PHYSIOLOGICAL AND GENETIC DETERMINANTS OF YIELD AND QUALITY IN RICE

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OBJECTIVES:

The general objectives of the project are to develop physiological and genetic information for raising the yield ceiling of rice and for increasing the efficiency of rice breeding programs.

The specific objectives are as follows:

1) Determine the heritable and physiological stability of rice seedling performance under a wide range of temperature and other environmental factors and isolate superior genetic lines which can be used to improve stand establishment.

2) Determine the nature and cause of panicle blanking and develop accurate methods for inducing blanking for purposes of screening for genotypes that are resistant.

3) Testing the applicability of newly available procedures and theories for testing genotypes for photosynthetic efficiency.

4) Determine the relationship of specific leaf and stem characteristics to yield under California conditions and select useful genotypes for use in breeding programs.

5) Determine physiological and heritable differences in uptake and translocation of nitrogen in high protein lines, isolate high and low oil lines, and screen for lines with low ash and silica content of hulls and stems (This objective will be funded entirely by USDA but is part of the total physiological-genetic research program).

WORK IN PROGRESS:

Research is in progress on all of the above stated objectives. Summer periods are devoted almost entirely to field research. Winter periods are used for seed processing and preparation for planting, for greenhouse and laboratory studies, and for making crosses.

EXPERIMENTS COMPLETED:

Experiments completed during the past year include the following:

1) Effect of water temperature and depth on the percent of sterile florets.

2) Sterility percent from 59 fields of certified, registered, and foundation rice fields throughout California.

3) Sterility percent estimates from all varieties grown at Davis included in statewide yield tests.

4) Yields, sterility, and other data from F_3 lines of rice classified according to height.

5) Effects of day and night temperature fluctuations on sterility in rice.

6) Analysis of seedling cold tolerance of about 350 varieties of potential usefulness in crossing programs.

7) Effects of nitrogen fertilization, and plant spacing on yields and protein content of several rice genotypes (chemical data not completed).

8) Developed two additional sources of short stature lines for California: a) mutation-induced short stature lines from Calrose; and b) short stature lines from a cross with a short Japanese variety.

9) In a components of yield study, several F_3 plants with more than 300 seeds per panicle (compared to 150-170 for check varieties) have been selected for further study and purification.

10) Inheritance of protein and its relation to yield were studied in two new crosses.

11) Tests of the feasibility of a measuring system capable of rapid (5 minutes or less) simultaneous measurement of transpiration, CO_2 exchange rate, leaf temperature, air temperature and incident photosynthetically active radiation on intact individual leaves under conditions where gas composition and light intensity could be varied.

12) Tests of physiological variability in net assimilation parameters among single genotypes grown under greenhouse conditions and moved to a growth chamber for environmental preconditioning and measurement.

13) Development of a computer program necessary for data analysis of large numbers of screening measurements.

WORK PLANNED:

Research planned for 1973 is as follows:

1) Complete several studies on seedling cold tolerance including proof of the relationship of the test to actual field response, write up the results and describe the test so it can be used by the plant breeders.

2) Devise testing procedures to evaluate sensitivity of introduced genotypes to low night temperatures during the vegetative stage (from the 4- to 8-leaf stage) which might limit their usefulness in crossing programs (this is particularly of concern in the program for developing suitable long-grain types for California).

3) Continue and expand research on the effects of temperature extremes (low and high) on floret sterility.

4) Initiate introductory studies on the effect of rapid senescence (as evidenced by premature drying and death of leaves and stems) on rice yields and protein content.

5) Determine if correlations exist between temperature responses of different genotypes in the seedling, vegetative, reproductive, and ripening stages.

6) An analysis of genetic and physiological relationships of leaf characteristics to production.

7) Determine grain/straw ratios among promising new genotypes.

Net assimilation studies will be continued under a separate project next year headed by R. W. Breidenbach and J. N. Rutger. Work planned under the new project includes the following:

1) Final improvements in the measuring system based on the feasibility tests of breadboarded system will be completed.

