Chapter-III
RESULTS

R E S U L T S

3.1.0 AMBIENT AIR EXPOSURE STUDIES - FIRST YEAR

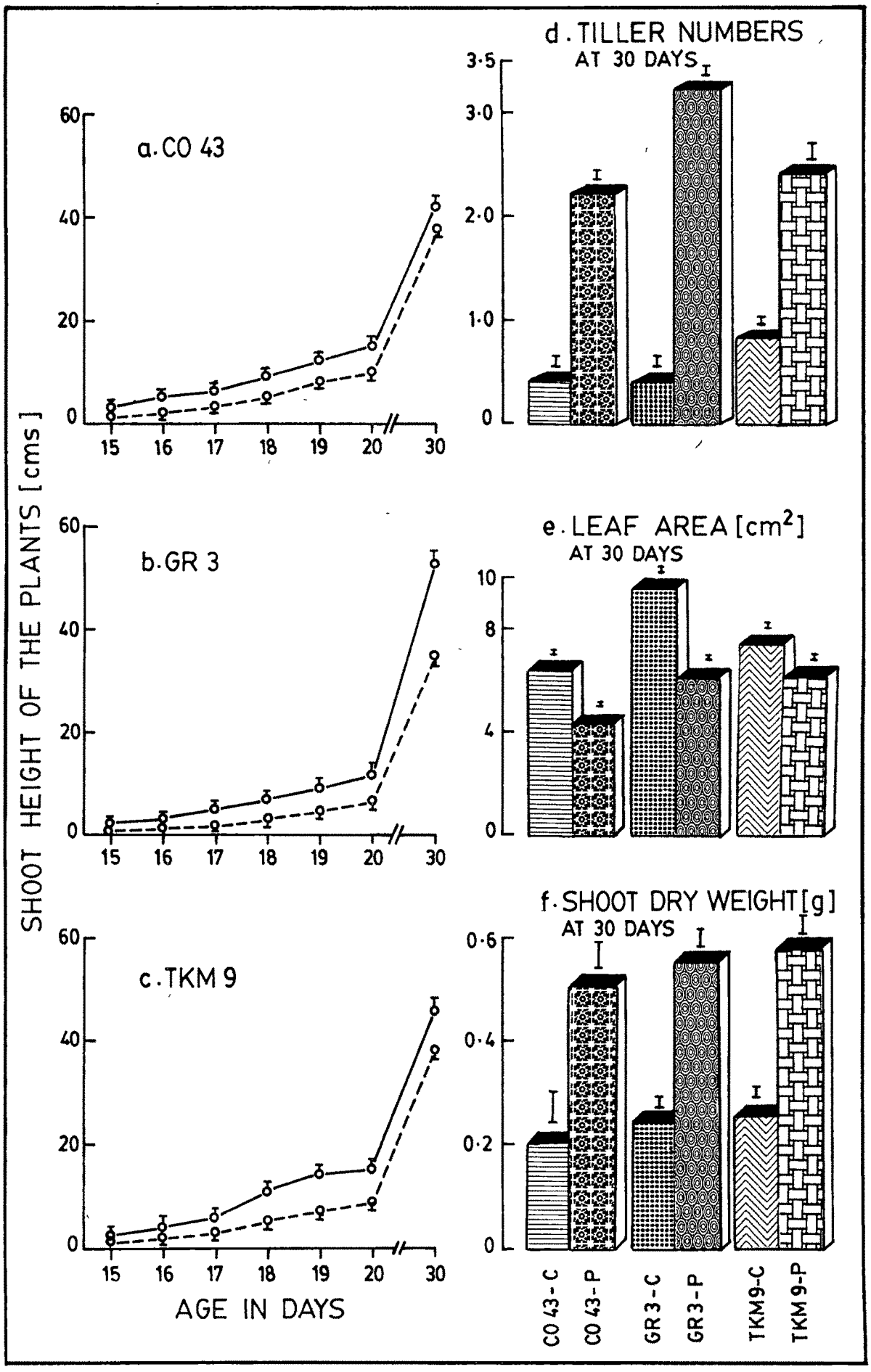
3.1.1.0 Early Growth Studies

The early growth of cultivars of rice exposed to the polluted environment near the fertilizer plant was appeared to be adversely affected. The plant height at the age of 15 days was reduced by 50 % as compared to control. However, 30 day exposure to the polluted environment indicated reduction in the growth by 10% in cv CO 43, 34% in GR 3, and 15% in TKM 9 (Fig.5 a-c). A significant increase in the number of tillers and shoot dry matter production with reduced leaf area was also evident in the 30 day old polluted test site plants (Fig.5, f and e).

3.1.1.1 Later Growth Studies

The growth measurements were taken on 30 (the day on which the imposition of regimes started), 55, 70 and 85 days after seeding. The number of tillers produced was tremendously increased under the polluted environment (Fig. 6 and 7). The increase was 1.7, 0.5 and 1.2 fold under NN of cvs CO 43 GR 3 and TKM 9 at the final harvest, over the respective control (Fig.6). Further, the production of tillers reached to a level of 11.2 in cvs CO 43 and GR 3 under HN regime and it reached a highly significant level of 11.6 in cv GR 3 in the polluted environment under WS-HN (Fig.6 b and 7 b). On the other hand the height of the shoot system was markedly inhibited in the test site plants at all the time of growth in all the regimes (Fig. 6 and 7). The percentage of reduction in height was 32, 44 and 52 in cvs CO 43, GR 3 and TKM 9 respectively, at the age of 55 days. The reduction was 34, 27 and 16 % accord-

Fig. 5 Effects of ambient air pollution on the plant height, tiller numbers, leaf area and shoot dry weight of three cultivars of rice at early stages, grown near to and distant from a fertilizer plant. Vertical bars represent standard error. Even lines = control and dotted lines = polluted.


a. CO 43
b. GR 3
c. TKM 9
SHOOT HEIGHT OF THE PLANTS [cms]
AGE IN DAYS
d. TILLER NUMBERS AT 30 DAYS
e. LEAF AREA [cm²] AT 30 DAYS
f. SHOOT DRY WEIGHT [g] AT 30 DAYS
CO 43-C
CO 43-P
GR 3-C
GR 3-P
TKM9-C
TKM 9-P

ingly at 85 days as compared to control (Fig. 6 c). The imposition of nitrogen and water regimes did not bring out any significant improvement in the plant height (Fig. 6 d and 7 d). The increased tiller formation and reduced plant height are clearly pictured at the age of 45 days (Plate 5-16).

The number of leaves in the polluted test site plants was significantly increased under all the regimes as compared to control at 55 days (Fig.8). Though the photosynthetic leaf area also showed an increase in the test site under normal watering, there was no positive relationship between the area and number of leaves in the test site plants. The leaf area of cv CO 43 under both N levels and GR 3 under WS-HN conditions was reduced in the test site. Marginal bleachings were evident in the leaves of all the rice cultivars at the polluted site, approximately after 15 days and later they progressed towards the centre of the leaf blade ending in tip burnings, associated with necrotic areas (Plate 6, 8, 10-16).

The weight of fresh and dry shoot system was determined at the age of 30, 55, 70 and 85 days. The polluted environment brought about an increase in the fresh and dry matter accumulation of shoots in rice cultivars (Fig. 9 and 10). At the final harvest the increase in the fresh weight of shoot was 2, 1.2 and 1.4 fold of the controls in cvs CO 43, GR 3 and TKM 9 respectively (Fig. 9 a). The maximum production was evident in the HN regime of CO 43 and GR 3 cultivars (Fig. 9 b). Though the exposure to pollution did not bring any difference in the fresh matter accumulation in the shoot system of water stressed cv GR 3, at initial stages, prolonged exposure recorded a significantly increased fresh matter at the later stages (Fig. 10 a and b). However, there

