show differences at the .05 level.

It is generally recognized that planting density influences straw strength. The 1965 spacing experiment with variety PI 215936 again confirmed this common observation. Table 7 shows the significant effect of spacing on P/E values. The higher P_2/E values confirm the importance of the outer leaf sheath to lodging resistance. Plants spaced closer than 28 cm lodged while those at wider spacings did not lodge.

The manipulation of plant spacing seems a promising method to reduce lodging. Spacing could be varied in accordance with the fertility of the soil, the seasonal light intensity, and the variety or plant type. Square and row spacings were observed to lodge in a pattern in the 1965 spacing experiments. In general, lodging was severe for row spacings under 60 cm and square spacings under 30 cm.

Nitrogen is the second variable that has a predictable effect on lodging. Figs. 12 and 13 show the P/E values for two varieties grown with different rates of N in the 1965 Agronomy experiments. Again the P_2/E values indicate the importance of the outer leaf sheath.

HARVESTING

Philippine farmers have objected to the introduction of hard-to-thresh rice varieties. To overcome these objections, extension personnel have requested IRRI to investigate simple threshers such as the pedal thresher, long used in Japan and Taiwan for similar varieties. One model, purchased in Taiwan in 1962, was tried previously by IRRI laborers with little success. During their October 1965 visit to Taiwan, the agricultural engineer and his assistant had the opportunity to see the pedal thresher in use in Kaohsiung county and to photograph the actual field operation. These observations indicated that the important points in using the pedal thresher were the addition of a box and screen to the machine, and the organization of the field crew. A leaflet is being prepared to instruct farmers and extension workers on the use of the pedal thresher.

Cone thresher

A third model of the cone thresher was built, incorporating a serrated triangular fan blade for entrance feeding and threshing. The feed rate and threshing efficiency were satisfactory on dry grain and straw, but separation of the grain from the straw was not satisfactory. From 30 to 50 percent of the grain was blown out with the straw. The separation was clearly inadequate. Since work on cage wheels and rotary tillers seemed to show greater promise, work on the cone thresher has been discontinued for the present.

TRANSPORTATION OF PALAY

Transportation of the harvested rice crop is a major problem in areas where there are no field roads and the grain must be carried manually. A time study was conducted to obtain data on the rate of such transportation and on the time involved in returning unladen. Under a contractual system of wage payment of ₱10.00 per ton-kilometer which the laborers set themselves, six laborers each carried a 50-kg load 12 kilometers and returned the 12 kilometers unladen, thus transporting a total of 0.6 ton-kilometer in one day. Only two men out of 8 were able to carry the 50-kg load 15 kilometers and return unladen to transport 0.75 ton-kilometers in 6 hours. The men worked to exhaustion and refused further work even though permitted to set their own contract rates. Table 17 is a guide for persons interested in rate of manual transport of palay.

IRRIGATION

Irrigation projects in tropical countries have been designed mostly for supplemental irrigation of rice grown during the rainy season. The water required is supplied by effective rainfall and supplemental diversion irrigation. Since the water usually is distributed free of charge, there is a tendency for the farmer to get more water than is actually needed. The total water required by rice under flooded conditions must be estimated more precisely in the future by designers of irrigation systems and others concerned with irrigation because water costs for reservoirs and pumping are becoming the limiting factor in dry season rice production.

Due to limited research data, the designers of an irrigation system usually have to assume quantities of water lost by evapotranspiration, by gravity, and the conveyance losses in canals. Presently, the evapotranspiration is calculated by empirical formulas based on climatic data. The water losses by gravity and overflow in paddy fields are calculated as a percent of water requirement. Irrigation designers often assume 1 cm per day as the total requirement of rice.

Evapotranspiration or consumptive use. A high correlation between solar radiation and evapotranspiration was proved for rice at the Institute in 1963. The measurements were made from a small tank, but similar results were obtained in the field during the 1964 wet season (August to December) and reported in the 1964 IRRI Annual Report. Additional measurements of solar radiation, pan evaporation, and other climatic indices of evapotranspiration from rice were made on the same experimental plot from January 5, 1965. (Figs. 14 and 15). Water depth was maintained at 60 to 90 mm; seepage losses were almost eliminated by using multiple metal levees. Decrease in water level in the 400 sq m plot with 1 m buffer area was regarded as evapotranspiration plus percolation. Three piezometers were installed to measure the water table and study the effect of percolation.

Twenty-day old seedlings of PI 215936 were transplanted at 20 x 20 cm spacing on January 5 and harvested 119 days later on May 3. Heavy rain fell in January and early February, but under the influence of the northeast monsoon dry season conditions prevailed in March and April. The temperature in January and February was about 24°C but rose to a maximum of 29°C in April.

Evaporation and rainfall were measured from three metal tanks, size 2.40 x 2.40 x 0.6o meters, with closed bottoms. All tanks were installed with the bottoms 40 cm below the soil surface. The soil which had been removed for the installation of the tanks was carefully placed in each tank up to the external soil level. Water level was recorded to 0.1 mm scale division on a water level recorder in one tank and checked by hook gauges in the others.

Gross solar radiation, mean air temperature, relative humidity, and wind velocity were measured in the U. P. College of Agriculture Weather Station located 1 km south of the experimental plot. The data for 25 days were discarded because of heavy rain, wind, or irrigation disturbances, but accurate evapotranspiration measurements were obtained for 94 days.

Assuming that theoretical evaporation in the rice field follows the thermodynamic conditions, it takes 582 gm-cal to evaporate 1 cc of water at 26.5°C, thus 582 gm-cal per sq cm per day of solar radiation should evaporate 10 mm of water in the field, or

$$y = \frac{1}{58.2} x = 0.0172 x$$

where y = mm of water

and x = $gm/cal/cm^2$

For the 1965 dry season, the relationship of pan evaporation to gross solar radiation was

$$y = -0.19 + 0.0098 x$$

with $r = 0.9035$. In comparison with the theoretical evaporation equation, the ratio,

$$\frac{Y_{pan}}{Y_{Th}} = \frac{0.0098\ x}{0.0172\ x} = 0.55$$

indicates that 55% of the gross solar radiation was used in evaporation of water from the 2.40 x 2.40 x 0.60 meter sunken pan.

The best estimate of evapotranspiration was obtained by subtracting the night evaporation pan losses from the 400-square-meter field night losses. The difference of night evaporation pan and night field data was assumed to be gravity losses due to percolation and seepage for one-half day. The formula for calculating evapotranspiration was

$$ET = (ET + SP)_d + 2E_n - (ET + SP)_n$$

ET = evaporation, mm/day

$(ET + SP)_d$ = evapotranspiration + percolation in the daytime, mm

E_n = pan evaporation in the nighttime, mm

$(ET + SP)_n$ = evapotranspiration + percolation in the nighttime, mm

The relationship of evapotranspiration to gross solar radiation during vegetative and reproductive stage was $y = 0.0108x$. The ratio 0.0108/0.0172 indicates that 63% of gross solar radiation was used in evapotranspiration.

Solar radiation largely determines temperature and relative humidity. Thus these climatic elements are correlated with evapotranspiration. Fig. 16 shows the relationship between evapotranspiration to relative humidity and mean air temperature. These climatic factors showed a lower correlation coefficient than solar radiation.

Fig. 17 shows the daily evapotranspiration from the field and daily solar radiation. The cumulative evapotranspiration of 94 days in three different stages of growth shows the same slope as the regression equation for the daily evapotranspiration values. (Fig. 18). Many researchers have reported that during heading the rice plant uses more water than either before or after this stage. In this experiment, the difference between the vegetative and reproductive stages of growth were not significant. However, during the ripening stage when the leaves turned brown the rate was a little lower.

Fig. 18 also shows the cumulative evapotranspiration compared with the cumulative evaporation. The ratio between ET and E is almost constant for vegetative, reproductive, and ripening stages. Solar radiation is the major factor in the vaporization of water from the evaporation pan and ET from the crop, and both were highly correlated with solar radiation.

Percolation. Deep percolation is the downward flow through a depth of soil. Seepage is the lateral loss of water from a shallow depth of standing water through levees and boundary soil profile. Under field conditions percolation and seepage are major losses which may exceed the evapotranspiration. Percolation mainly depends on vertical permeability, porosity, texture and structure of soil, depth of soil profile, pan formation, and ground water table.

The seepage and percolation rates of an experimental area of Maahas clay were reported in the 1963 and 1964 Annual Reports as 0.50 and 0.15 mm/day. During 1965, additional measurements were made on the piezometric head with three piezometers installed to depths of 50, 100 and 150 cm in the buffer area of the experimental plot. Percolation rates increased as the piezometer heads and hydraulic gradient increased. Soil permeability (k) was found to be constant at 2.2 mm/day while seepage from the experimental plot was found to be negligible due to the metal levees and a buffer area in which water was maintained at the same level as in the plot.

Seepage. Seepage through earth levees under field conditions is a major source of water loss. Seepage is affected by soil permeability, soil cracks, and insect tunnels. Darcy's Law may be applied for calculating rate of seepage due to permeability which varies with the hydraulic gradient. However, turbulent flow may occur through small channels and exceed laminar flow. Thus, the condition and age of the levee affect the rate of seepage. The turbulent flow varies from place to place along the levee. Several methods for measuring seepage were compared in an attempt to develop a simple method, applicable for use on irrigation projects, to estimate re-usable water that may seep out of higher fields into lower fields.

Seepage through 10-meter long levee. This first experiment was conducted to measure seepage through representative strips of levee 10 m long. Seven sites were selected and metal levees installed.

The regression equations for seepage and depth of water were significant for the following sites:

Site No. 1 $y_1 = -5.801 + 1.915x_1$ $r = 0.741$
Site No. 2 $y_2 = -7.871 + 1.510x_2$ $r = 0.748$
Site No. 5 $y_5 = -0.338 + 5.367x_5$ $r = 0.949$
Site No. 6 $y_6 = +2.629 + 1.196x_6$ $r = 0.650$
Site No. 7 $y_7 = -2.183 + 2.815x_7$ $r = 0.661$

To check the overall accuracy of the 10-meter strips, two water level recorders were installed to record water level of complete plots. One plot gave reliable data on the seepage rate through a 168 meter levee. The equation, $y_8 = -0.468 + 4.322x$ with $r = 0.942$, was obtained for the relationship of rate of seepage of the entire plot to depth of water.

The regression equation of Site No. 5 represents seepage from levees bordering ditches, while Sites Nos. 6 and 7 represent the seepage from levees between plots. Using average weighted y values the rate of seepage from the entire plot was: $\bar{y}_{5,6,7} = 0.136 + 2.526\bar{x}$. This differs from y_8 and indicates that three 1 x 10 meter plots when used as seepage meters would only approximate the rate of seepage.

Lateral seepage into drains. A second experiment was conducted to estimate the seepage which reappears in surface ditches or streams and is available to lower areas. If re-used, the seepage losses from higher elevations would not be lost, and the seepage from the perimeter levees could be of economic importance from a water conservation point of view.