2) Modification of facilities for growing plants so that reproducible environmental conditions approaching or identical to measuring conditions and approaching optimal field conditons can be attained.

3) Re-evaluations of physiological variability within genotypes under growth conditions and tests of methods for eliminating variabilities confounding evaluation of genetic variability.

4) First full scale screening tests on range of genotypes.

5) Some initial in-the-field measurement of individual leaf and plant assimilation parameters and their growing season variability.

MAJOR ACCOMPLISHMENTS:

1) RICE SEEDLING PERFORMANCE

Research completed over a year ago by Philip P. Osterli for his M.S. thesis showed that sensitivity of rice seedlings to low temperatures was a major cause of stand failures with water sown rice. He devised a testing method by which varieties and hybrids could be screened for cold sensitivity and he completed initial work on heritability of this characteristic.

Following-up on this good beginning we have just completed screening 354 varieties of potential usefulness in breeding and genetics programs for growth rate at 65°F. Origin of these varieties are the United States, U.S.S.R., Turkey, Portugal, Philippines, Malaysia, Korea, Japan, Italy, India, Hungary, France, Comoro Islands, Taiwan, Mainland China, Bulgaria, and Australia. Following are some of the promising sources of seedling cold tolerance:

Identification	Country of Origin
PI 348911	U.S.S.R.
PI 175017	Portugal
PI 291478	Hungary
PI 282203	Hungary
PI 266163	Hungary
PI 291517	Hungary
PI 282190	Hungary
PI 291495	Hungary

Nearly all available sources of short-statured lines show very poor performance in the seedling stage under cold conditions. An attempt is being made to combine seedling cold tolerance and short stature in a crossing program. These studies are not far enough advanced to provide conclusive answers.

2) NATURE AND CAUSE OF PANICLE STERILITY

A survey of sterility in rice panicles was completed on 59 fields of foundation, registered, and certified rice. The average percent of sterile florets in 1972 for all fields was 15.4 (Table 1) compared with 12.5 percent in 1971. The range in sterility was from 2.7 to 34.8%. It is evident that losses in some fields are very large. Earlirose and Coloro showed average sterility values that were higher than Calrose, CS-M3 and Colusa. Differences in sterility between fields of the same variety indicate that the environment as well as heredity are involved.

A study was completed to determine the effect of water temperature and depth on the percent sterility among 12 genotypes that differed in height characteristics. Results shown in table 2 indicate that cold water (10C or 50F) can increase sterility even if the water is very shallow (4 cm or 1 1/2 inches). Deep cold water (16 cm or about 6 inches) increased sterility very greatly compared to deep warm water. Plant height did not appear to be a significant factor affecting sterility. Differences between genotypes and the stability of genotypes over a range of environmental conditions was a very important factor. These results indicate that varieties can be developed which show little sterility even under conditions which cause very high sterility in other genotypes.

Previous results reported earlier showed that low night temperature was the principle environmental cause of sterility. These studies were extended this year to include the effects of high temperatures and of fluctuations between day and night temperatures. Results shown in table 3 lead to the conclusion that high daytime temperatures (97F) as well as low night temperatures increase sterility. Greatest sterility occurred with 97F daytime and 61F nighttime temperatures. Least sterility occurred with 82F daytime and 75 nighttime temperatures. Variety S-6183 showed an average sterility of 16.7% over all treatments and Earlirose 37.1%. Also S-6183 exhibited more stability over the entire range of temperature treatments.

3) YIELDS AND OTHER CHARACTERISTICS OF TALL, INTERMEDIATE AND SHORT GENOTYPES

Research results from the International Rice Researh Institute in the

Philippines emphasize the importance of short-stature as a factor in rice yields. No evidence has accumulated from the U.S. to indicate short stature would give a yield advantage. A study was initiated several years ago to gather evidence on this factor. A short variety introduced from the Philippines (443) was crossed with Earlirose and the F_2 population grown in the field in 1971. The F_2 plants were classified according to tall, intermediate, and short types. Two experiments completed in 1972 compared yield and other characteristics of these different height classes. Table 4 presents yields, heights, maturity, and sterility of the parents and the F_3 progeny bulked according to height. Differences in yields between the short, intermediate, and tall progeny were very small and not significant.