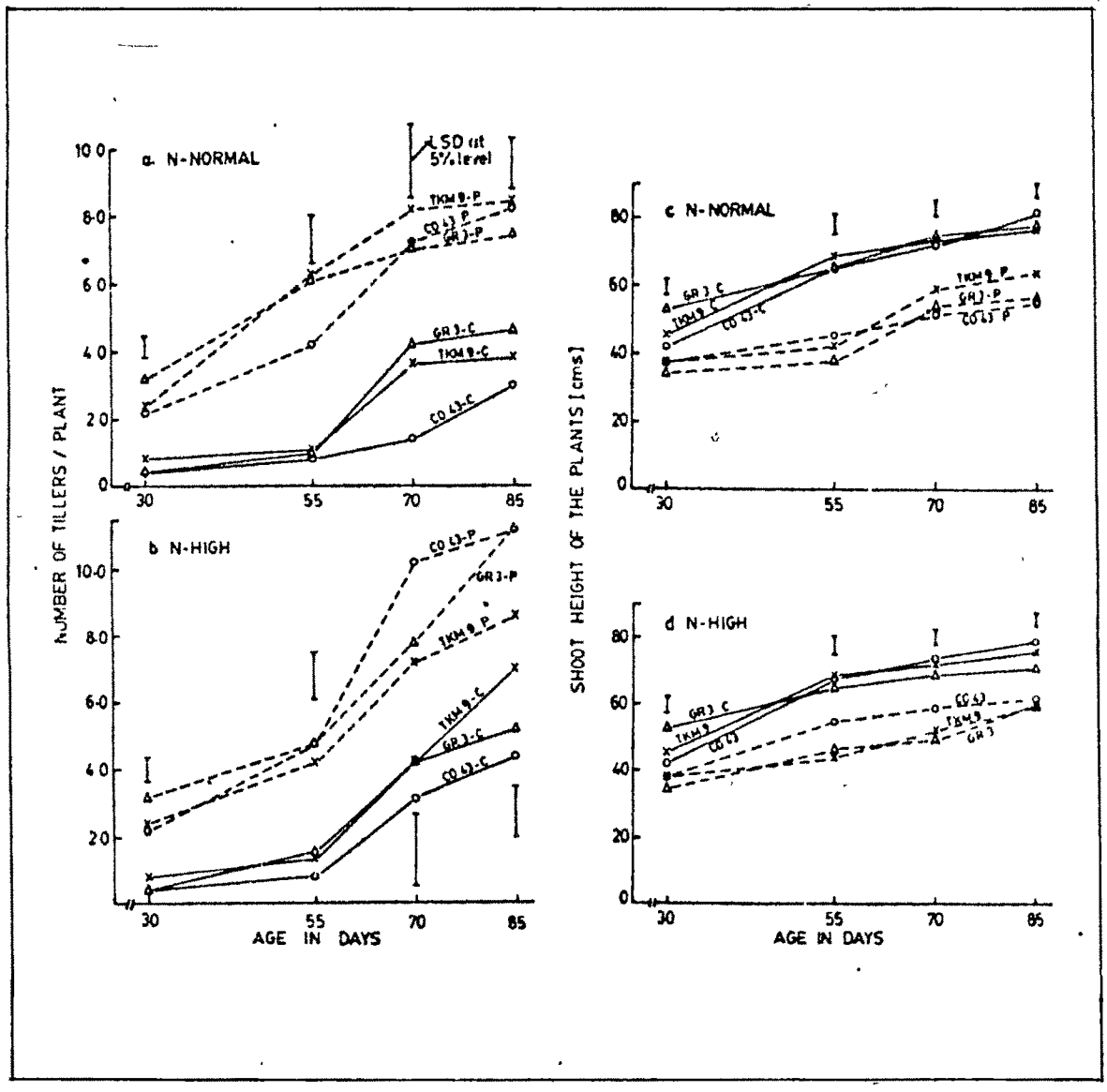
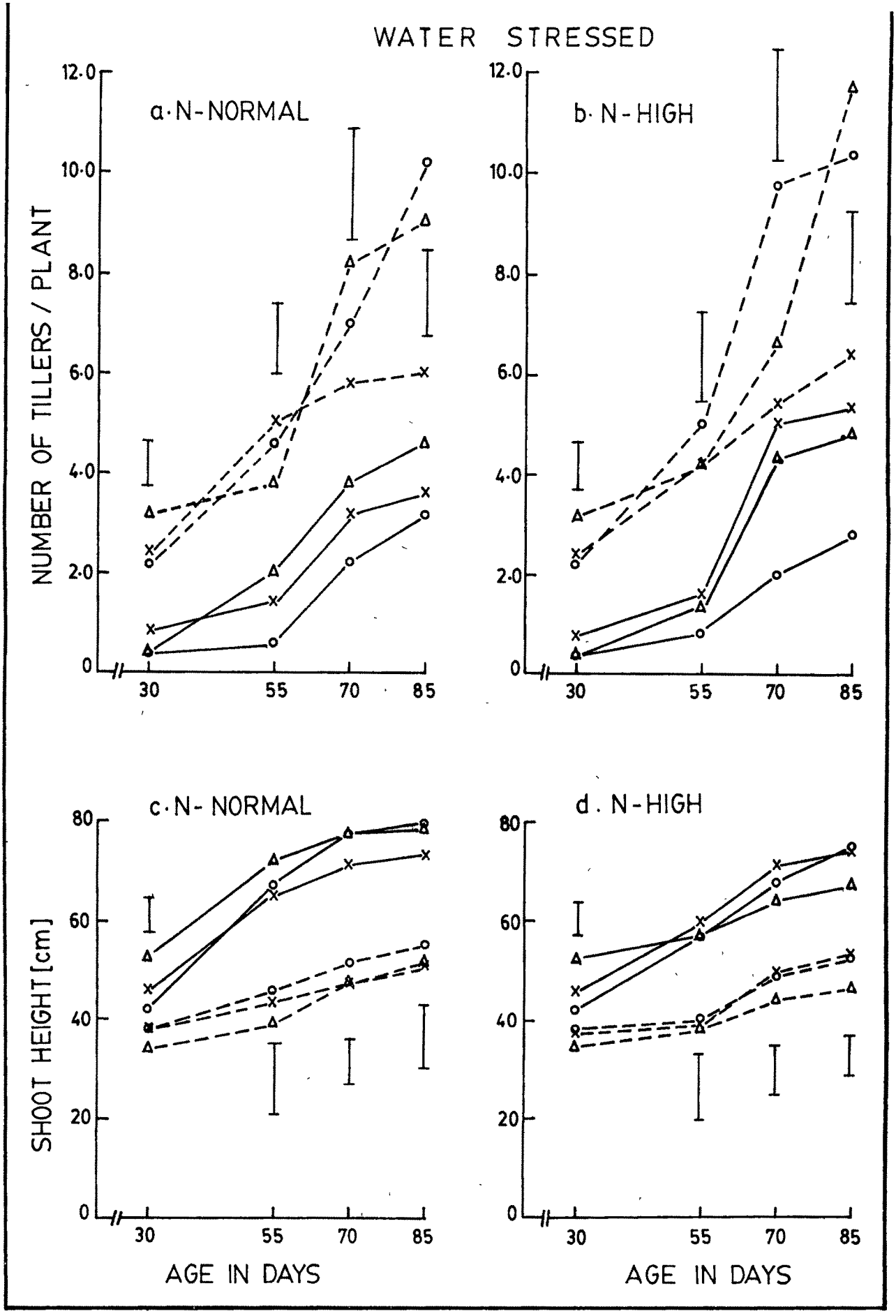


Fig. 6 Effects of ambient air pollution on the number of tillers and shoot height of three cultivars of rice, at later stages under two N levels, grown near to and distant from a fertilizer plant.

Fig. 7 Effects of ambient air pollution on the number of tillers and shoot height of three cultivars of rice, at later stages under two N levels with 50 % water stress, grown near to, and distant from, a fertilizer plant. Vertical bars represent LSD at 5 % level; o ——— o = cv CO 43; Δ ——— Δ = cv GR 3; x —— x = cv TKM 9.


WATER STRESSED
a·N-NORMAL
b·N-HIGH
c·N-NORMAL
d·N-HIGH
NUMBER OF TILLERS / PLANT
SHOOT HEIGHT [cm]
AGE IN DAYS
AGE IN DAYS
0
2·0
4·0
6·0
8·0
10·0
12·0
20
40
60
80
30
55
70
85