Accurate measurement of each individual length of levee is not practicable; but an approximate estimate can be made by measuring the water which reappears in surface ditches. A 3-inch throat Parshall flume was installed and water flow from a 1540 m ditch drain measured daily.

Flow rates for rainy days were higher than for dry days. (Fig. 19). During the first period after rain, the flow through levee openings and from the road bed gave a high discharge rate. The flow then decreased gradually until stable. The steady flow rate on rainy days was usually higher than on dry days; thus, two regression equations were chosen to best fit the data.

Re-usable seepage water from this 1540-meter road ditch averaged 5.4 lit/hr/lin m on dry days and 13.6 lit/hr/lin m on wet days. The flow of water increased 1.6 to 4.7 lit/hr/lin m per cm increase in average water depth. These values may serve to estimate perimeter seepage losses from other projects with similar levees. Field engineers may check these values by setting up a similar experiment on drains which are near boundary levees.

Re-usable water from higher fields. A third study was conducted to estimate the flow from upper fields through levees to lower fields. Metal levees along the side levees adjacent to drains minimized seepage from the plots to the road drains, thus the water lost from one plot entered directly into the next lower plot.

In the first of the experiments the average levee thickness was 30 cm at the top and 40 cm at the base. The natural grade was 0.7%, and the average difference in elevation between plots was 18 cm. Seepage from the highest plot was maintained at a rate sufficient to irrigate four lower plots. The computed water requirement of the lower plots was based on a 6 mm/day rate of P + ET. To supply this requirement, total excess water from the highest plot was computed to be 26 lit/hr/lin m. The amount of seepage through one meter of levee was to be adequate to irrigate a 104 m strip below the levee. To maintain the necessary rate, the depth of water in the high plot was maintained at about 5.5-6.0 cm.

After the highest plot had been flooded to a depth of 8 cm, water seeped to the lower plots; hydrograph patterns displayed a sharp peak indicating rapid movement into the first plot, but patterns were smoother for lower ones, and the fourth plot hydrograph was almost static.

In the second experiment, the natural grade was 0.25%, and the plots differed in elevation by an average of 6 cm. The seepage rate in the highest plot with a depth of 10 cm of water, was only 5 lit/hr/lin m -- sufficient to maintain the water requirement of 0.6 cm/day for an area of 20 sq m, on only a 20-m strip below the levee. A parallel pattern was given by the hydrograph.

The last two experiments thus indicated that the rate of seepage through an earth levee may be used to supply a 20 to 100 m strip of lower land when water levels are 1 to 10 cm deep.

Table 1. Field performance of I-H D-439 tractor while rotovating flooded clay soils in the Maligaya Rice Research and Training Center.[1]

	Range	Average, $\bar{x} \pm 2\sigma_{\bar{x}}$
Field size, sq. m.	1125 - 9212	3333
Operator hours/hectare [2]	1.95 - 2.58	2.16 ± 0.16
Time for 90° turn, sec.		5.54 ± 0.45
Effective field capacity, sq. m/hr.	3877 - 5145	4682 ± 313.69
Area, sq. m., tilled per RHp-hr.	99 - 132	120 ± 8.03
RHp-hr/hectare	75 - 100	84 ± 5.95
Fuel consumption, lit/hr.	4.40 - 7.47	6.04 ± 0.75
" " lit/ha.	9.9 - 17.1	12.99 ± 4.95
Width of rotor, m.		1.5
Average swath, m.	1.54 - 1.77	1.7
Depth of tillage, cm.	10 - 18	13.34 ± 1.42
Slippage, percent [3]	18.8 - 27.7	22.73 ± 0.02
Penetrometer cone index at 12" depth, psi	7 - 160	77.65 ± 13.72
" " at 18" depth, psi	45 - 215	102.58 ± 18.52
Time to cross levee, sec.[4]	1.4 - 8.1	3.36 ± 0.30

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[1] 10 trials

[2] 3rd gear, 10th notch

[3] For every 3 rev. of wheels $(3\pi D)$, D = 1.40

[4] Average levee height, cm = 18.08 ± 1.47
" " width, cm = 44.08 ± 3.50

Table 2. Effect of soil depth on yield of Tainan 3. 1964 Wet season (spacing 30 x 30 cm non-fertilized).

Soil Depth cm	Straw Ht. cm	No. of Tillers per m^2	No. of Panicles per m^2	Weight, gm/sq. meter				N Content (gm/sq. m.)[1]		
				Panicle	Straw	Grain	Plant	Straw	Grain	Plant
4	66	58	38	99	64	91	163	.39	1.12	1.51
8	68	68	56	153	129	138	282	.69	1.58	2.27
12	70	83	71	223	152	202	375	.76	2.29	3.05
16	72	110	71	256	206	231	462	1.48	2.70	4.18
20	74	121	77	285	246	258	531	1.62	3.72	5.34
24	77	129	87	340	264	293	604	1.96	3.89	5.85
28	79	141	90	363	310	310	673	2.20	4.42	6.62
32	79	146	82	341	336	299	677	2.53	4.14	6.67
36	80	152	92	383	332	331	715	2.59	5.10	7.69
k	89	175	96	433	539	356	924	4.23	6.46	10.57
a	-24	-129	-53	-339	-468	-272	-763	-4.05	-5.55	-9.48
b	.882	.805	.734	.798	.890	.767	.845	.889	.857	.869

Centimeters soil depth estimated for 90 and 95 percent of maximum value k.

Y = 0.9k	46	40	28	40	78	35	54	81	60	67
Y = 0.95k	61	53	38	52	102	45	70	122	78	88

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[1] Average soil N = 21.4 gm/cu. m. or 86 kg N/ha to 40 cm depth.

Values of coefficients in formula $Y = k + ab^x$; $x = \frac{\text{Soil Depth} - 4}{4}$

Table 3. Effect of soil depth on yield of PI-215936. 1965 dry season. (Spacing 15 x 20 cm, non-fertilized.)

Soil Depth cm	Straw Ht. cm	No. of Tillers per m^2	No. of Panicles per m^2	Weight, gm/m^2			N Content, gm/m^2		
				Straw	Grain	Plant	Straw	Grain	Plant
8	48	88	83	122	122	244	.81	1.47	2.28
14	50	116	116	193	192	382	1.09	2.48	3.57
20	56	149	145	294	284	578	1.57	3.54	5.11
26	60	185	178	405	384	788	2.16	4.98	7.14
32	64	208	187	461	446	906	2.59	5.81	8.40
38	68	232	216	546	575	1121	3.33	7.80	11.13

Average N removed by plant from soil = 29.3 gm/cu. m. or 117 kg N/ha to 40 cm depth.

Table 4. Effect of soil depth on yield of PI 215936. 1965 dry season. (Spacing 15 x 20 cm; non-fertilized (NF) and fertilized (F) 50 kg N/ha.)

Soil Depth	Straw Ht. cm		No. per Sq. M.						Weight, gm/sq. m.						N Content, gm/sq. m. [1]					
			Tillers		Panicles		Straw		Panicle		Grain		Plant		Straw		Grain		Plant	
cm	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F
10	56	66	168	305	151	218	283	605	261	455	229	400	544	1060	1.33	3.42	2.09	3.88	3.42	7.30
20	66	75	259	316	196	221	496	751	406	503	356	442	902	1254	2.49	5.81	3.96	4.97	6.45	10.78
30	76	81	268	337	208	231	653	905	485	533	426	468	1128	1438	4.20	8.05	5.14	6.02	9.34	14.07
40	77	82	274	341	207	233	688	918	553	595	486	522	1241	1513	5.53	9.42	6.40	7.32	11.93	16.72
50	81	83	272	344	209	237	679	915	590	604	518	519	1268	1519	5.92	9.94	7.21	7.35	13.13	17.29
60	81	82	274	349	217	234	745	925	610	622	535	508	1355	1547	6.80	10.21	7.42	7.53	14.22	17.74
70	80	83	281	348	212	245	769	1008	598	675	525	570	1367	1683	6.88	1078	7.35	8.29	14.23	19.07
k	83	83	280	349	214	244	772	956	663	680	552	573	1368	1664	7.66	10.78	7.78	8.12	15.02	18.57
a	-28	-19	-97	-51	-58	-28	-505	-397	-396	-228	-322	-177	-833	-646	-6.75	-7.82	-5.78	-4.54	-12.54	-12.09
b	.539	.333	.373	.513	.4	.693	.515	.401	.661	.759	.608	.717	.532	.649	.697	.576	.65	.626	.605	.577
Centimeters soil depth estimated for 90 and 95 percent of maximum value k																				
Y=0.9k	30	18	22	16	21	14	38	26	53	54	45	44	40	41	70	46	57	47	52	44
Y=0.95k	41	24	30	26	28	33	49	33	70	79	60	65	50	57	(90)	58	73	62	62	57

Average soil N = 32 gm/cu. m. or 128 kg N/ha to 40 cm depth.

Values of coefficients in formula,

$$Y = k + ab^x$$

$$x = \frac{\text{Soil Depth} - 10}{10}$$

Table 5. Variety PI-215936 grain, straw, and total plant weight for anhydrous ammonia application rates of 5 to 235 kg N per hectare.†

Applied Nitrogen Kg N/hectare	Grain gm/sq. m.	Total Dry Matter Panicles + Straw gm/sq. m.
5	433	844
15	480	907
25	513	1025
35	518	1029
45	515	1071
55	548	1157
65	546	1140
75	549	1106
85	518	1061
95	523	1153
105	536	1106
115	521	1147
125	519	1255
135	459	1059
145	480	1101
155	472	1087
165	434	1026
Average 175 to 235	486	1070

†Harvested Nov. 29, 1965. This was a wet season crop in which the gross solar radiation during the eight weeks prior to November 28 was as follows (in order from last week before harvest) -

1930; 2010; 2119; 1803; 2413; 1899; 1959; 2785 --- Total, 16918 gm-cal/sq. cm.

Table 6. Experiment No. 1 - Plant density, panicle number, panicle weight, and light transmission rate (LTR) at flowering of variety PI 215936. Planted Aug. 22, 1964 and harvested Dec. 1, 1964. Location: Plot M-5(b); fertilizer rate 100-40-30 NPK kg/ha.

No. of Plants per m^2	No. of Panicles per m^2	Panicle Weight gm/m^2	LTR %
1.00 [2]	47 [2]	143 [2]	60 [2]
1.25	58	174	59
1.50	67	202	55
1.75	74	226	52
2.00	80	243	46
2.50	95	284	43
3.00	108	319	37
3.50	117	347	33
4.00	126	365	30
4.50	130	371	26
5.00	137	376	23
5.50	140	385	21
6.00	143 [1]	386 [1]	18 [1]
7	149	395	17
8	161	437	14
9	157	420	12
10	158	415	12
12.5	177	463	12
15	178	454	11
17.5	178	455	10
20	180	428	8
25	192	432	8
30	210	411	7
35	224	441	6
40	236	468	5
45	216	427	4
50	235	455	4
55	209	412	4
60	222	414	4
70	217	427	3
80	240	488	3
90	243	468	2
100	239	430	2
125	262	437	2
150	255	405	2
175	280	455	2
200	300	440	2
250			
300			
350			
400			

[1] Last row lodged

[2] Border effect 1 plant/sq. m. was outer row.