Table 5 presents the yields and other characteristics of the 10 highest yielding lines among all the F_3 progeny grown as individual lines replicated 4 times. All 10 of the highest yielding lines were shorter than Earlirose and the two highest yielding lines were 74 and 67 cm tall respectively. Results indicate that it should be possible to breed short-statured varieties that yield satisfactorily.

4) ALTERNATIVE SOURCES OF SHORT STATURE FOR CALIFORNIA

At Davis many problems (sterility, lack of cold tolerance, early senescence, sensitivity to iron deficiency) have been observed in crosses with the tropical sources (IR8, etc.) of short stature. Therefore, we are developing alternative sources of short stature lines for California:

4a) Mutation breeding development of short stature and early Calrose lines

Four short stature and two early Calrose lines have been obtained by irradiating Calrose seeds to produce mutations. Three of the short stature lines are about 25 cm (10 inches) shorter than Calrose; the fourth is 16 cm (6 inches) shorter (Table 6). One early line is 15 days earlier than Calrose; the other is 5 days earlier. In a preliminary yield trial at Davis in 1972, two of the short stature and both early lines equaled or exceeded the yield of Calrose. Quality tests are underway to determine if these mutants have maintained the desirable quality features of Calrose. Seed was produced in 1972 for yield trials at Davis, West Side Field Station, and Biggs in 1973. Mutation breeding may be a fast way of reducing height of an existing variety without disrupting the otherwise desirable attributes of the variety.

4b) Japonica source of short stature

A population of 77 F_3 lines from the cross between a short Japanese variety and Colusa were evaluated at Davis in 1972. The correlation between height and yield (r = 0.077) was not significantly different from zero, indicating that it should be possible to select short, high yielding lines. In fact, examination of the population revealed that twelve lines equaled or exceeded the yield of Colusa, averaged 13 cm shorter, and were 3 days earlier than Colusa (Table 7). These 12 pearl lines represent an alternative source of short stature in which blanking is no worse than the Colusa parent. Further purification and yield testing of selected lines will be performed in 1973.

5) COMPONENTS OF YIELD

In rice the components of yield are: panicles/unit area, seeds/panicle, and weight/seed. When multiplied together these components constitute yield: yield = (panicles/unit area) x (seed/panicle) x (weight/seed). If one or more of these components can be increased, higher yields should result. At Davis we are studying components of yield in an attempt to get a better understanding of how to increase yield. In 1972 a study was conducted on the inheritance of seeds/panicle. In a cross between two varieties with normal numbers of seeds/panicle (150-170), F_2 plants with as few as 83 and as many as 510 seeds/panicle were observed in 1971. Progenies of each F_2 plant were tested in 1972. The average numbers of seeds/panicle for five many = seeded lines are shown in Table 8. Seeds/panicle was found to be highly heritable (heritability = 77%). Several F_3 plants averaging 300 or more seeds/panicle (compared to 150-170 for check varieties) have been selected for further purification. Limited yield testing will be done in 1973 to determine if these selected many-seeded lines are higher yielding than the check varieties.

Crosses have also been made with large-seeded lines (with seed weight of up to 44 grams/1000 seeds, compared to about 26 grams/1000 seeds for California check varieties). The first segregating generation of these crosses will be evaluated in 1973.

6) INHERITANCE OF PROTEIN AND ITS RELATION TO YIELD

Continuing work has shown that the highest protein source available in California is a Hungarian variety called Szegedi Szakallas (SS for short). Over four years, SS has averaged 10.4% protein, compared to 9.3% for a high protein Japanese variety, and 6.5% for Calrose (other California varieties are similar to Calrose). SS itself cannot be grown as a high protein variety because it has very weak straw. Therefore, at Davis we crossed SS to a California variety, Earlirose, in an attempt to transfer the high protein into a better background. Average protein of 94 F_3 lines was intermediate between the parents (Table 9). The correlation between yield and protein ($r = -.012$) was not significantly from zero, indicating that it would be possible to select for the combination of high yield and high protein. However, the entire population had extremely weak straw and was discarded.