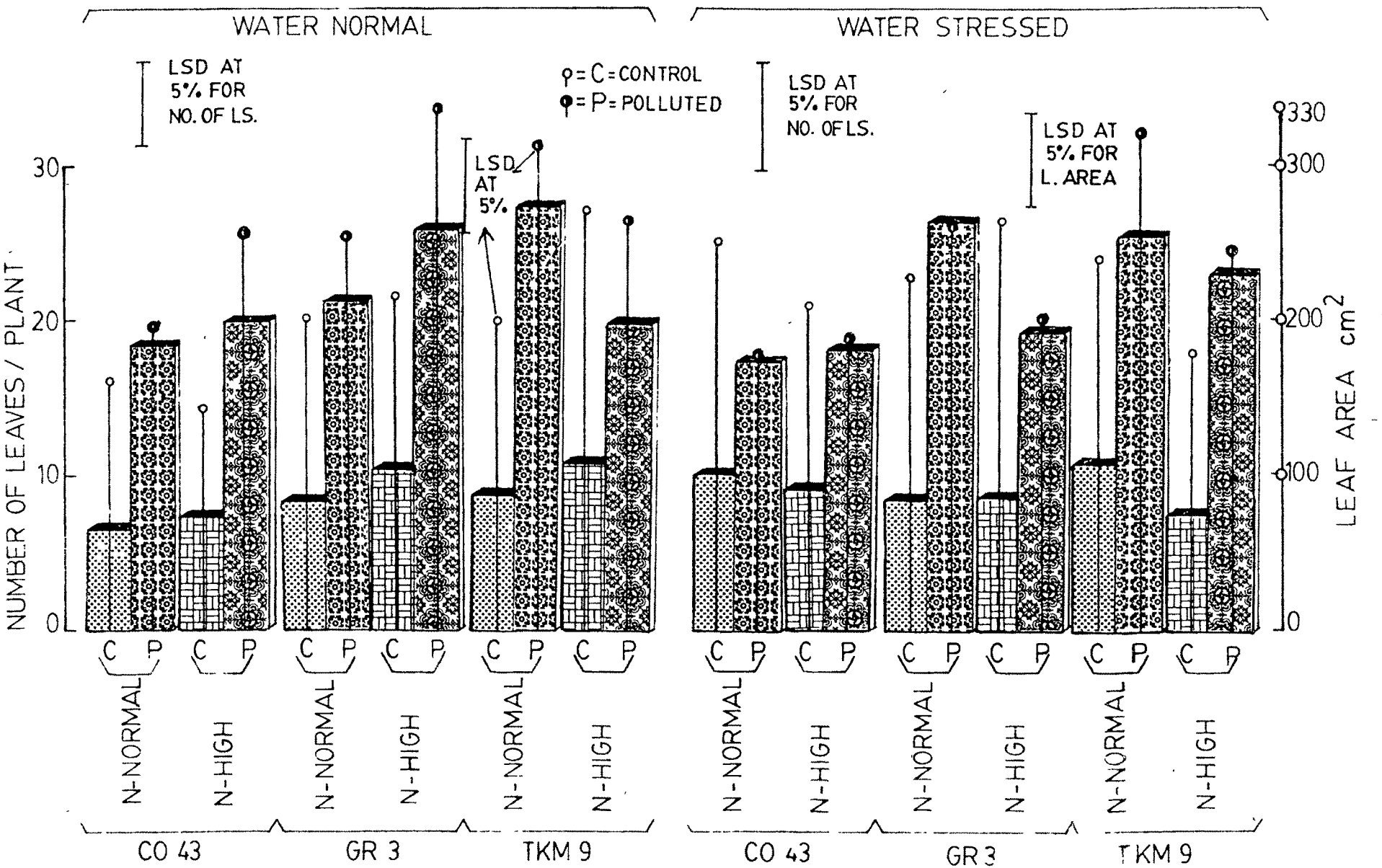


Fig. 8 Effects of ambient air pollution on the number of leaves and photosynthetic leaf area of three cultivars of rice, under two N and water regimes, grown near to, and distant from, a fertilizer plant.

Fig. 9 Effects of ambient air pollution on the fresh and dry weight of shoots of three cultivars of rice, at later stage under two N levels, grown near to, and distant from, a fertilizer plant. Vertical bars represent LSD at 5 % level; o —— o = control cv CO 43; o -- o = polluted cv CO 43; Δ —— Δ = control cv GR 3; Δ---Δ = polluted cv GR 3; x —— x = control cv TKM 9; x --- x = polluted cv TKM 9.

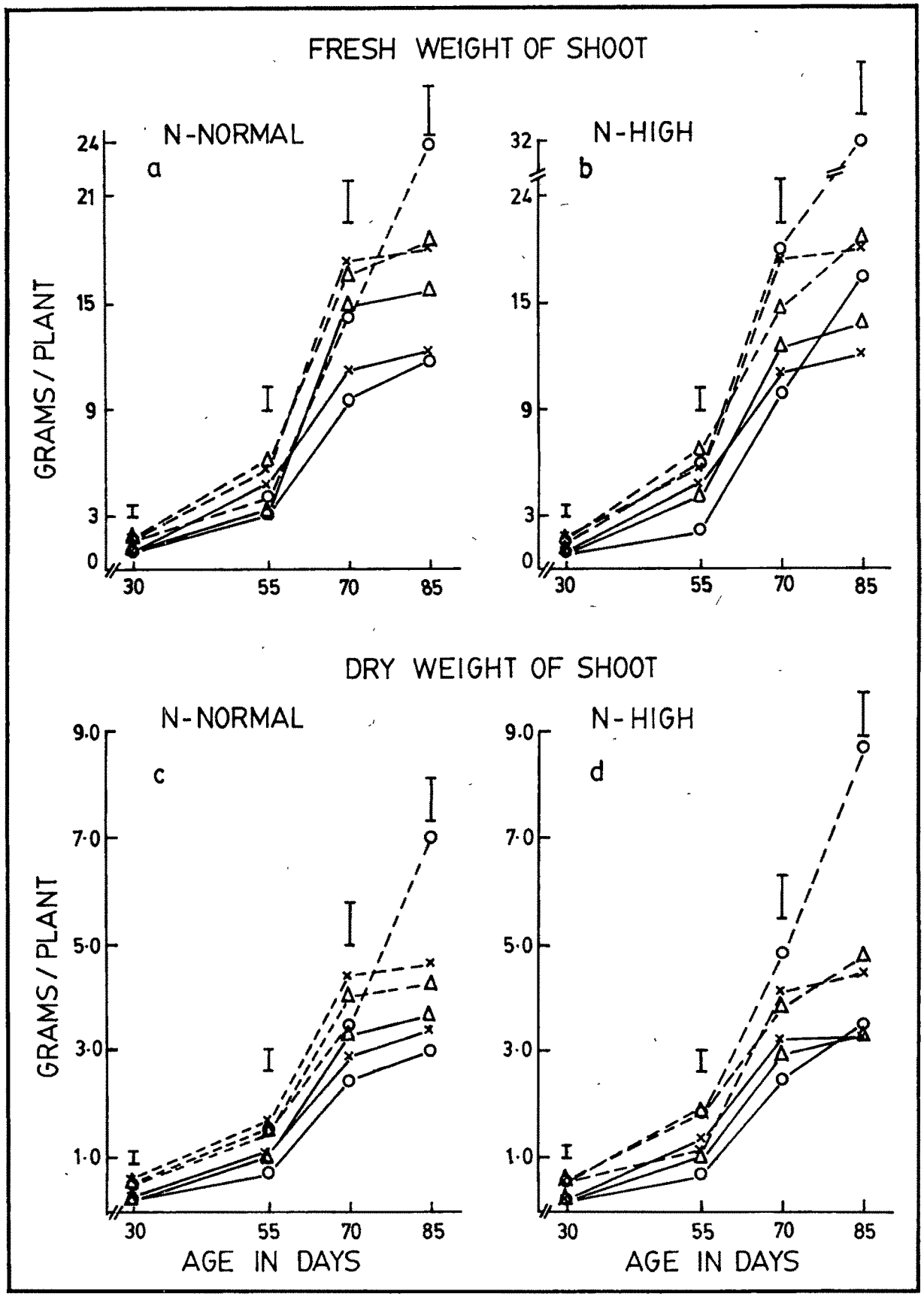

FRESH WEIGHT OF SHOOT
N-NORMAL
a
N-HIGH
b
GRAMS / PLANT
24
21
15
9
3
0
32
24
15
9
3
0
30
55
70
85
DRY WEIGHT OF SHOOT
N-NORMAL
c
N-HIGH
d
9·0
7·0
5·0
3·0
1·0
AGE IN DAYS

Fig. 10 Effects of ambient air pollution on the fresh and dry weight of shoots of three cultivars of rice, at later stage under two N levels with 50 % water stress, grown near to, and distant from, a fertilizer plant. Vertical bars represent LSD at 5 % level; o — o = control cv CO 43; o -- o = polluted cv CO 43; Δ— Δ = control cv GR 3; Δ-- Δ = polluted cv GR 43; x — x =control cv TKM 9; x -- x = polluted cv TKM 9.