Table 7. Experiment No. 2a - Plant density, panicle number, panicle weight, and light transmission rate (LTR) of variety PI 215936 at flowering. Planted Feb. 4 and harvested May 18, 1965. Location Plot M-5(b), fertilizer rate 100-40-30 Kg/ha.

No. of Plants per m^2	No. of Panicles per m^2	Panicle Weight gm/m^2	LTR %	Leaf Area Index (LAI)	P_2/E	Lodged at Harvest %
1.00 [2]	66 [2]	188 [2]	80 [2]	0.59 [2]	50 [2]	0 [2]
1.25	79	237	76	1.00	45	0
1.50	93	276	71	0.83	50	0
1.75	103	213	66	1.03	51	0
2.00	108	333	64	0.95	37	0
2.50	128	408	58	1.43	49	0
3.00	143	472	51	2.14	25	0
3.50	152	508	53	1.98	26	0
4.00	169	564	41	2.60	38	0
4.50	172	593	37	2.07	23	0
5.00 [2]	208 [2]	690 [2]	26 [2]	1.52	34	0
5.50	201	670	19	2.76	33	0
6.00	203	681	21	3.11	28	0
7.00	215	707	13	3.06	30	0
8.00	228	729	11	2.35	27	0
9.00	238	744	8	1.45	21	0
10	232	703	8	1.67	24	3
12.5	250	749	6	2.97	21	25
15	252 [1]	749 [1]	5	3.26 [1]	28 [1]	75
17.5	248	755	5	4.95	19	75
20	242	741	4	2.13	23	78
25	265	781	3	3.90	23	84
30	276	757	2	2.71	17	97
35	308	792	2	2.30	12	97
40	320	816	2	3.54	14	97
45	310	773	2	3.13	13	97
50	325	772	2	3.83	11	100
55	330	780	2	4.04	10	100
60	330	763	2	1.96	12	100
70	357	788	1	3.66	11	100
80	344	756	1	2.52	8	100
90	360	783	1	3.44	5	100
100	360	751	1	5.20	4	100
125	412	805	1	4.86	5	100
150	435	805	1	4.54	5	100
175	455	772	1	1.96	2	100
200	460	752	1	4.86	6	100
250	525	800	1	4.87	2	100
300	540	798	1	5.61	2	100
350	560	871	1	5.10	3	100
400	445	675	1	3.06	2	100

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[1] Last row lodged.

[2] Border effect 1 replicate with 1 plant/sq. m. outer row and 3 replicates with 5 plants/sq. m. as outer row.

Table 8. Experiment No. 2b - Comparison of yields from rice transplanted 5 cm apart between hills within rows and square transplants. Variety PI-215936 transplanted Feb. 4 and harvested May 18, 1965. Location: Plot M-5(b); fertilizer rate 100-40-30 NPK kg/ha.

Row x Plant Distance cm	Panicles per m^2	Panicle Weight gm/m^2
144 (5)[2]	156[2]	510[2]
116.5 (5)	156	564
89 (5)	206	751
72 (5)	231	813
55 (5)	267	833
44.5 (5)[1]	285[1]	809
34 (5)	332	895
27.5 (5)	358	762
21 (5)	369	715
17 (5)	411	749
13 (5)	454	782
10.5 (5)	386	579
8 (5)	488	725
6.5 (5)	487	738
5 (5)	502	753
5 (5)[2]	707[2]	1117[2]
5 (5)[2]	800[2]	1168[2]
6.5 (6)[2]	615[2]	1067[2]
8 (8)	453	894
10.5 (10)	400	881
13 (13)	361	874
17 (16)	301	924
21 (21)[1]	283[1]	925[1]
27.5 (26)	259	881
34 (34)	239	806
44.5 (42)	186	715
55 (55)	157	588
72 (68)	117	429
89 (89)	84	288
116.5 (110)	56	183
144 (144)	35	108

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[1] Last row lodged

[2] Border effect

Table 9. Experiment No. 3. - Plant density, panicle number, panicle weight, and light transmission rate (LTR) at flowering of variety PI 215936 x CI 9214; planted July 12 and harvested Oct. 10, 1965. Location: Plot No. C-27, subplots 4 & 5. Fertilizer rate: 60-0-0 NPK kg/ha. No lodging.

No. of Plants per m^2	No. of Panicles per m^2	Wt. of Panicles gm/m^2	LTR %
5.0	76 [1]	298 [1]	57 [1]
5.5	96	378	46
6	101	402	32
7	118	458	28
8	125	478	24
9	139	518	20
10	125	450	14
12.5	157	539	12
15	181	608	11
17.5	161	522	11
20	169	536	9
25	188	553	10
30	206	580	9
35	206	562	8
40	234	612	8
45	225	563	8
50	194	489	8
100	236	550	7

[1] Border effect.

Table 10. Experiment No. 4 - Comparison of direct seeded rows (200 seeds/lin. meter row) and square transplanted low tillering rice variety PI 215936 x CI 9214. Location: Plots Nos. C-28(11) and C-28(12). Fertilizer rate 60-0-0 NPK kg/ha.

Row Distance Average cm	Ave. No. of Plants per m²	Expt. No. 4a Plot 11		Expt. No. 4b Plot 12			
		No. of Panicles per m²	Wt. of Panicles gm/m²	No. of Panicles per m²	Wt. of Panicles gm/m²	Light Transmission Rate Oct. 15/65 %	Light Transmission Rate Oct. 26/65 %
95	R	145	395	160	342	45	19
85	o	194	478	235	382	40	16
75	w	186 [1]	411 [1]	218 [1]	390 [1]	28	Lodged [1]
65		196	341	227	326	18	"
55	s	260	407	179	277	11	"
50	e	278	371	208	313	9	"
45	e	275	340	259	350	8	"
40	d	266	347	219	381	7	"
35	e	303	334	226	315	6	"
30	d	344	396	355	343	6	"
25 "		240	262	199	196	4	"
20		350	344	258	257	3	"
20 "		667 [2]	1219 [2]	598 [2]	887 [2]	3	"
T "	25	108 [2]	275 [2]	102 [2]	258 [2]		24
r	25	155 [2]	425 [2]	105 [2]	250 [2]		25
a "	25	230	642	162	415		22
n	16	158	443	149	346		16
"	11.11	145	438	142	323		12
s	8.16	104	345	121	243		18
p "	6.25	88	321	91	216		28
l	4.94	77	246	73	171		31
a	4.00	60	192	82	210		34
n	3.30	62	195	64	146		38
t	2.37	42	116	54	126		36
	1.78	40	121	33	79		54
e	1.38	33	93	31	94		71
d	1.11	23	64	22	57		65

[1] Last row lodged
[2] Border effect

Drill row:	Plot 4a	planted	July 23,	harvested	Oct. 28, 1965
	" 4b	"	Aug. 6,	"	Nov. 8, 1965
Transplant:	Plot 4a	"	Aug. 13	"	Nov. 8, 1965
	" 4b	"	Aug. 28	"	Nov. 19, 1965

Table 11. Experiment No. 5. - Comparison of broadcast and direct seeded rows (200 seeds per lin. m. row). Variety Fujisaka #5. Planted: Aug. 13, 20, 1965. Harvested: Nov. 8, 9, 1965. Location: Plot C-28(26) and C-28(25). Fertilizer rate: 100-0-0 NPK kg/ha.

Distance	Expt. No. 5a Plot C-28(26)		Expt. No. 5b Plot C-28(25)			
cm	No. of Panicles per m^2	Wt. of Panicles gm/m^2	No. of Panicles per m^2	Wt. of Panicles gm/m^2	Light Transmission Rate Oct. 15/65 %	Oct. 26/65 %
95	263	398	177	239	58	56
85	306	434	370	474	54	47
75	325[1]	458[1]	221	270	45	30
65	342	474	355[1]	405[1]	33	17
55	382	435	373	418	22	Lodged
50	406	418	402	436	16	"
45	382	353	434	430	12	"
40	407	343	372	393	8	"
35	419	366	409	403	8	"
30	503	389	407	346	5	"
25	447	380	501	560	2	"
20[2]	797[2]	922[2]	578[2]	527[2]	3[2]	"
Broadcast	350	371	367	287	4	"

[1] Last row lodged

[2] Border effect

Table 12. Experiment No. 6 - Yield of variety PI 215936 x CI 9214 transplanted at 25 x 25 cm, four planting dates, eight yield samples of 10 plants each. Non-fertilized plots C-27(7), (8), (9) and (10).

Data	1	2	3	4	5	6	7	8	Σx	$\bar{x}$
Panicles per sq. m.										
C-27(7)	134	162	147	166	141	112	174	173	1210	151
C-27(8)	154	168	130	174	150	139	130	146	1190	149
C-27(9)	138	126	136	112	115	128	128	152	1035	129
C-27(10)	160	174	174	178	166	147	198	176	1374	172
Panicle wt., gm/m^2										
C-27(7)	536	597	613	640	605	440	656	683	4770	596
C-27(8)	717	714	581	770	610	616	514	613	5133	642
C-27(9)	574	590	566	496	509	574	522	552	4384	548
C-27(10)	613	581	654	630	618	485	592	730	4902	613
Weekly solar radiation in weeks prior to harvest, gm-cal/cm^2										
C-27(7)	2971	2187	1820	3268	2590	2968	1747	2235	19786	
C-27(8)	2139	1924	3338	2671	2785	1666	2153	2268	18944	
C-27(9)	2107	3128	2943	2448	1846	2110	2356	2644	19582	
C-27(10)	2713	3160	1930	2015	1975	2555	2620	2237	19205	

Planting and Harvesting Dates

	Transplanted	Harvested
C-27(7)	June 3, 1965	Sept. 12, 1965
C-27(8)	May 27, 1965	Sept. 4, 1965
C-27(9)	May 24, 1965	Aug. 27, 1965
C-27(10)	May 13, 1965	Aug. 16, 1965

Table 13. Experiment No. 7 - Physical dimensions and yield components of seven varieties of widely differing growth habits when interspaced hexagonally 1 plant per square meter. (25 plant samples.)

	Taichung Native 1	PI 215936	IR 9-60	BPI-76 non-photo-sensitive	Century Patna 231	81B-25	Chianung 242
Transplanted	May 18	May 18	May 18	May 18	May 18	May 18	May 18
Harvested	Sept. 14	Sept. 15	Sept. 8	Sept. 15	Sept. 15	Oct. 6	Sept. 14
No. of days in the field (from transplanting to harvesting)	120	121	114	135	121	144	120
Panicles per plant	158	70	126	113	46	94	54
Panicle weight, grams/plant	349	166	384	536	134	325	143
Grain and chaff, grams/plant	320	148	353	500	118	300	122
Clean grain, grams/plant	287	133	336	460	98	267	99
Height of plants, H_{max} cm	98	97	71	116	106	159	97
" " " H_{min} cm	56	74	34	90	91	131	76
Radius of tiller, r cm	75	84	65	105	97	136	83
Dia. of leaf spread above D_a, cm	114	91	128	126	79	91	80
Hill base dia. below D_b, cm	16	12	17	18	12	17	12
Total tillers per plant	172	84	146	121	59	107	75
Plant area* sq cm	10,207	6,504	12,868	12,469	4,902	6,504	5,027
Plant area x No. of days, m^2 x day	122	77	147	168	59	94	60

* πD_a^2 divided by 4

Table 14. Prediction equations of panicle number (Y_1) and panicle weight (Y_2) per square meter when plants per square meter (x) are varied.