Fortunately SS was also crossed with the southern long grain variety Bluebelle, which has very stiff straw. The progenies from this cross combine high protein and stiff straw. Again the correlation between yield and protein ($r = -.087$) was not significantly different from zero, indicating that progress can be made in recombining high yield and high protein. Examination of the data revealed 5 lines which equaled or exceeded the Earlirose check variety in yield, averaged 3 days earlier, were 12 cm taller, and were nearly two percentage points higher in protein than Earlirose (Table 10). Although this population has suitable straw strength, it is tall and has considerable sterility (data not shown). Thus, more selection and purification of this population are still needed.

7) MEASUREMENTS OF PHOTOSYNTHETIC EFFICIENCY

A measuring system having the characterisitcs required for rapid measurement of all of the necessary quantities has been developed (Fig. 1, 2, 3).

After an initial 5 min equilibration of the inserted intact leaf, the required data for mass balance analysis of gas exchange rates at 5 different carbon dixoide concentrations (or light intensities) is obtained within 10 minutes. (Fig. 4, 5, and 6).

Greenhouse conditions are too variable for growing plants. Environmentally induced physiological variability is too large to permit analysis of genotypic variability. The chief difficulty is lack of facilities for growing plants at saturating light intensities. Facilities are being modified to attempt to overcome these difficulties.

IMMEDIATE APPLICABILITY OF RESULTS:

Data and materials produced by this project are to provide essential information and materials for breeding better rice varieties for California.

The four short stature Calrose lines developed by mutation breeding have been released to CCRRF plant breeders for use in their breeding program. A many-seeded line has also been given to the CCRRF plant breeders. Other promising lines will be released as they are purified and their value determined.

EVALUATION OF THE PROJECT:

This project has made excellent progress during 1972 on essentially all objectives. We have concluded that some objectives offer greater promise than others, therefore in the future, a shift in priorities will occur. For example, the prospects for hybrid rice appear so remote based on our data in 1972 that our research on hybrid rice will be phased out. Research on high protein rice will continue for another year or two but will not require substantial resources. Prospects will be re-evaluated in another year.

Research on the inter-relationships of genetics and physiology of temperature responses is very promising and will be further strengthened. We also will place greater emphasis on the genetics of yield components as a more promising method of improving yield than by hybrid rice. Research on leaf and stem characteristics as related to yield, lodging, and photosynthetic efficiency also will be enlarged.

PUBLICATONS OR REPORTS:

Peterson, Maurice L., J. N. Rutger, D. W. Henderson, Shiow Shong Lin. Rice Panicle Blanking. California Agriculture Vol. 46, No. 4, p. 3-5. 1972.

Rutger, J. N. and M. L. Peterson. Rice Genetics and Physiology at Davis, California. The Rice Journal Vol. 75, No. 9. 1972.

Osterli, Philip P. Methods of Evaluating Seedling Vigor in Rice Varieties and Related F_4 Lines. M.S. Thesis. 52 pgs. 1971.

Lambers, Derk Hille Ris. Genetic and Environmental Variation in Protein Content of Rice (Oryza sativa. L.) Ph.D. Thesis 88 pgs. 1972.

TABLE 1. Sterility estimates from 59 fields of Foundation, Registered, and Certified rice fields in California in 1972.

Variety	No. Fields Examined	Panicle Length	Floret per Panicle	Sterile Florets	Sterility Range*
	No.	Cm.	No.	%	%
Calrose	14	20.1	113.7	10.1	4.4-15.1
CS-M3	15	19.7	138.1	11.6	5.8-19.5
Colusa	14	18.7	106.5	12.1	2.7-20.8
Earlirose	8	17.6	136.3	16.6	8.4-23.0
Caloro	8	18.9	103.9	17.6	5.7-34.8
All Fields	59	19.5	119.8	15.4	2.7-34.8

* Between individual fields

TABLE 2. Effect of water temperature and depth on percent sterility of 12 rice cultivars with different height characteristics.