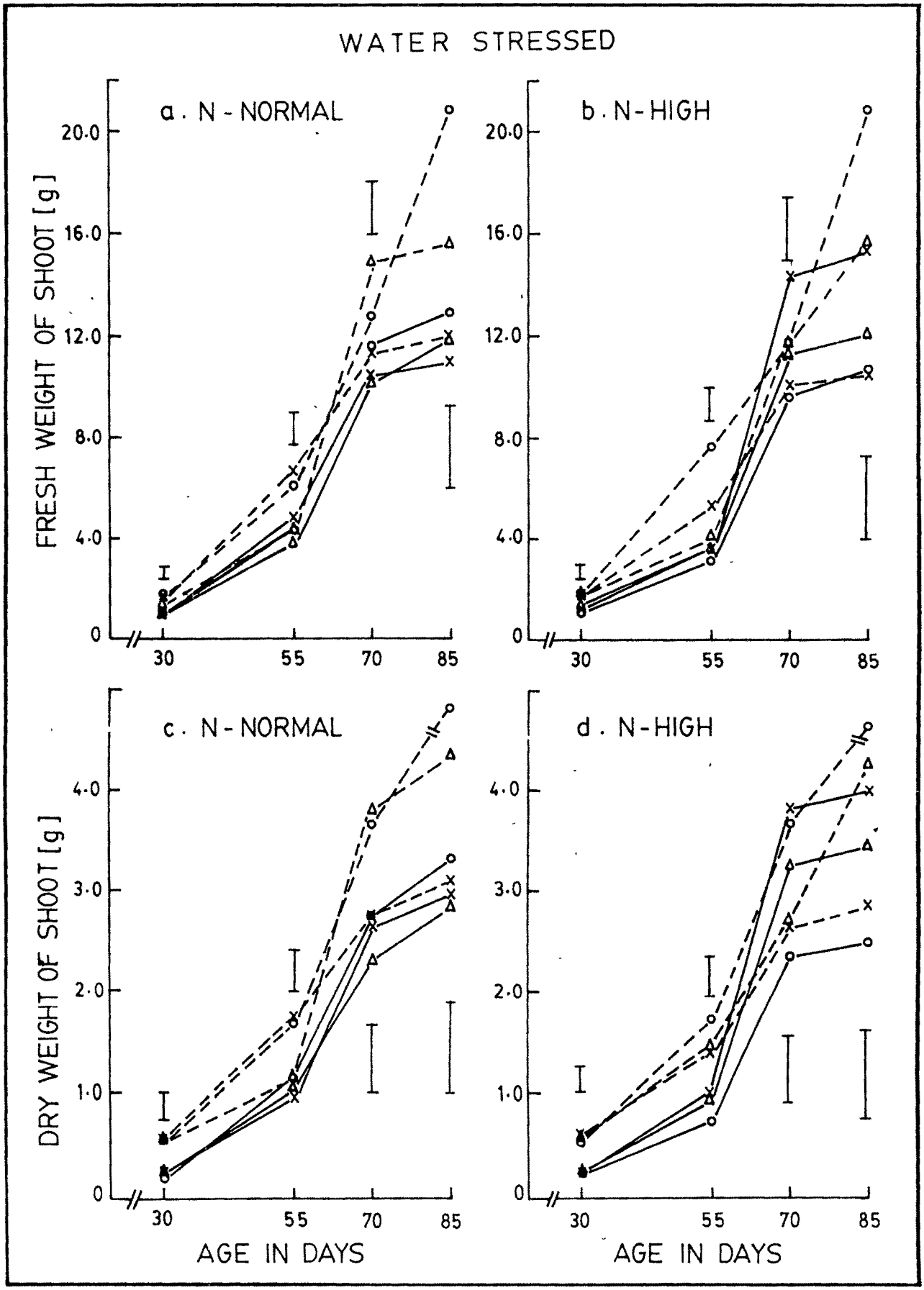

WATER STRESSED
a. N - NORMAL
b. N - HIGH
c. N - NORMAL
d. N - HIGH
FRESH WEIGHT OF SHOOT [g]
DRY WEIGHT OF SHOOT [g]
20·0
16·0
12·0
8·0
4·0
0
3·0
2·0
1·0
30
55
70
85
AGE IN DAYS

Plate-9 Forty-five day old plants of cv TKM 9 at the control site grown in polythene containers under two soil nitrogen and water levels.

Plate-10 Forty-five day old plants of cv TKM 9 at the polluted site grown in polythene containers under two soil nitrogen and water levels.

Plate-5 Forty-five day old plants of cv CO 43 at the control site grown in polythene containers under soil nitrogen and water levels.

Plate-6 Forty-five day old plants of cv CO 43 at the polluted site grown in polythene containers under two soil nitrogen and water levels.

Plate-7 Forty-five day old plants of cv GR 3 at the control site grown in polythene containers under two soil nitrogen and water levels.

Plate-8 Forty-five day old plants of cv GR 43 at the polluted site grown in polythene containers under two soil nitrogen and water levels.

Plate-11 Forty-five day old normal watered individual plants of cv CO 43 at control and polluted sites.

Plate-12 Forty-five day old water stressed individual plants of cv CO 43 at control and polluted sites.

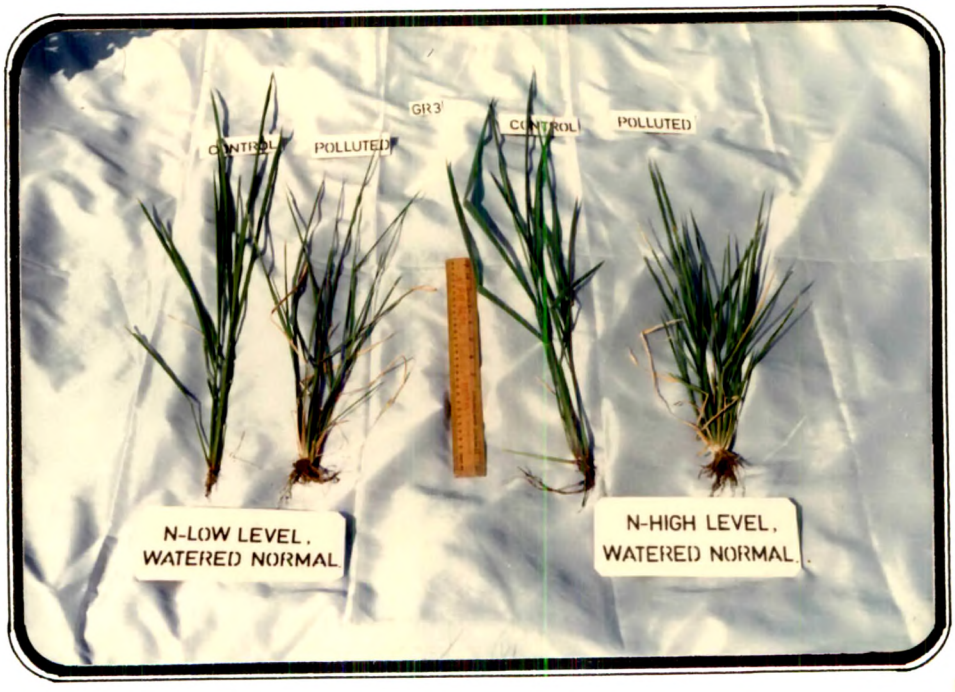


Plate-13 Forty-five day old normal watered individual plants of cv GR 3 at control and polluted sites.

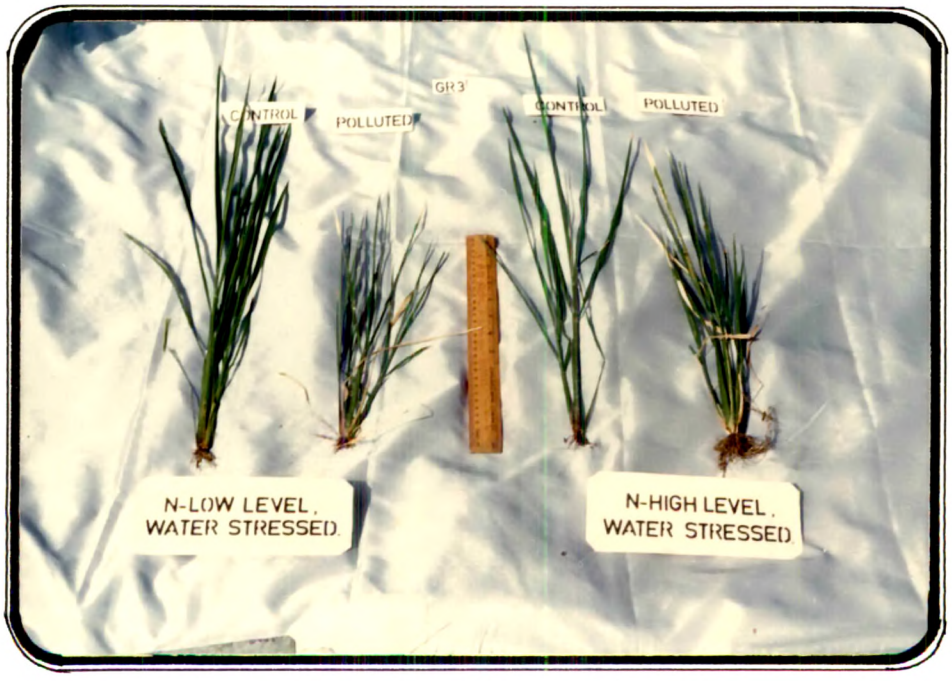


Plate-14 Forty-five day old water stressed individual plants of cv GR 3 at control and polluted sites.

Plate-15 Forty-five day old normal watered individual plants of cv TKM 9 at control and polluted sites.