Expt. No.	$Y_1 = k + ab^x$	$Y_2 = k + ab^x$
1	$252 - 250(0.756)^x$	$433 - 426(0.664)^x$
2a	$168 - 166(0.721)^x$	$754 - 921(0.658)^x$
$2b_1$ square transplant		$850 - 850(0.71)^x$
$2b_2$ drill row transplant		$850\sqrt{1 - (0.71)^{2x}}$
3	$221 - 242(0.896)^x$	$578 - 594(0.818)^x$
4	$215 - 217(0.907)^x$	$638 - 618(0.94)^x$

≡ ≡

Table 15. Prediction equation of panicle number (Y_1) and panicle weight (Y_2) per m^2 when the Light Transmission Ratio (LTR) is measured at flowering.

Expt. No.	$Y_1 = a + b(LTR)$	$Y_2 = a + b(LTR)$
1	190 - 224(LTR)	519 - 576(LTR)
2a	258 - 228(LTR)	818 - 723(LTR)
3	226 - 319(LTR)	599 - 520(LTR)
4 (transplant)	164 - 224(LTR)	377 - 492(LTR)
4 (seeded drill row)	228 - 297(LTR)	377 - 77(LTR)
5 (seeded drill row)	459 - 385(LTR)	430 - 174(LTR)

Table 16. Average straw strength values of lodged and non-lodged plants of Peta and Tainan 3. Computed from 60 paired samples.

Variety		Non-lodged plants P_1/E	Non-lodged plants P_2/E	Lodged plants P_1/E	Lodged plants P_2/E
		$mm^2 \times 10^{-5}$		$mm^2 \times 10^{-5}$	
Peta	$\bar{x}$	7.4	18.4	5.6	14.0
	$s_{\bar{x}}$	0.325	0.942	0.323	0.665
	cv(x)	34.18	38.08	44.91	36.73
	cv($\bar{x}$)	4.42	5.12	5.78	4.73
Tainan 3	$\bar{x}$	3.5	8.5	1.8	4.3
	$s_{\bar{x}}$	0.61	0.88	0.106	0.32
	cv(x)	95.96	57.04	32.76	41.39
	cv($\bar{x}$)	17.57	10.41	5.98	7.44

≡ ≡ ≡ ≡ ≡ ≡ ≡ ≡ ≡ ≡

Table 17. Rate of manual transport based on $T = 340\ W^{-0.931}$. (Two-way travel on smooth grassed shoulders of earth road.)

Weight, kg	Manhours/Ton-km
10	39.8
15	27.3
20	20.9
25	17.0
30	14.3
35	12.4
40	11.0
45	9.8
50	8.9
*- - - - -	- - - - -
60	7.5
70	6.5
80	5.8
90	5.2
100	4.7

* Values over 50 kg extrapolated.
Also increase for narrow paths, and poor walking conditions.

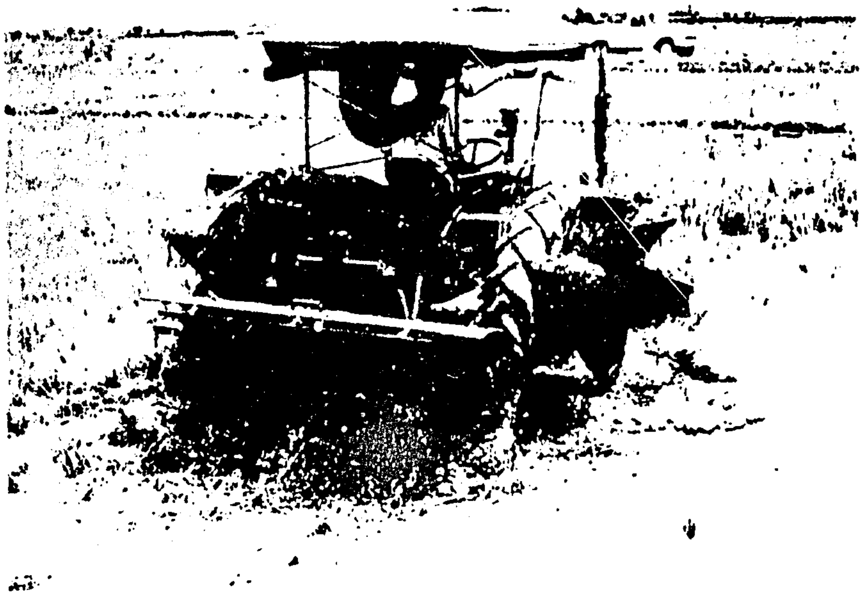

Fig. 1. Special lug wheels mounted inside and outside the tires permit a 40-Rhp tractor to use a 60-inch rotary tiller in soft soils.

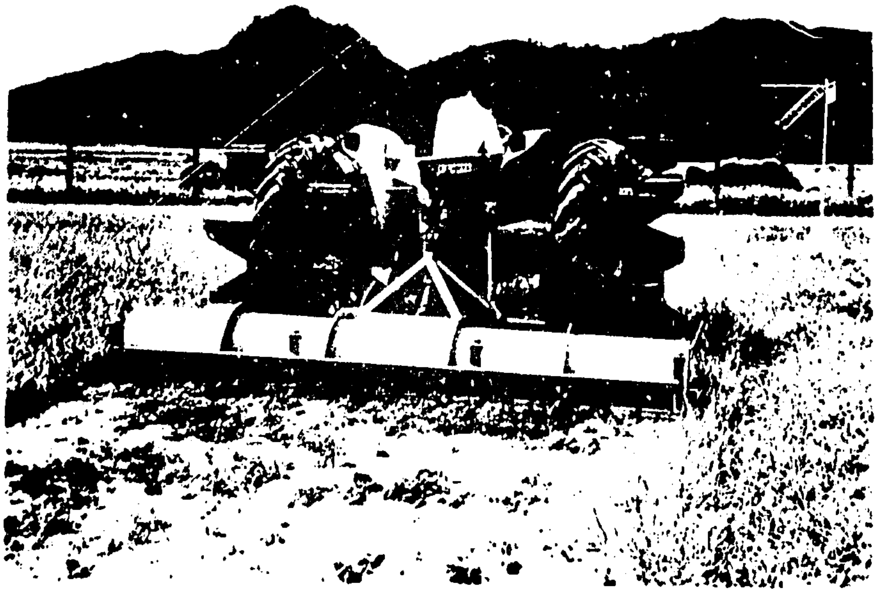

Fig. 2. A 300-cm rotary tiller with Japanese rotary tiller blades for use with 40- to 60 Rhp tractors.

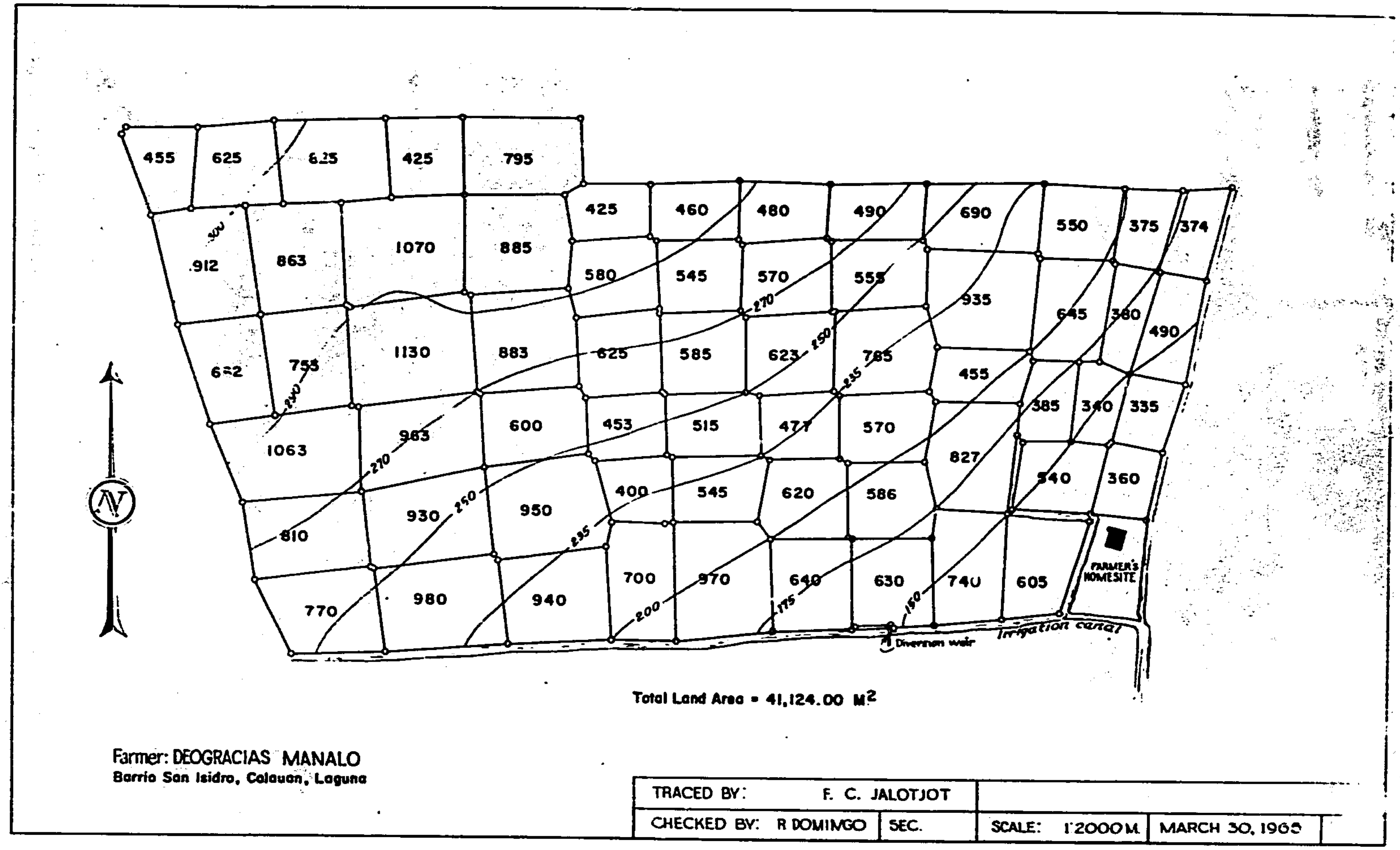

Fig. 3. – Map of rice farm showing present field layout and area in square meters and contour lines for future field layout.