Identification No.	Mean Height	10° C		32° C		Mean	Treatment range
		4cm	16cm	4cm	16cm		
	cm	%	%	%	%	%	%
5683	106	17.4	16.7	9.6	5.8	12.4	11.6
5883	74	19.4	31.8	13.2	5.9	17.6	25.9
5896	98	17.9	21.3	12.9	29.5	20.4	16.6
Earlirose	106	21.7	39.0	13.0	11.5	21.3	27.5
5751	84	26.9	31.5	14.8	24.8	24.5	16.7
3957	86	34.4	25.2	34.2	8.2	25.5	26.2
5797	81	26.2	41.6	25.3	10.4	25.9	31.2
5965	68	35.8	48.3	7.8	13.5	26.4	40.4
4197	64	30.2	58.0	18.7	13.6	30.1	44.4
6074	75	31.9	58.0	17.1	18.0	31.2	40.9
5720	78	32.5	81.3	14.4	19.0	36.8	66.9
5780	97	54.2	81.7	32.2	35.1	50.8	49.5
Mean	85	29.0	44.5	17.8	16.3	26.9	33.1

TABLE 3. Effect of temperatures during the light and dark period on percent of sterile florets in two rice cultivars.

Dark Period Temperature	Light Period Temperature 75	82	90	97	Mean
		S-6183			
61	11.7	12.7	16.3	29.3	17.5
68	19.0	12.3	17.0	18.4	16.7
75	21.2	5.9	13.9	23.3	16.1
Mean	17.3	10.3	15.7	23.7	16.7
		Earlirose			
61	24.2	51.3	37.7	79.7	48.2
68	28.5	28.2	24.9	40.3	30.5
75	26.4	15.0	21.4	68.1	32.7
Mean	26.4	31.5	28.0	62.7	37.1

TABLE 4. Yields and other characteristics of parental varieties and F_3 lines bulked according to short, intermediate, and tall height characteristics.

Source	Seedling Vigor cm*	Heading Days	Height cm	Sterility %	Yield Lbs/acre
Tall parent (Earlirose)	23.9	103	109	11.9	6855
Short parent (443)	18.7	117	52	--	3819
Bulk of 39 short lines	22.2	103	71	25.6	5370
Bulk of 83 intermediate lines	23.1	103	90	35.0	5154
Bulk of 59 tall lines	24.5	103	100	26.9	5220

* Height in cm 39 days after planting

TABLE 5. Yields and other characteristics of the 10 highest yielding F_3 lines from a cross between Earlirose and dwarf line 443.

Source		Seedling Vigor cm	Heading Days	Height cm	Sterility %	Yield Lbs/acre
Earlirose		25.5	103	108	8.7	7824
F_3 Line	125	21.2	105	74	8.7	8760
"	119	21.0	109	67	8.7	8381
"	236	25.0	100	91	10.0	8095
"	270	25.0	103	96	12.5	8093
"	214	26.0	99	82	13.3	7954
"	225	25.0	100	91	15.0	7910
"	229	26.2	99	92	16.2	7853
"	108	22.2	104	73	12.5	7584
"	137	21.8	100	70	11.2	7574
"	273	23.5	103	98	10.0	7574

TABLE 6. Performance of short stature and early Calrose lines produced by cobalt irradiation at Davis.

Line	Heading days	Height cm	Yield lb/Acre	Principal feature
51	116	94	11930	Short stature
7	115	96	10350	" "
24	112	95	9650	" "
66	118	105	9540	" "
18	100	112	11240	Earliness
14	110	115	10250	"
Calrose check	115	121	10090	

TABLE 7. Performance of 12 short F_3 lines from the cross between Tedoriwase and Colusa.