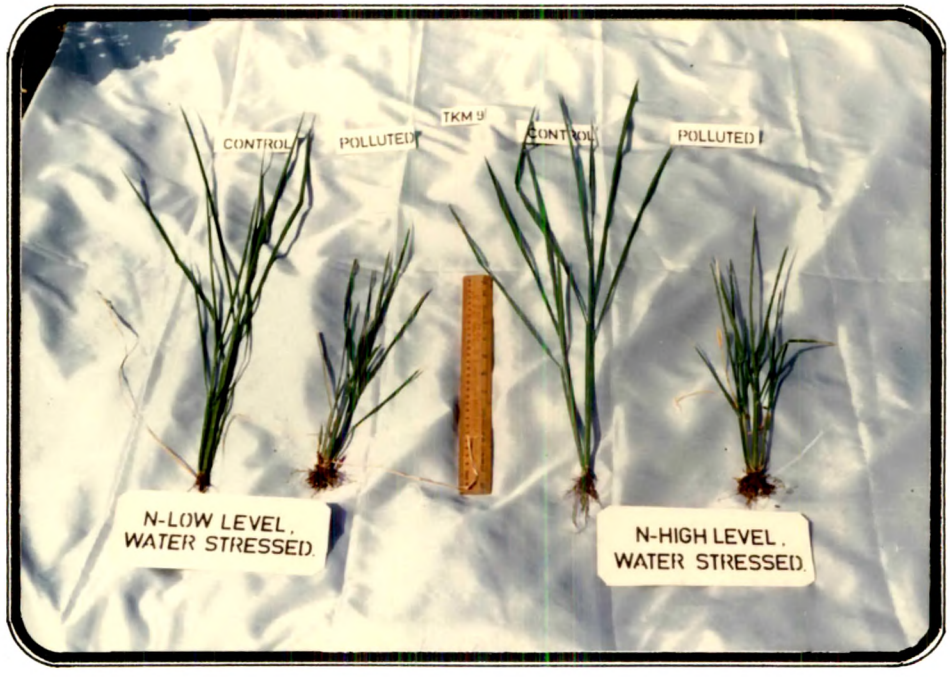


Plate-16 Forty-five day old water stressed individual plants of cv TKM 9 at control and polluted sites.

was not much difference in the cv TKM 9 under WS-HN (Fig. 10 b). The dry weight of shoot system was found to be increased in the polluted environment in all the cultivars. The increase was 104, 63 and 22 % in cvs CO 43, GR 3 and TKM 9 respectively in 55 days (Fig. 9 c). At the final harvest the increase was 132, 18 and 42 % accordingly. A high amount of dry matter production was observed in cvs CO 43 and GR 3 under HN regime (Fig.9 d). However, under WS-HN the dry matter accumulation was reduced as compared to the un-polluted plants of cv TKM 9, at 70 and 85 days of growth (Fig. 10 d) and it appeared to be increased in other variables.

3.1.1.2 Yield and Yield Attributes

The effects of air pollution on the yield and yield attributes of rice cultivars are shown in Table 6. Under NN conditions, there was a significant reduction in the panicle length of all the test site plants, but with a distinct increase in the number of panicles per plant in cvs GR 3 and TKM 9. The number of spikelets per panicle was found to be reduced in CO 43 cultivar. The sterility index was higher in all the cultivars as a response to pollution stress. Further, it was interesting to note that CO 43 cultivar accumulated a larger amount of straw yield than the other cultivars, with a drastic reduction in the production of economic yield (dry filled grains). Conversely, cvs GR 3 and TKM 9 at the polluted site exhibited a tendency to produce higher economic yield than the control. However, the 100 seeds weight (quality) of cv GR 3 was found to be less in the polluted environment. Further, the air pollution had markedly affected the harvest index in all the cultivars.

Table : 6 Yield and Yield attributes (per plant) of rice cvs CO 43, GR 3 & TKM9 to chronic air pollution under two N regimes.

	N- N O R M A L						N - H-I G H						
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9		LSD at 5 %
	C	P	C	P	C	P	C	P	C	P	C	P	
Panicle length (cm)	16.5	10.6*	18.8	14.0*	16.6	14.0*	15.2	14.4	15.8	14.4	14.7	11.8*	2.6
Panicles (number)	2.6	3.8	2.8	11.2*	3.4	6.0*	3.0	4.0	4.2	11.6*	3.8	5.0	1.8
Spikelets/panicle	7.3	4.8*	8.6	6.9	5.3	5.2	6.3	6.1	7.9	7.0	5.0	4.3	1.25
Sterility Index (%)	32	99*	28	63	29	56*	32	92*	66	52	49	70*	14.6
Dry filled grains(g) (Economic yield)	1.81	0.02	1.90	2.32	1.66	2.10	1.63	0.19*	0.75	3.75*	0.84	0.75	0.76
Dry unfilled grains (g)	0.15	0.35	0.20	1.21*	0.15	0.65*	0.12	0.42*	0.43	1.31*	0.21	0.36	0.34
Straw yield (g)	3.19	7.97*	3.02	5.38*	2.84	3.67	3.36	5.56*	2.71	5.55*	2.63	3.02	1.16
100 grains (g)	1.40	1.40	1.63	1.46*	1.68	1.62	1.28	1.05*	1.51	1.52	1.59	1.57	1.16
Biological yield (g)	5.19	8.34*	5.12	8.81*	4.65	6.42	6.74	6.17	3.89	10.95*	3.68	4.13	2.24
Harvest Index	0.36	0.00*	0.37	0.26*	0.36	0.29	0.31	0.03*	0.18	0.38*	0.23	0.18*	0.07

C = Control, P = Polluted; * = significant difference over the control at CD 5 % level.

The imposition of high nitrogen regime had definitely increased the production of panicles, economic yield, straw yield and biological yield of cv GR 3 in the test site, thereby increasing its harvest index distinctly over the control. Though cv GR 3 produced an increase in the amount of unfilled grains, its sterility index and quality of the seeds were not affected. In contrast, the cv CO 43 was drastically affected by the air pollution as indicated by an increase in the sterility index, dry unfilled grains and decrease in the economic yield, 100 grains weight and finally the harvest index. The increase in the production of straw yield as a response to air polluted environment in the cv CO 43 did not affect the biological yield due to the loss in economic yield. On the other hand the cv TKM 9 gave a different picture with no significant effect on the yield and most of the yield attributes. However, there was an evident reduction in the panicle length and harvest index and an increase in sterility index.

The imposition of water stress in addition to N regimes provided yet another pattern in the yield components as affected by air pollution (Table 7). Eventhough there were marked inhibitions in the panicle length, number of spikelets and 100 grains weight in the cv GR 3, a 2.5 fold increase in the number of panicles per plant had brought a remarkable increase in the amount of dry filled grains (economic yield) with a parallel increase in the straw yield, biological yield and harvest index. In contrast, cv CO 43 which had an increase in the straw as well as biological yield, had a dramatic decline in its economic yield due to its significant increase in sterility index and insignificant number of panicles. Hence, a decrease in the harvest index was also evident in the cv CO 43. In the cv TKM 9 air pollution had rendered an inhibition in the panicle length, increased sterility index, and decreased biological yield, with a

Table : 7 Yield and Yield attributes (per plant) of rice cvs CO 43, GR 3 and TKM 9 to chronic air pollutioin under two N levels with 50 % water stress.

	N - N O R M A L						N - H I G H						
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9		LSD at
	C	P	C	P	C	P	C	P	C	P	C	P	5 %
Panicle length (cm)	15.2	14.1	18.0	14.3*	15.7	12.4*	17.3	9.3*	16.2	13.2*	17.4	11.8*	5.8
Panicles (number)	2.6	1.6	2.6	7.8*	2.8	2.6	1.6	2.6	3.0	9.0*	3.6	4.0	1.8
Spikelets/panicle	6.6	6.5	9.1	6.0*	5.4	4.6	7.9	4.7*	7.8	5.1	6.5	4.6	1.37
Sterility Index (%)	56.0	97.0*	51.0	50.0	36.0	71.0*	49.0	100.0*	50.0	52.0	47.0	67.0*	15.6
Dry filled grains (g) (Economic yield)	1.09	0.05*	0.89	2.64*	1.51	0.35*	1.00	Nil*	0.92	1.94*	1.83	0.73*	0.51
Dry unfilled grains(g)	0.26	0.24	0.23	1.01*	0.20	0.22	0.13	0.18	0.18	0.76*	0.33	0.34	0.32
Straw yield (g)	3.00	5.95*	2.37	4.01*	2.35	1.80	2.33	7.74*	2.63	4.50*	3.01	2.14	1.45
100 grains (g)	1.37	1.25*	1.53	1.34*	1.70	1.44*	1.22	Nil*	1.47	1.40	1.67	1.61	0.07
Biological yield (g)	4.35	6.24*	3.49	7.66*	4.05	2.38*	3.56	7.92*	3.73	7.20*	5.17	2.61*	1.86
Harvest Index	0.27	0.01*	0.26	0.34	0.39	0.15*	0.28	0.00*	0.25	0.28	0.36	0.29	0.09

C=Control; P = Polluted; * Significant difference over control at C.D.5 % level.

corresponding decrease in the economic yield, 100 grains weight and harvest index.