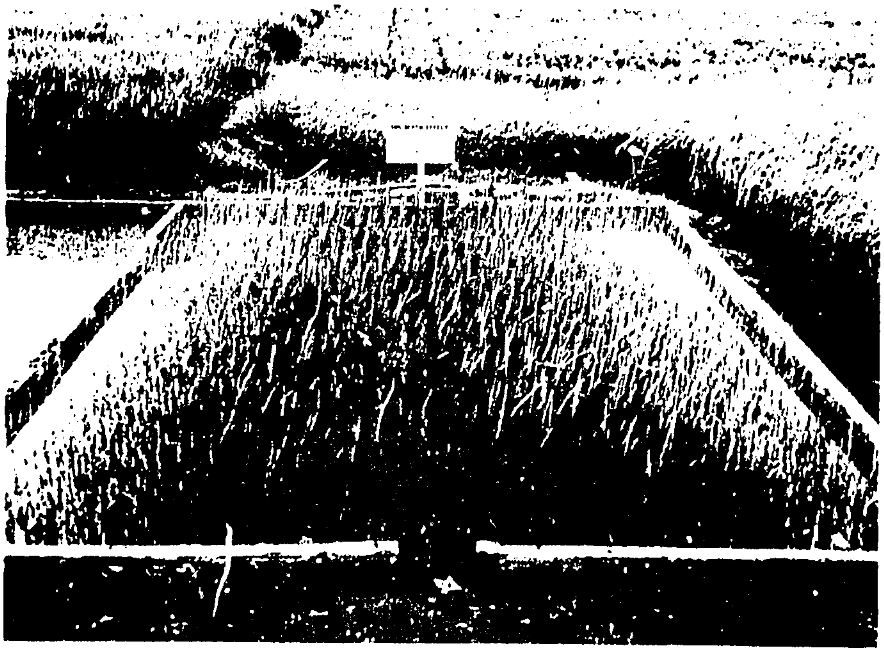

Fig. 4. Forty-seven day old PI-215936 seedlings planted in plot with soil depth shallow on edges and deep in the center.

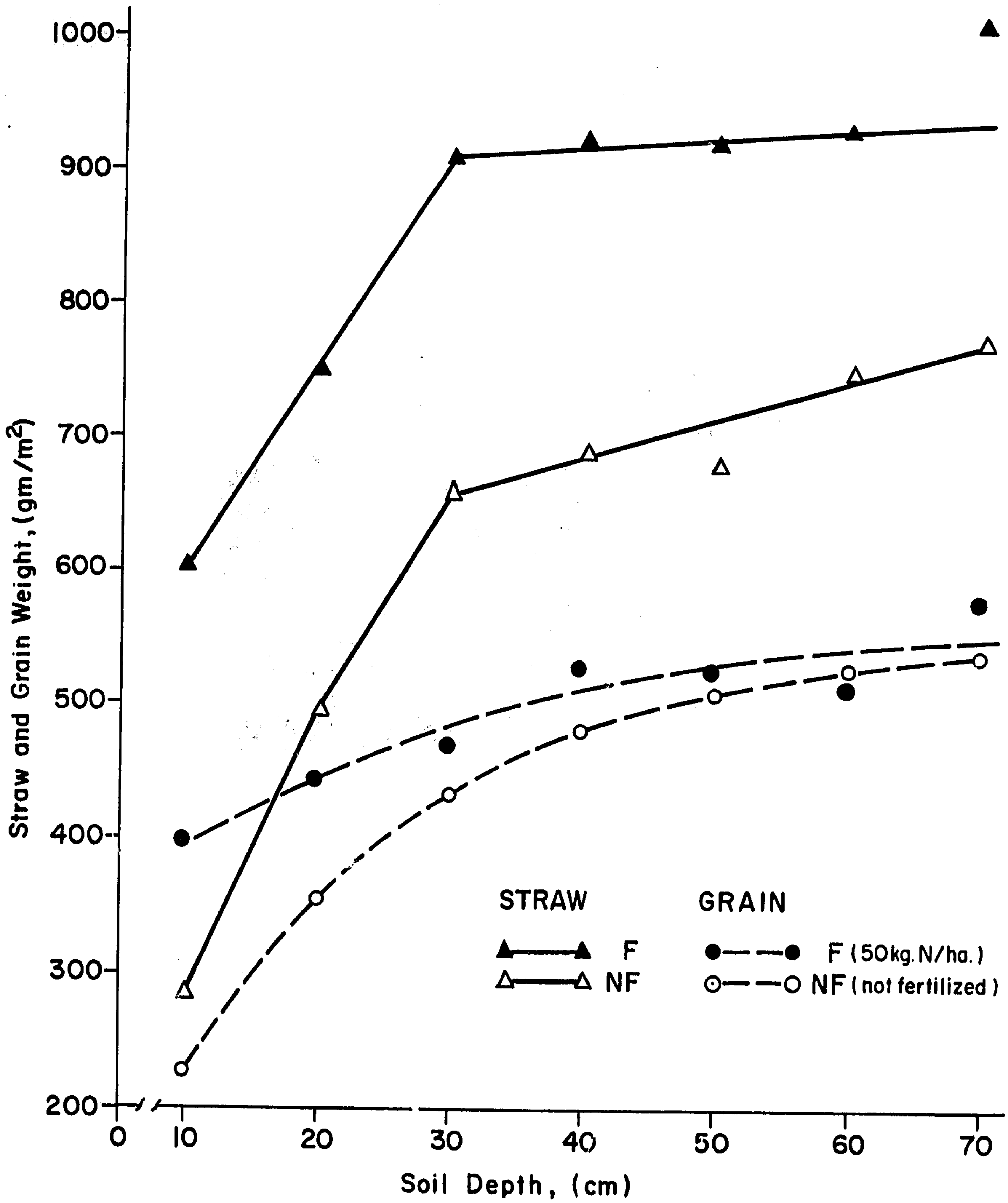

Fig. 5. Effect of soil depth and nitrogenous fertilizer (50 kg/ha) on straw and grain yield.

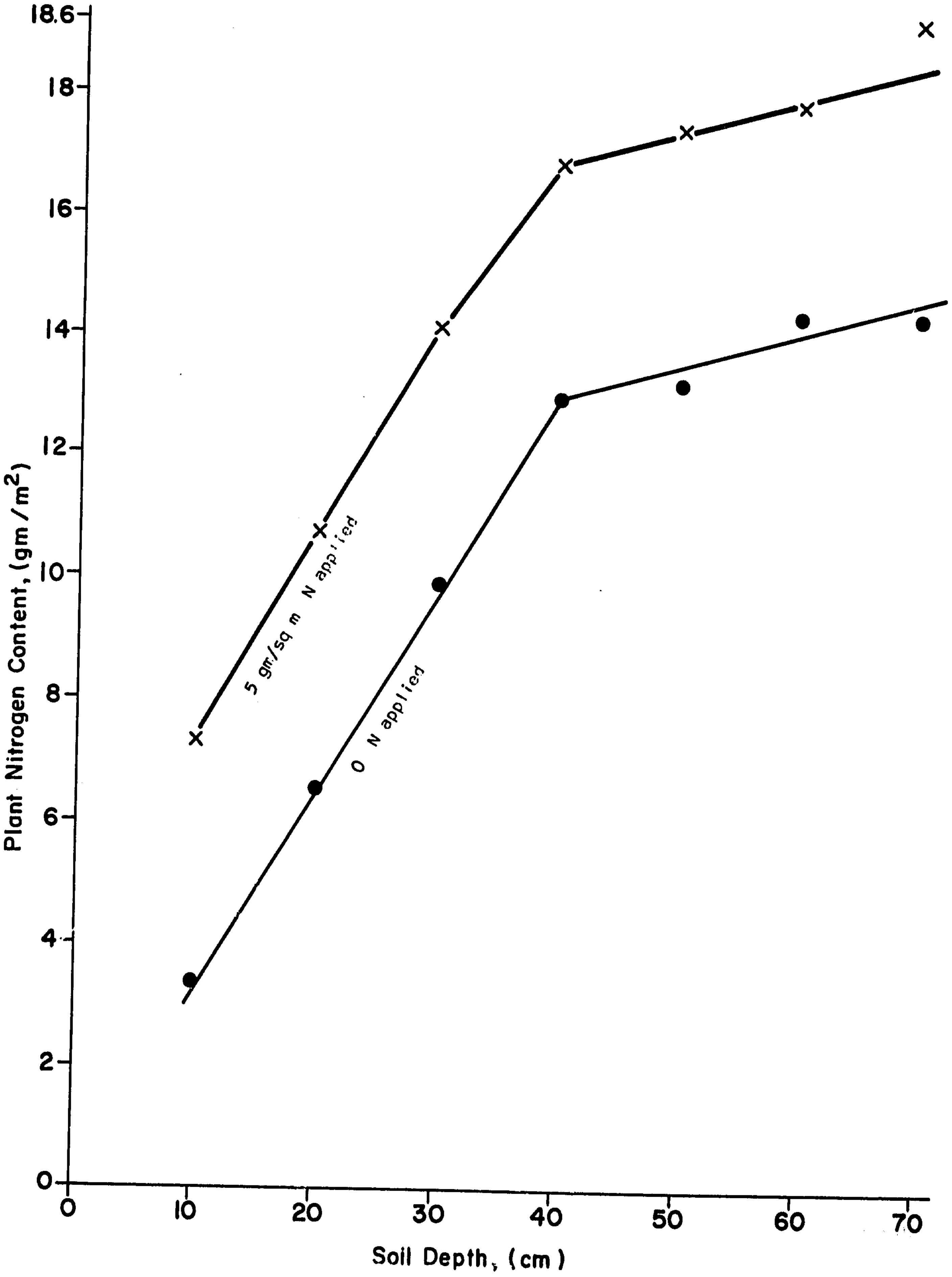

Fig. 6. Effect of soil depth and nitrogenous fertilizer on plant nitrogen content.