Line	Heading days	Height, cm	Yield lb/Acre
52	98	98	10410
47	98	104	10140
86	103	98	9840
61	102	101	9810
55	96	94	9390
1	100	97	9030
21	101	105	9030
12	98	99	9000
20	102	106	8970
56	100	95	8940
28	99	101	8880
41	104	98	8880
Average	*100*	*100*	*9360*
Colusa Check	103	113	8880
Tedoriwase	94	78	5910

TABLE 8. Seeds/panicle of five many-seeded lines and parent varieties at Davis in 1972.

Line #	Number of plants examined	Average number of seeds/panicle	Range of seeds/panicle
		Actual	
68	19	255	94 - 425
105	20	237	109 - 351
70	20	231	94 - 359
28	17	215	113 - 353
40	13	196	106 - 245
Check varieties			
Calady 40	14	170	104 - 218
Norin 20	14	149	80 - 182

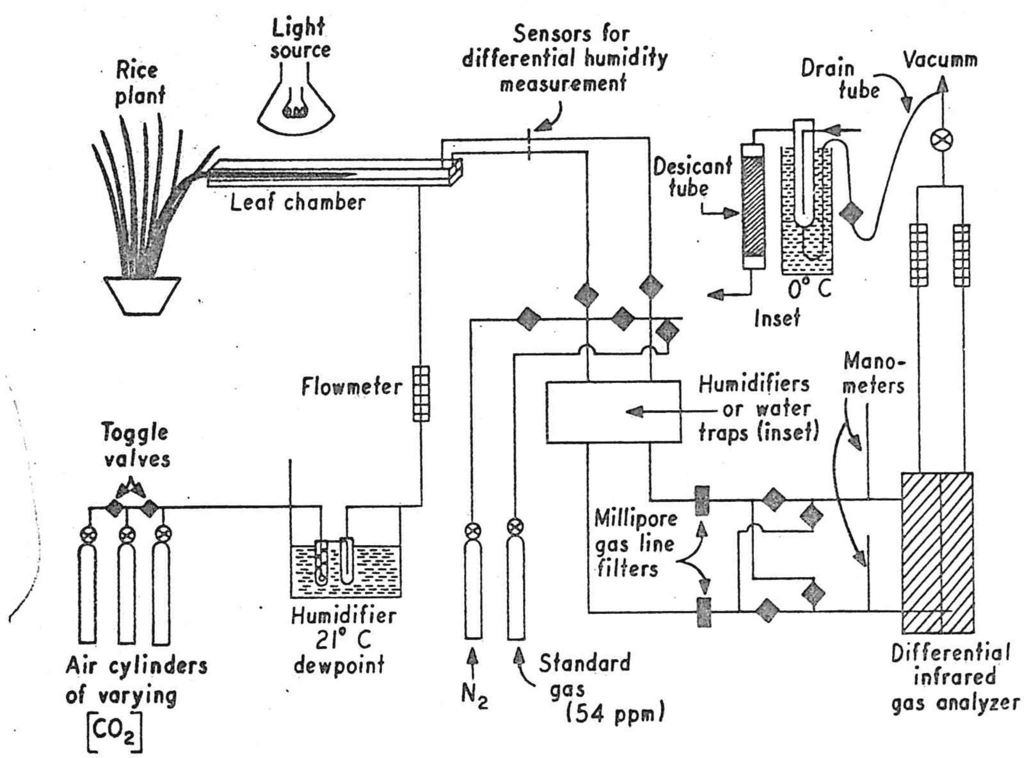
TABLE 9. Protein content of 94 F_3 lines and parents of the cross Earlirose x SS.