The panicle length of all the cultivars was significantly inhibited by air pollution under WS-HN. However, 3 fold increase in the number of panicles with increased straw and biological yield along with distinct increase in economic yield was evident in the cv GR 3 when compared to the respective control. Conversely, under the same regime cv CO 43 with increased straw and biological yield along with decreased spikelet numbers and 100% sterility, suffered a 100% reduction in its economic yield. With increased sterility index and decreased straw yield cv TKM 9 also had a significant reduction in the economic yield. Imposition of water stress in addition to high N application provided no strategy against air pollution effect in CO 43 and TKM 9 cultivars.

3.1.1.2 a Main Effects of Air Pollution on Yield and Yield Attributes

The main effects of cultivars on the yield and yield attributes of rice grown near to and10 km distant from a fertilizer factory are shown in Table 8. The panicle initiation was delayed by 13 days in cvs GR 3 and TKM 9, while 35 days in cv CO 43 at the test site as compared to the controls. The mean of all the cultivars showed a significant increase in the number of panicles, sterility percentage and biological yield near the factory. A significant reduction in the harvest index and insignificant reduction in the number of filled grains and economic yield were also evident in the plants grown in the polluted environment. A three fold increase in the production of panicles and a dramatic increase in the number of filled grains rendered the cultivar GR 3 to produce

Table : 8 Main effects of cultivars on the yield and yield attributes of rice grown near (P), or 10 km distant (C), from a fertilizer plant.

Panicle initiation delayed at P (days)(NSA)	Panicles number/plant^{-1}		Filled grains number/plant^{-1}		Sterility Index (%)		Economic yield g/plant^{-1}		Biological yield g/plant^{-1}		Harvest Index	
	C	P	C	P	C	P	C	P	C	P	C	P
					cv CO 43							
35	2.4	3.0	103.7	5.7**	43.7	97.7**	1.38	0.07**	4.58	6.81*	0.305	0.013**
					cv GR 3							
13	3.2	9.9**	71.9	185.0**	48.1	54.0	1.12	2.66**	4.06	8.43**	0.265	0.313
					cv TKM 9							
13	3.4	4.4	93.8	54.5	40.5	64.6**	1.46	0.98	4.39	3.89	0.333	0.229*
					Mean							
20	3.0	5.8*	89.8	81.7	44.1	72.1**	1.32	1.24	4.34	6.38*	0.301	0.185*

Levels of significance : at 5 % (*) and 1 % (**); NSA = not statistically analysed.

significantly high economic and biological yields in the polluted condition. However, there was no corresponding increase in its harvest index. The cultivar TKM 9 which experienced a significantly increased sterility index near the factory was not markedly affected in its economic and biological yields. Nevertheless, its harvest index was significantly reduced. Interestingly, though there was an evident increase in the biological yield of the cv CO 43 in the polluted environment, a reduced number of filled grains and increased sterility percentage rendered a sharp reduction in its economic yield and harvest index.

3.1.1.2 b Interaction on Growth of Rice Response Variables

An interaction due to environment on the number of tillers was highly significant in 55, 70 and 85 day old plants as shown by the mean square values from the ANOVA (Table 9). The effect of applied nitrogen was evident at 70 and 85 days. The cultivar effect was evident on 55 and 85 days. The interaction due to cultivar and nitrogen with environment, cultivar and water with environment, and all the 4 factors together were significant on the number of tillers at 70 and 85 days. Other cases of interactions due to the factors were not significant.

The interaction due to environment was highly significant on the fresh as well as dry matter production of 55, 70 and 85 day old plants (Table 10 and 11). The interaction due to water was evident on 70 and 85 days. The cultivar effect was highly significant only at 85 days. A significant interaction of cultivar with environment was noted on 85 day old plants in the fresh and dry matter. The cultivar and nitrogen or cultivar and water with the environment showed mostly significant interaction on 55 and 70 days and it was highly

Table : 9 Mean square values from the analysis of variance of rice response variables, on the number of tillers.

Source	df	Numbers of tiller/plant 55 days	70 days	85 days
Replication	4	11.45**	5.39	1.88
Cultivar (C)	2	5.06*	4.26	13.23*
Nitrogen (N)	1	0.54	13.34*	60.21**
Water (W)	1	3.34	10.80	5.21
Environment (E)	1	488.04**	496.14**	658.00**
C x N	1	0.35	1.10	0.19
C x E	1	0.15	5.36	4.33
C x W	1	0.45	0.33	1.30
W x N	1	0.01	0.09	0.47
W x E	1	0.04	<0.01	0.10
E x N	1	0.07	0.26	0.06
C x N x E	1	0.61	26.39**	12.23*
C x N x W	1	0.97	1.30	4.36
C x E x W	1	1.51	13.06*	9.64*
N x E x W	1	0.87	0.51	0.45
C x N x W x E	1	6.64*	16.84*	27.82**
Error	99	2.12	4.04	3.17
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

Table : 10 Mean square values from the analysis of variance of rice response variables, on the fresh weight of shoot system.

Source	df	Fresh weight of shoot system		
		55 days	70 days	85 days
Replication	4	29.0**	50.3**	48.6**
Cultivar (C)	2	4.8*	12.6	534.5**
Nitrogen (N)	1	1.4	1.5	42.5**
Water (W)	1	0.1	178.5**	385.2**
Environment (E)	1	135.3**	221.6**	932.7**
C x N	1	0.3	1.2	1.5
C x E	1	1.1	0.5	24.9*
C x W	1	2.4	0.6	0.8
W x N	1	0.2	< 0.1	0.4
W x E	1	< 0.1	< 0.1	< 0.1
E x N	1	< 0.1	5.1	4.3
C x N x E	1	3.6	6.9	55.8**
C x N x W	1	0.8	5.7	16.9*
C x E x W	1	5.5*	26.9*	74.9**
N x E x W	1	0.2	10.0	9.0
C x N x W x E	1	73.4**	70.9**	600.7**
Error	99	1.7	9.0	4.3
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

Table : 11 Mean square values from the analysis of variance of rice response variables, on the dry weight of shoot system.

Source	df	Dry weight of shoot system		
		55 days	70 days	85 days
Replication	4	1.24**	2.34*	1.99
Cultivar (C)	2	0.03	0.57	21.23**
Nitrogen (N)	1	0.01	<0.01	1.76
Water (W)	1	<0.01	5.99**	16.78**
Environment (E)	1	7.65**	17.52**	88.26**
C x N	1	<0.01	0.04	0.03
C x E	1	0.20	0.19	3.01*
C x W	1	0.04	0.02	0.27
W x N	1	<0.01	0.81	0.03
W x E	1	0.03	0.02	0.01
E x N	1	0.02	0.37	0.40
C x N x E	1	0.50*	0.94	6.49**
C x N x W	1	0.13	0.48	0.98
C x E x W	1	0.59*	3.55*	7.69**
N x E x W	1	0.15	1.06	0.87
C x N x W x E	1	7.02**	5.80**	31.26**
Error	99	0.10	0.76	0.99
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

significant on 85 days. The interaction of all the 4 factors were significant on the fresh and dry matter production at all the stages.

The interaction of the cultivars, applied nitrogen and environment (C x N x E) brought about a significant increase in the number of tillers in all the cultivars at both N levels (Table 12). The fresh weight of shoot system was found to be highly significant in cv CO 43 at both N levels and only significant under HN in cv GR 3 and under NN level in cv TKM 9. The dry weight of the shoot system was found to be significantly increased at both N levels in cvs CO 43 and GR 3 but not in cv TKM 9.

The interaction of water stress, cultivar and environment showed significant increase in the tiller formation at both water levels (Table 13). Fresh weight of shoot appeared to be significantly increased in the cv CO 43 at both water levels, in the cv TKM 9 under normal watering and in cv GR 3 under water stress. The dry weight of shoot was increased in all the polluted plants except 50% water stressed cv TKM 9.

3.1.1.2 c Interaction on Yield Attributes

(i) Interaction due to Rice Response Variables

The independent effects of cultivars and environment were significantly evident in the panicle length, number of panicles, number of spikelets per panicle, sterility percentage, biological yield and harvest index (Table 14-16). The effect of water was evident in all the parameters except the number of

Table : 12 Interaction of cultivar, applied nitrogen and environment on the tiller numbers, fresh and dry weight of shoots of rice grown near to (P), or distant from (C), a fertilizer plant.