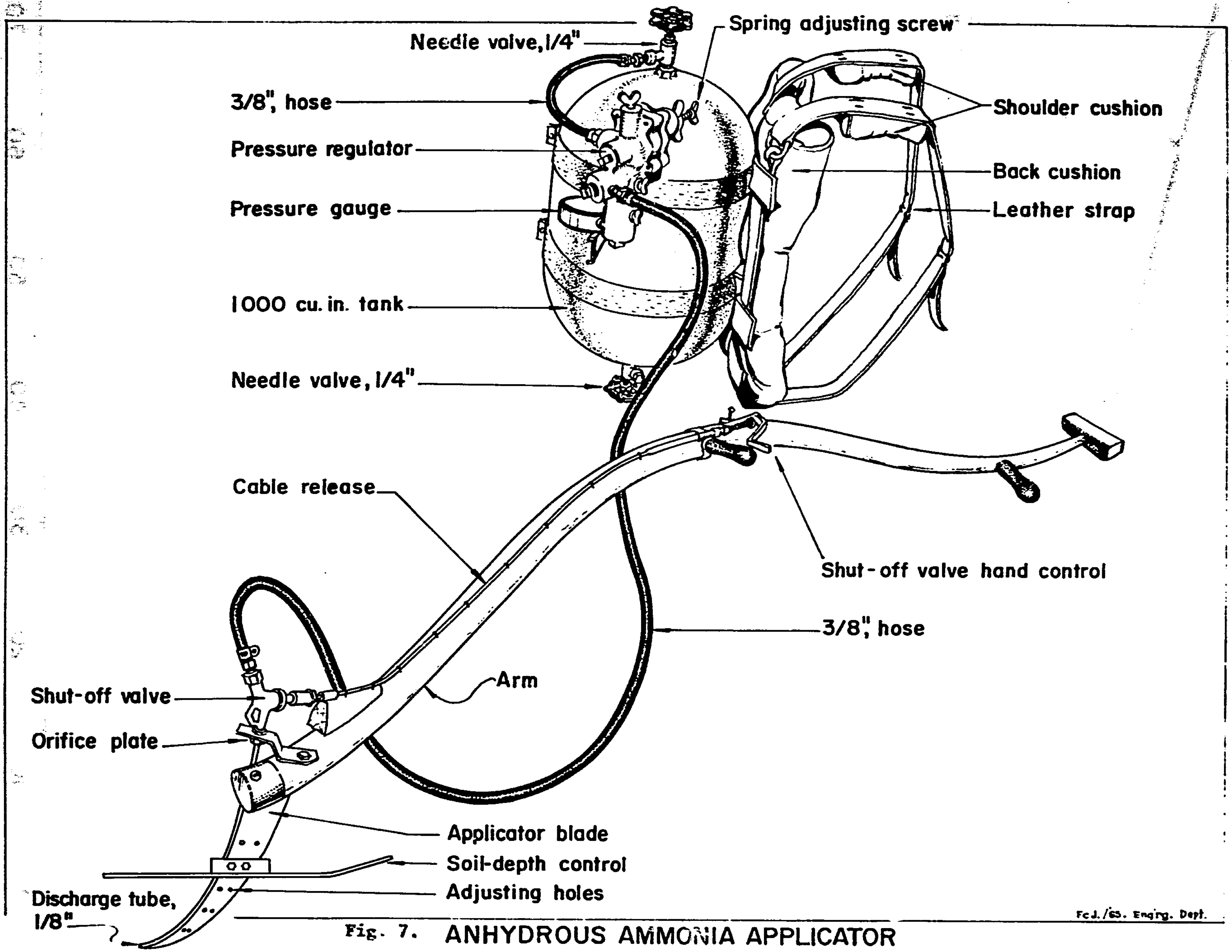

Fig. 7. ANHYDROUS AMMONIA APPLICATOR

Fig. 8. Experiment No. 2a - Square transplanted PI 215936 at flowering, April 6, 1965.

Fig. 9. Experiment No. $2b_1$ and $2b_2$ - Variety PI 215936 square transplanted and transplanted drill rows at flowering, April 6, 1965.

Fig. 10. Experiment No. 4 - Variety PI 215936 x CI 9214 direct seeded in drill rows (left) and square transplanted (right).

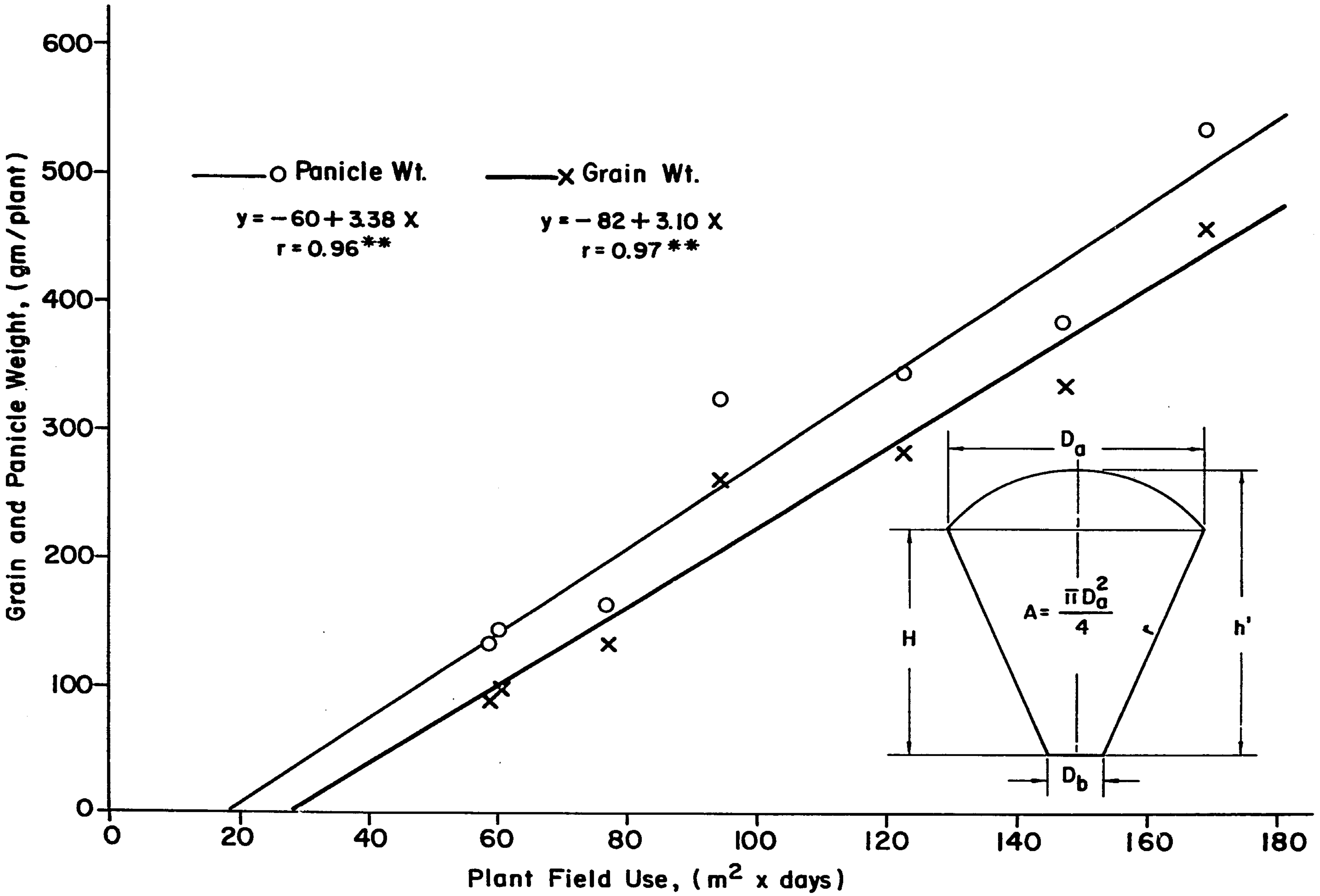

Fig. 11. Plant area multiplied by days in the field explain yield differences of seven widely differing varieties in Experiment No. 7.

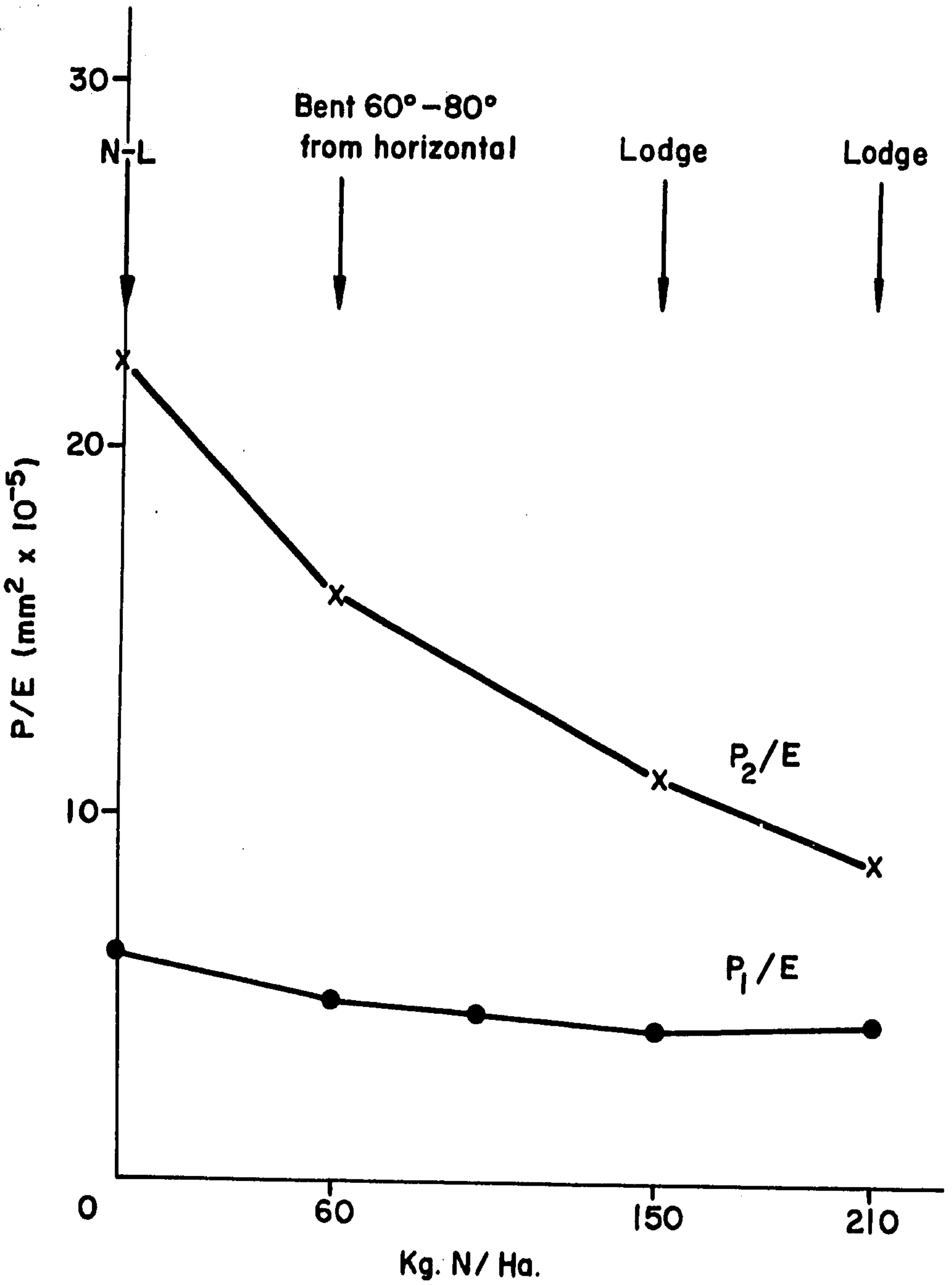

Fig. 12. Effect of the amount of nitrogen on P/E of PI 215936.