Variety	Protein content, %
94 line average	7.95
Earlirose	6.70
SS	9.21

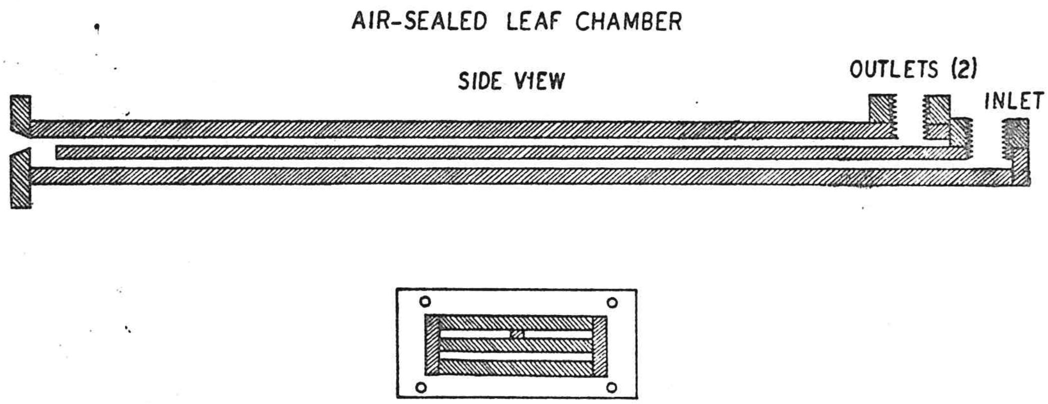
TABLE 10. Performance of 5 high protein F_3 lines from the cross Bluebelle x SS.

Line	Heading Days	Height cm	Yield lb/Acre	Protein, %
155	99	120	10300	8.48
161	105	130	10160	8.92
188	102	120	9760	9.02
200	104	134	9510	8.72
216	100	125	9450	8.60
Average	102	126	9840	8.75
Bluebelle	120	103	3800	8.78
SS	91	111	8040	9.48
Earlirose check	105	114	9470	6.79

Figure 1. Schematic view of basic exchange measuring system: air of desired external CO_2 concentration is humidified to a set dew point and flows into the leaf chamber at a rate greater than rate of withdrawal through the measuring system (excess flow exits through leaf insertion aperture preventing entry of outside air. The air stream splits, one half of return flow passing over leaf, the other half serving as a reference. The two streams then pass through humidity sensor that measures difference in H_2O content of reference and sample streams. They are then dried and the difference on $[CO_2]$ is measured. Temperature and light intensity sensors built into the leaf chamber monitor other essential parameters.



Figures 2 and 3. Expanded schematic views of air sealed leaf chamber showing input sector reference and leaf sector and the aperture leaf insertion.