Amount of applied nitrogen	Cultivar	Tiller numbers		Fresh weight of shoot g plant^{-1}		Dry weight of shoot g plant^{-1}	
		C	P	C	P	C	P
Small	CO 43	3.1	9.2**	12.4	22.3**	3.2	6.3**
	GR 3	4.6	8.0**	13.5	16.4	3.2	4.3**
	TKM 9	3.7	7.2**	11.3	15.7*	3.1	3.9
Large	CO 43	3.6	10.8**	13.6	26.3**	3.0	7.3**
	GR 3	5.0	11.4**	14.1	17.1*	3.4	4.5**
	TKM 9	6.0	7.5*	13.7	14.1	3.6	3.6

Levels of significance : at 5 % (*) and 1 % (**), separately analysed for each parameter; Each value is the mean of 10 replicates.

Table : 13 Interaction of waterstress, cultivar and environment on the tiller numbers fresh and dry weight of shoots of rice grown near to (P), or distant from (C), a fertilizer plant.

Watering regimes	Cultivar	Tiller numbers		Fresh weight of shoot g plant^{-1}		Dry weight of shoot g plant^{-1}	
		C	P	C	P	C	P
Field capacity	CO 43	3.7	9.7**	14.2	27.7**	3.2	7.8**
	GR 3	4.9	9.1**	15.5	18.0	3.4	4.5**
	TKM 9	5.4	8.5**	11.8	18.7**	3.3	4.6**
50% field capacity	CO 43	3.0	10.3**	11.8	20.9**	3.0	5.7**
	GR 3	4.7	10.3**	12.1	15.5*	3.2	4.3**
	TKM 9	4.3	6.2*	13.2	11.1	3.4	2.9

Levels of significance : 5 % (*) and 1 % (**) separately analysed for each parameter; Each value is the mean of 10 replicates.

Table : 14 Mean square values from the analysis of variance of rice response variables, on the yield attributes.

Source	df	Panicle length	Number of panicles	Number of spikelets/ panicle
Replication	4	17.16**	7.75*	6.53*
Cultivar (C)	2	27.35**	153.08**	47.35**
Nitrogen (N)	1	16.58**	7.01*	2.00
Water (W)	1	596.68**	66.01**	< 0.01
Environment (E)	1	396.76**	232.41**	68.25**
C x N	1	0.68	1.70	0.16
C x E	1	0.96	170.95**	0.39
C x W	1	0.03	1.61	0.30
W x N	1	0.15	1.21	0.01
W x E	1	0.33	26.02**	0.21
E x N	1	< 0.01	0.09	0.17
C x N x E	1	2.14	23.88**	1.07
C x N x W	1	1.66	0.70	1.14
C x E x W	1	1.12	26.07**	1.67
N x E x W	1	2.60	26.46**	0.97
C x N x W x E	1	14.64**	53.94**	7.96*
Error	99	1.48	1.89	1.75
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

Table : 15 Mean square values from the analysis of variance of rice response variables, on the yield attributes.

Source	df	Number of filled grains x 10^{-3}	Sterility index x 10^{-2}	100 grains weight
Replication	4	8.2**	1.7	0.04
Cultivar (C)	2	116.8**	76.9**	5.54**
Nitrogen (N)	1	2.3	57.1**	0.01
Water (W)	1	95.3**	61.7**	0.84**
Environment (E)	1	1.9	302.0**	3.40**
C x N	1	0.1	0.4	<0.01
C x E	1	11.9**	5.9*	0.16
C x W	1	0.1	0.3	0.04
W x N	1	<0.1	0.3	<0.01
W x E	1	<0.1	0.1	0.01
E x N	1	<0.1	0.6	0.03
C x N x E	1	24.4**	14.1**	0.35*
C x N x W	1	2.3	1.8	0.12
C x E x W	1	24.9**	12.4**	0.47*
N x E x W	1	1.2	2.2	0.06
C x N x W x E	1	57.0**	32.6**	1.01**
Error	99	2.6	1.4	0.08
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

Table : 16 Mean square values from the analysis of variance of rice response variables, on the yield attributes.

Source	df	Biological yield	Economic yield	Harvest index x 10^3
Replication	4	20.80**	1.53	3.0
Cultivar (C)	2	47.85**	13.66**	605.0**
Nitrogen (N)	1	0.91	0.85	15.0*
Water (W)	1	29.51**	4.51**	1.0
Environment (E)	1	124.01**	0.21	410.0**
C x N	1	0.07	0.03	0.2
C x E	1	5.96	2.16*	29.0**
C x W	1	0.35	0.03	1.0
W x N	1	0.26	0.01	0.5
W x E	1	0.16	0.06	48.7**
E x N	1	0.01	0.01	2.0
C x N x E	1	12.65*	4.59**	152.0**
C x N x W	1	2.16	0.64	10.0
C x E x W	13.34*	4.58**	61.0**	
N x E x W	1	0.38	0.25	5.0
C x N x W x E	1	35.24**	11.66**	156.0**
Error	99	4.25	0.72	3.0
Total	119			

Levels of significance : P = 0.05 (*) and P = 0.01 (**).

spikelets per panicle and harvest index. Nitrogen had a definite infulence in the panicle length, number of panicles, sterility percentage, and harvest index. The interaction of environment with cultivar (E x C) or cultivar and nitrogen (C x N) or cultivar and water (C x W) and/or with all other factors were significantly evident in the number of panicles, filled grains, sterility percentage and harvest index. The interaction of environment with water (E x W) or nitrogen with water (N x W) were also observed in the number of panicles. A significant effect on the 100 grains weight was evident in the interaction of cultivar, nitrogen and environment (C x N x E) or cultivar, water and environment (C x W x E) and it was highly significant with all the 4 factors. It was interesting to note that the independent interaction due to environment on the biological yield was insignificant alongwith cultivar effect. On the other hand, the economic yield and number of filled grains showed no independent effect due to environment alone but the interaction was significant along with cultivar. The interaction due to environment and/or with other two or three factors were significant mostly in all the characters. However, other cases of interaction due to other factors were not significant.

(ii) Interaction due to Cultivar, applied N, and Environment (C x N x E)

The mean values regardless of soil water status showed a definite interaction due to cultivars, applied nitrogen and environment on the number of panicles, filled grains and sterility percentage (Table 17). The HN application brought about a highly significant 2.5 fold increase in the number of panicles of cv GR 3. Under NN application it was 3.5 fold over the control. The plants grown near the fertilizer factory exhibited a sharp reduction in the number

Table : 17 Interaction of cultivars and applied nitrogen on the mean and yield and yield attributes of rice grown near (P) or 10 km distance (C), from a fertilizer plant.

Nitrogen regimes	Cultivar	Panicles number/plant^{-1}		Filled grains number/plant^{-1}		Sterility Index (%)		Economic yield g/plant^{-1}		Biological yield g/plant^{-1}		Harvest Index	
		C	P	C	P	C	P	C	P	C	P	C	P
Normal	CO 43	2.5	2.7	104.0	2.5**	41.5	99.0**	1.46	0.04**	4.77	6.61	0.315	0.010**
	GR 3	2.7	9.5**	87.4	177.2**	38.3	56.9*	1.40	2.48**	4.31	8.23**	0.315	0.295
	TKM 9	3.1	4.3	106.6	63.0*	30.4	62.2*	1.59	1.23	4.35	4.40	0.375	0.220*
High	CO 43	2.3	3.3	103.3	8.8**	45.8	96.3**	1.32	0.10**	4.39	7.02**	0.295	0.015**
	GR 3	3.6	10.3**	56.3	192.7**	57.8	51.0	0.84	2.85**	3.81	8.63**	0.215	0.330*
	TKM 9	3.7	4.5	81.0	46.0	50.6	66.9*	1.34	0.74*	4.43	3.37	0.290	0.237

Levels of significance : at 5 % (*) and 1 % (**) analysed separately for each parameter. Each value is the mean of 10 replicates.

of filled grains in cv CO 43 under both N levels and in cv TKM 9 under NN, whereas it was significantly increased in cv GR 3 at both N levels. The polluted environment rendered in an increased sterility index of cv CO 43 and it was significant in cv TKM 9. Though cv GR 3 also experienced a significant sterility index under NN, it was insignificant under HN. The interaction of cultivar, nitrogen and environment also brought a sharp reduction in the economic yield of cv CO 43 and tremendous increase in cv GR 3, near the factory. Only the cv GR 3 appeared to increase the economic yield due to HN application under the polluted environment. The HN applied plants of cvs CO 43 and GR 3 produced a higher amount of biological yield than the control. Due to the decrease in the economic yield the cv CO 43 showed a significant reduction in its harvest index in the polluted site. The cv TKM 9 also experienced a reduction under NN. Interestingly, only cv GR 3 under HN application showed a significant increase in the harvest index of plants grown near the factory.