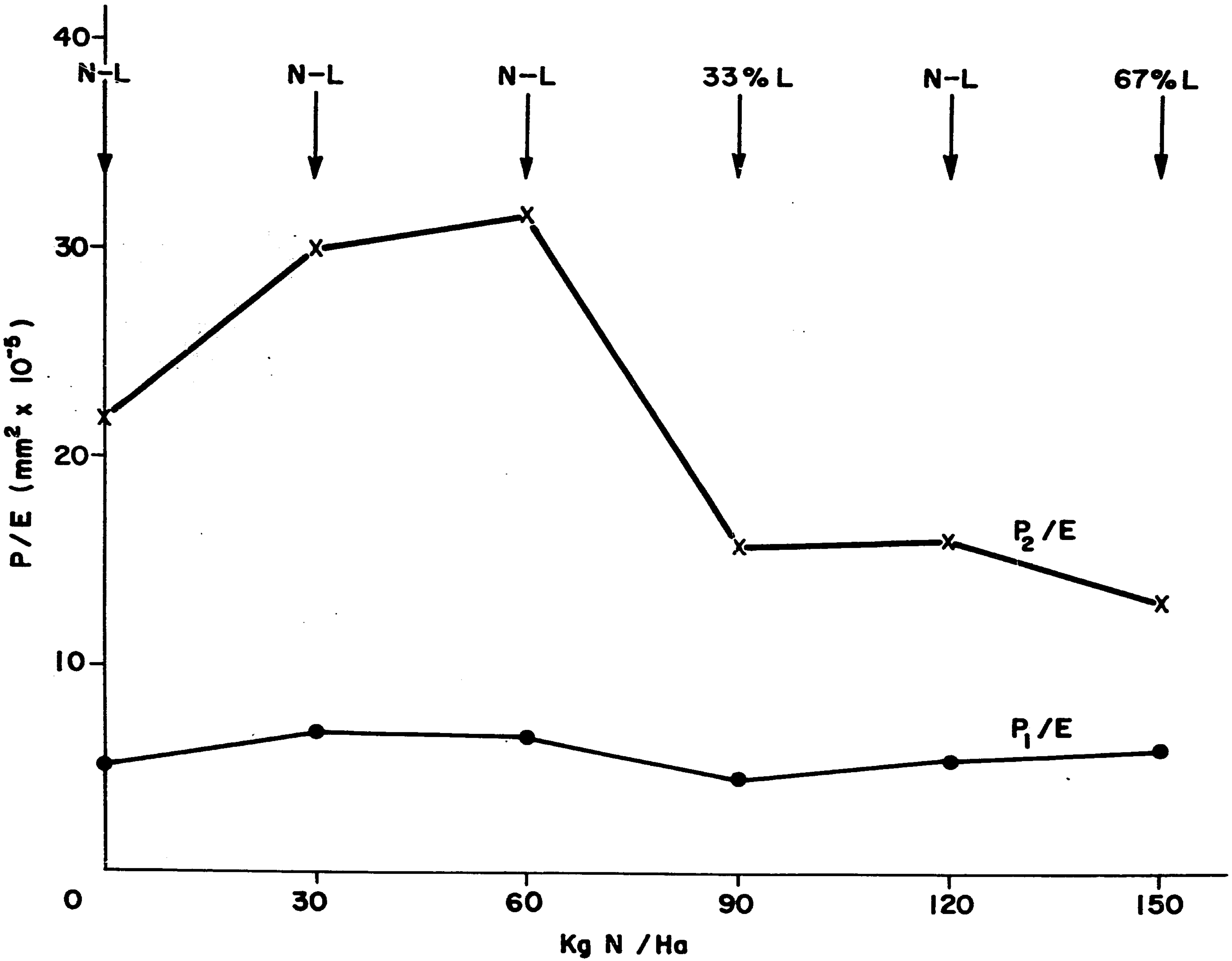

Fig. 13. Effect of the amount of nitrogen on P/E of Milfor-6(2).

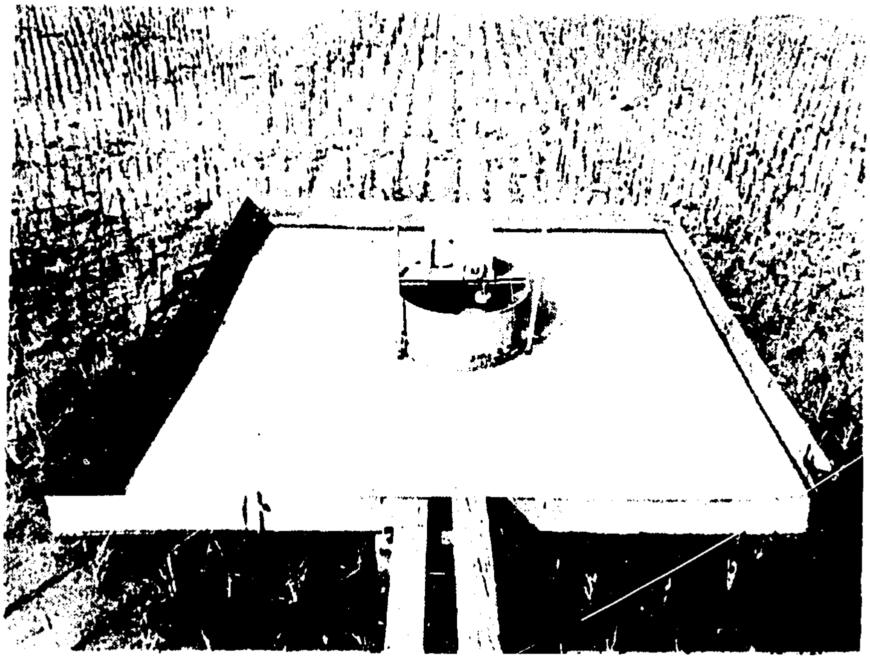

Fig. 14. Evaporation was recorded from a 2.40 x 2.40 x 0.60 meter sunken pan.

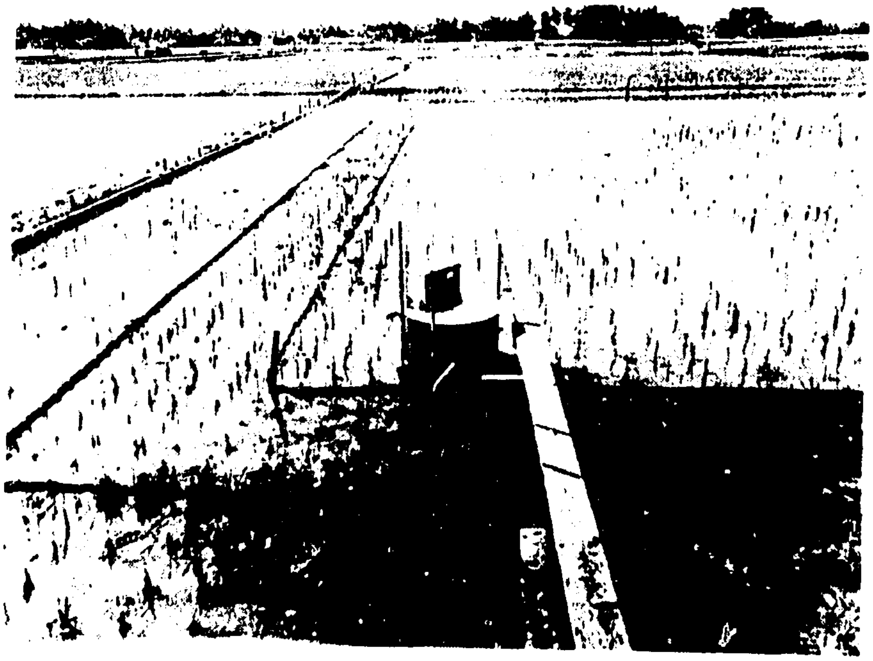

Fig. 15. Evapotranspiration and percolation were obtained from a 20 x 20 meter field plot by use of a water level recorder and piezometer tubes.

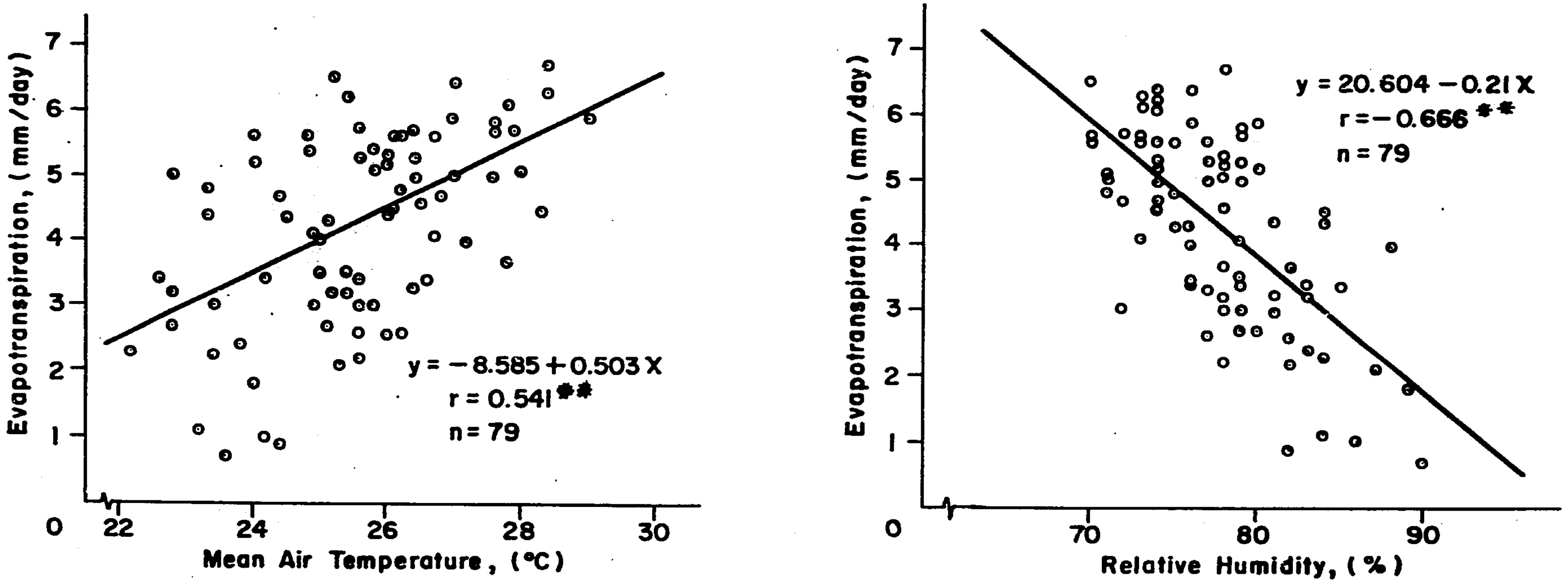

Fig. 16. The relationship of evapotranspiration in vegetative and reproductive stage of mean air temperature and relative humidity.