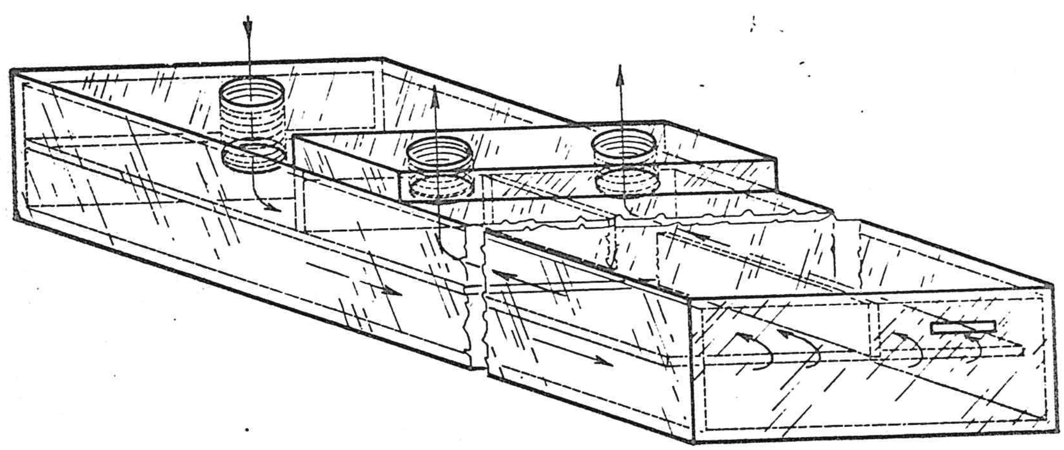
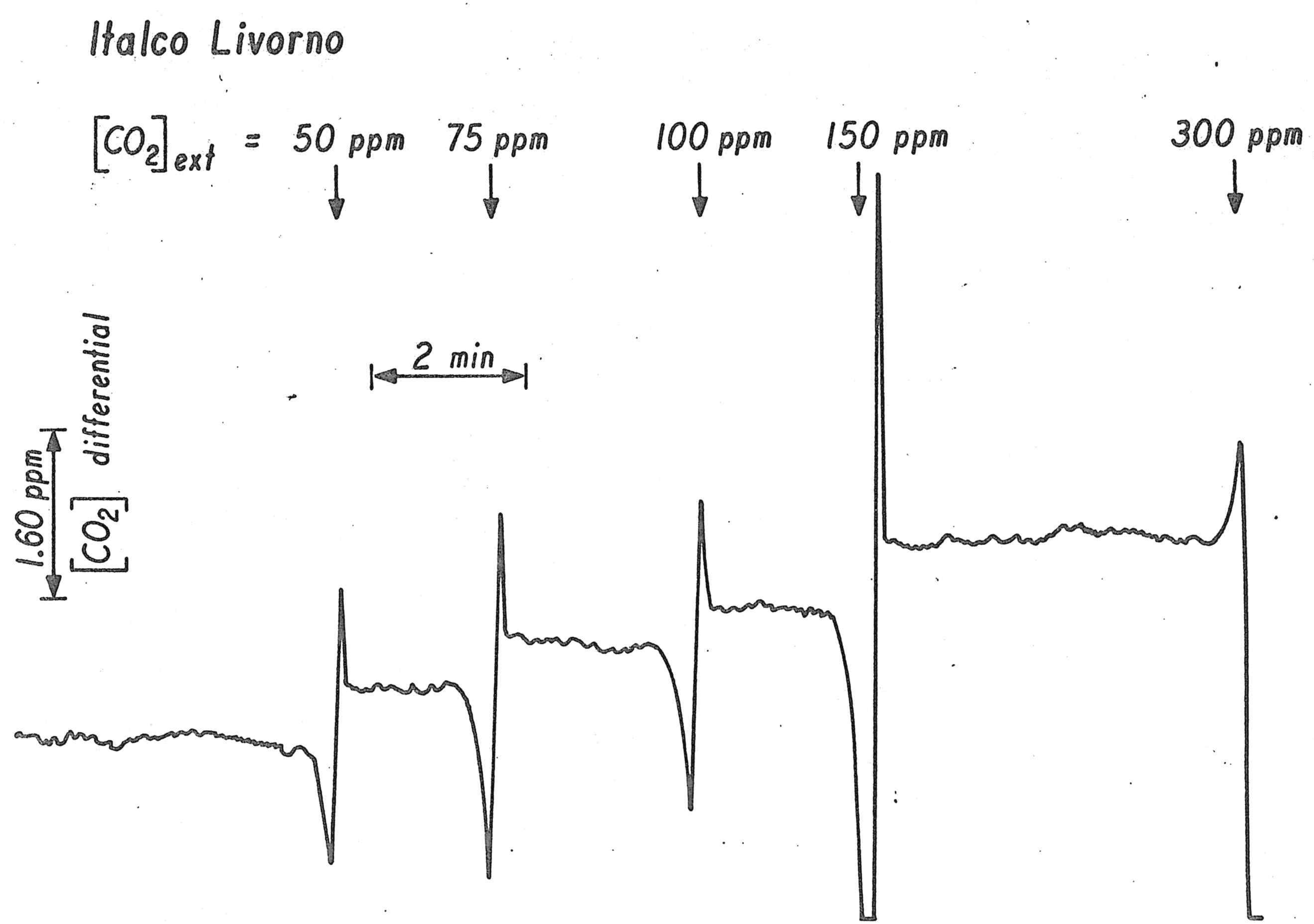


Figure 4. Actual traces from CO_2 analizer showing changes in $[CO_2]$ differential as a function of $[CO_2]$ external for two rice varieties.



Calrose No. 2

Figure 5. Actual traces from CO_2 analizer showing changes in $[CO_2]$ differential as a function of $[CO_2]$ external for two rice varieties.