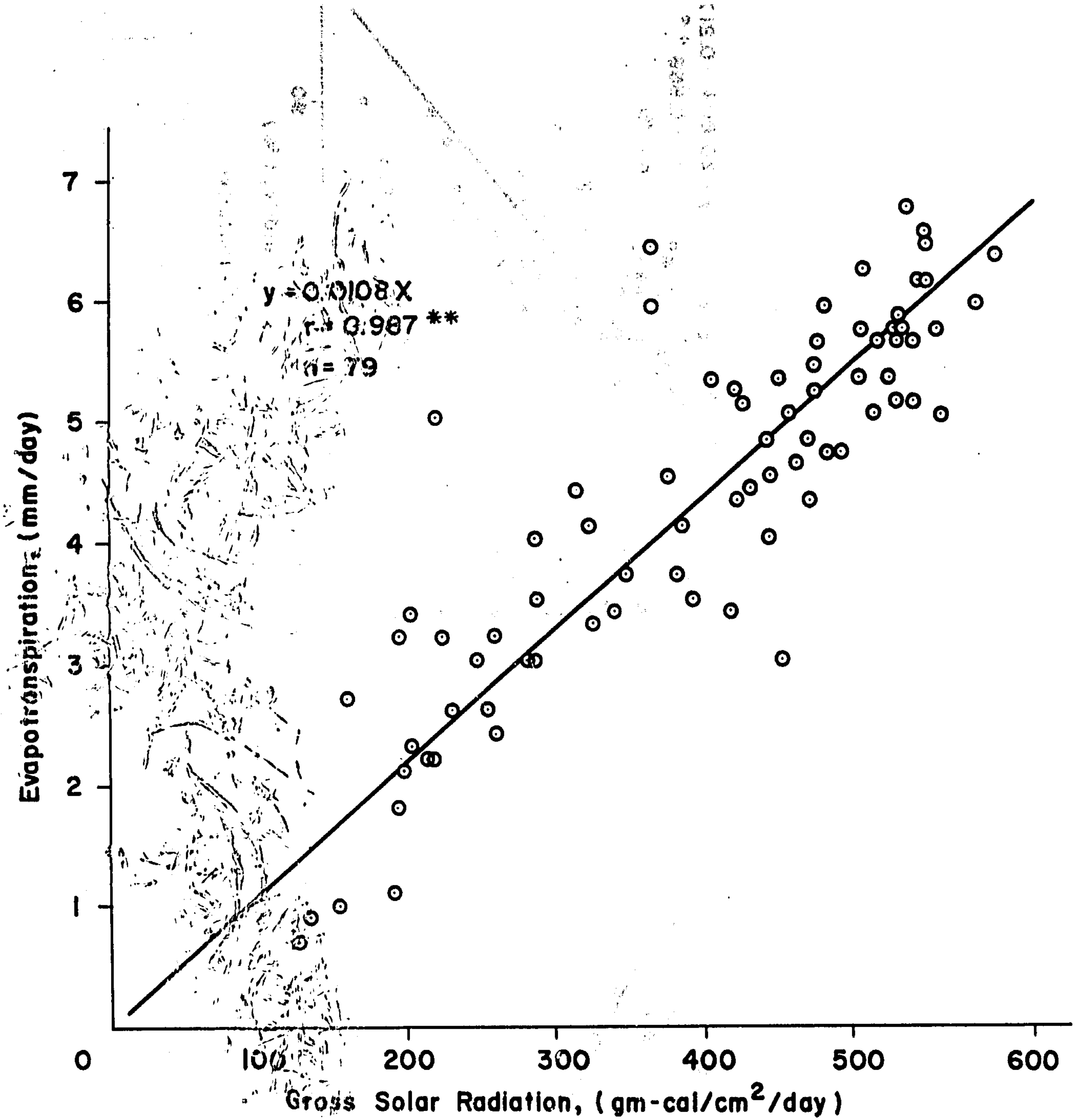

Fig. 17. Relationship of evapotranspiration in vegetative and reproductive stage to gross solar radiation.

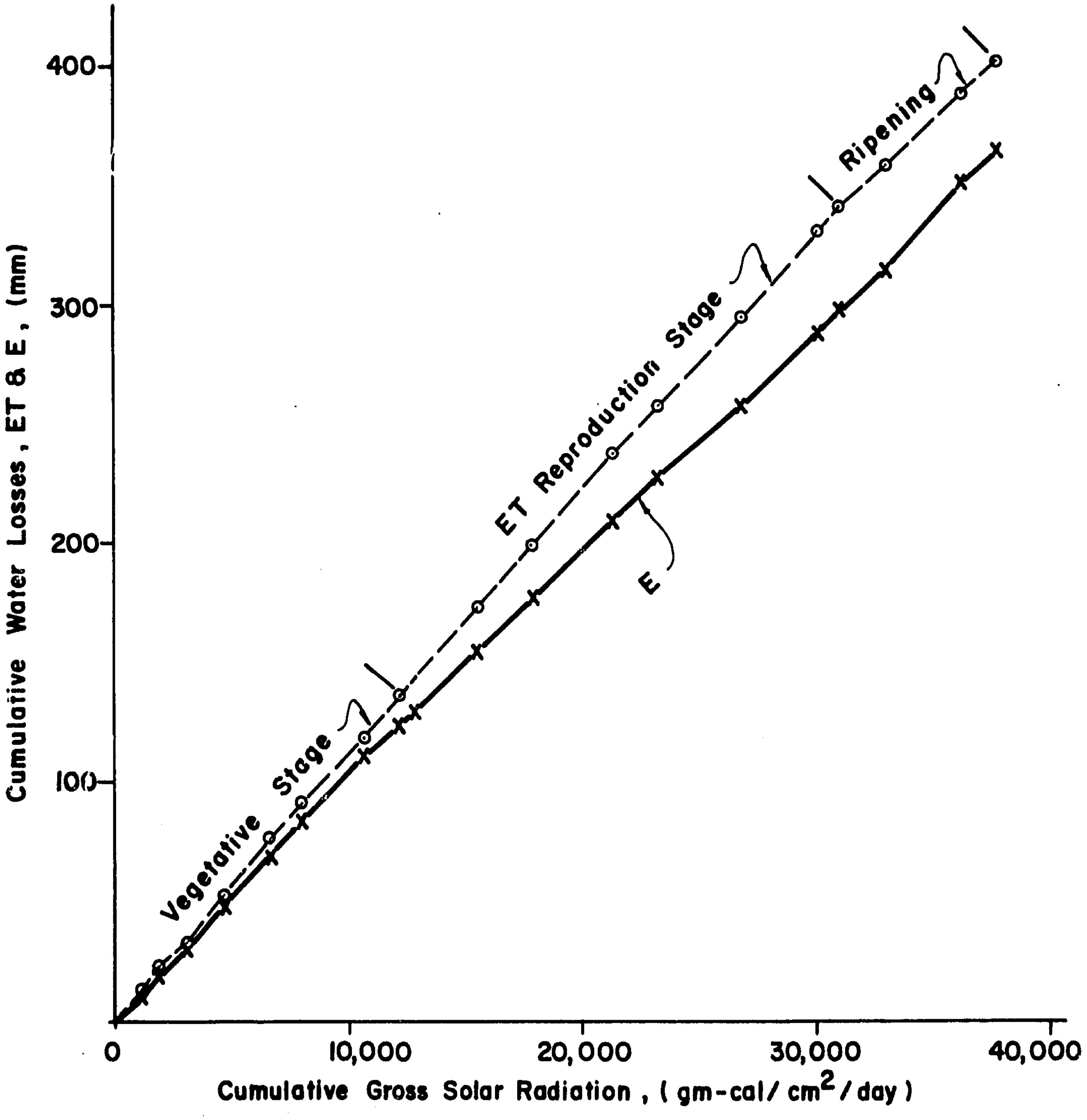

Fig. 18. Cumulative water losses from the field related to cumulative gross solar radiation.

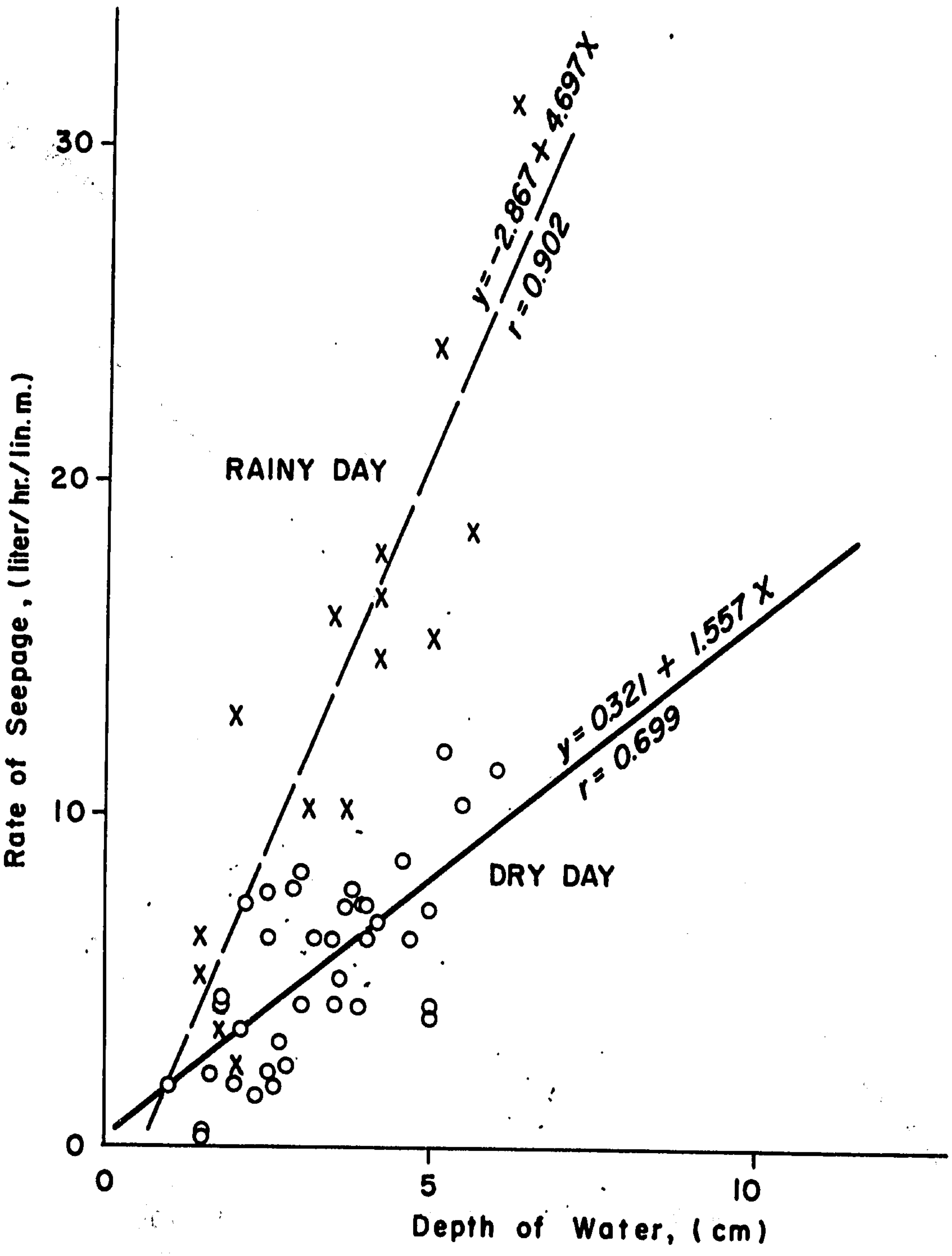

Fig. 19. Relationship of rate of seepage to depth of water in the field, measurement of seepage into drains of Plot B.