(iii) Interaction due to Cultivar, Water and Environment (C x W x E)

The interaction of soil water status, cultivar and polluted environment regardless of the soil N regime led a remarkable increase in the number of panicles in cv GR 3 (Table 18). The cv TKM 9 showed a higher number of panicles in the normal watered than the water stressed conditions. Under both water levels the cv CO 43 showed a significant reduction in the number of filled grains and the reduction was only registered under water stress in the case of cv TKM 9. Conversely, the cv GR 3 showed an increased number of filled grains under both water levels in the polluted conditions. However, the water stress alone did not bring any increase when compared to the plants

Table : 18 Interaction of water and cultivar on the mean and yield and yield attributes of rice grown near (P) or 10 km distance (C), from a fertilizer plant.

Watering regimes	Cultivar	Panicles number/plant^{-1}		Filled grains number/plant^{-1}		Sterility Index (%)		Economic yield g/plant^{-1}		Biological yield g/plant		Harvest Index	
		C	P	C	P	C	P	C	P	C	P	C	P
Field Capacity	CO 43	2.8	3.9	129.0	9.5**	36.9	95.9**	1.45	0.04**	5.20	6.55	0.335	0.015**
	GR 3	3.5	11.4**	83.1	201.3**	46.4	57.9	1.40	2.48**	4.51	9.43**	0.275	0.320
	TKM 9	3.6	5.5*	89.0	75.0	39.1	62.1**	1.59	1.23	4.35	4.40	0.295	0.235
50 % Field Capacity	CO 43	2.0	2.1	78.3	1.8**	50.4	99.4**	1.32	0.10**	3.96	7.08**	0.275	0.010**
	GR 3	2.8	8.4**	60.6	168.6**	49.7	50.0	0.84	2.85**	3.61	7.43**	0.255	0.305
	TKM 9	3.2	3.3	98.6	34.0**	41.9	67.0**	1.34	0.74*	4.43	3.37	0.370	0.222*

Levels of significance : at 5 % (*) and 1 % (**) analysed separately. Each value is the mean of 10 replicates.

grown in the normal watered conditions. It was also evident that there was no benefit by the water stress to the cvs CO 43 and TKM 9 in the polluted environment, as shown by the sterility index. Nevertheless, the cv GR 3 experienced no disparity between the control and polluted environment in the sterility index. A significant increase in the biological yield of cv CO 43 under 50% water stress became ineffective by the decreased economic yield, in the plants grown near the factory. The cv TKM 9 showed a significant reduction in its economic yield and harvest index under 50% water stress, in the polluted condition. The interaction of the cv GR 3 with water and environment rendered in the production of a high amount of economic and biological yields under both water levels in the polluted environment. Nevertheless, there was no corresponding increase in the harvest index.

3.1.2.0 Physiological and Biochemical Studies

3.1.2.1 Pigments

A higher amount of Chl 'a', Chl 'b' and total Chl content was evident in all the cultivars under the polluted environment than the control at the age of 47 days (Table 19). The percentage of increase in the Chl 'a' content was greater in the cv TKM 9 followed by GR 3 and CO 43 than the controls under both N levels. WN-HN regimed 87 day old plants of cv GR 3 also showed an enhanced Chl 'a' content in the polluted conditions. However, there were reductions in cv CO 43 in 87 days. The amount of Chl 'b' was found to be more by 47 and 73% in cvs GR 3 and TKM 9 under WN-NN and it was 19, 79 and 48% under WN-HN regime of cvs CO 43, GR 3 and TKM 9 respectively, than the control at

Table : 19 Effects of air pollution on the chlorophyll contents (mg/g fresh leaves) of rice cvs CO 43, GR 3 and TKM 9 under two applied nitrogen levels.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
						Chlorophyll 'a'						
47	3.40	4.54	2.50	3.54	2.35	5.01	3.69	4.99	2.18	3.23	3.01	5.05
	(0.10)	(0.11)	(0.09)	(0.10)	(0.06)	(0.18)	(0.11)	(0.10)	(0.07)	(0.12)	(0.11)	(0.17)
87	0.57	0.47	0.74	0.66	0.82	0.75	0.63	0.54	0.90	1.08	0.74	0.83
	(0.03)	(0.02)	(0.03)	(0.03)	(0.03)	(0.07)	(0.04)	(0.03)	(0.02)	(0.02)	(0.07)	(0.06)
						Chlorophyll 'b'						
47	2.70	2.70	1.44	2.11	1.06	2.89	2.49	2.97	1.29	2.31	1.70	2.52
	(0.08)	(0.09)	(0.05)	(0.08)	(0.06)	(0.09)	(0.08)	(0.09)	(0.04)	(0.06)	(0.04)	(0.08)
87	0.52	0.21	0.39	0.60	0.78	0.63	0.57	0.47	0.86	0.99	0.75	0.77
	(0.02)	(0.02)	(0.02)	(0.03)	(0.06)	(0.05)	(0.04)	(0.02)	(0.03)	(0.03)	(0.04)	(0.05)
						Total Chlorophyll						
47	5.48	7.25	3.95	5.65	3.41	7.89	6.19	7.97	3.48	5.54	4.70	7.57
	(0.17)	(0.20)	(0.14)	(0.18)	(0.12)	(0.27)	(0.19)	(0.19)	(0.11)	(0.18)	(0.15)	(0.25)
87	1.09	0.68	1.11	1.26	1.61	1.38	1.21	1.01	1.76	2.07	1.48	1.60
	(0.05)	(0.03)	(0.03)	(0.05)	(0.09)	(0.12)	(0.08)	(0.05)	(0.05)	(0.05)	(0.11)	(0.11)

C= control, P = polluted; values in parentheses represent SE of three replicates.

Table : 20 Effects of air pollution on the chlorophyll contents (mg/g fresh leaves) of rice cvs CO 43, GR 3 and TKM 9 under 50 % water stress with two N levels.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Chlorophyll 'a'												
47	2.95	4.23	2.50	3.38	3.28	4.54	3.77	3.80	2.73	4.02	3.22	3.97
	(0.11)	(0.16)	(0.08)	(0.10)	(0.12)	(0.13)	(0.13)	(0.12)	(0.10)	(0.13)	(0.08)	(0.10)
87	0.66	0.60	0.85	1.00	0.87	0.76	0.80	0.69	0.87	0.81	0.97	0.77
	(0.04)	(0.03)	(0.05)	(0.09)	(0.07)	(0.07)	(0.05)	(0.04)	(0.05)	(0.06)	(0.08)	(0.08)
Chlorophyll 'b'												
47	1.81	2.91	1.45	2.26	1.86	2.70	2.08	2.88	1.97	2.19	1.53	2.57
	(0.06)	(0.12)	(0.04)	(0.08)	(0.07)	(0.11)	(0.14)	(0.12)	(0.09)	(0.08)	(0.05)	(0.07)
87	0.55	0.51	0.79	0.84	0.81	0.71	0.74	0.59	0.81	0.69	0.89	0.72
	(0.03)	(0.03)	(0.02)	(0.02)	(0.05)	(0.03)	(0.04)	(0.04)	(0.05)	(0.07)	(0.04)	(0.04)
Total Chlorophyll												
47	4.75	7.14	3.95	5.64	5.14	7.25	5.48	6.72	4.70	6.22	4.75	6.54
	(0.17)	(0.28)	(0.12)	(0.18)	(0.19)	(0.24)	(0.27)	(0.24)	(0.19)	(0.21)	(0.13)	(0.17)
87	1.21	1.11	1.65	1.83	1.68	1.47	1.54	1.28	1.69	1.50	1.66	1.49
	(0.07)	(0.06)	(0.07)	(0.10)	(0.12)	(0.05)	(0.09)	(0.08)	(0.10)	(0.13)	(0.12)	(0.12)

C = control; P = polluted; values in parentheses represent SE of three replicates.

47 days. However, at the age of 87 days, only cv GR 3 showed a consistently increased Chl 'b' at the polluted environment, whereas in cvs CO 43 and TKM 9 the leaf Chl 'b' was sharply reduced by 60 and 20% respectively, under NN. The cv GR 3 showed a marginal increase in the amount of Chl 'b' under WN-HN regime in the test site. The content of total Chlorophyll also had a corresponding increase with the Chl 'a' and Chl 'b' in the polluted site, on 47 days. However, at the age of 87 days there were reductions in the total Chl contents of cvs CO 43 and TKM 9 under NN regime, whereas cv GR 3 had an increase of 13% in the polluted environment over the control. At the same age cvs GR 3 and TKM 9 were not affected under WN-HN, while the content of cv CO 43 was reduced by 17% when compared to the control. The ratios of Chl 'a'/Chl 'b' was found to be generally a marginal increase in the polluted plants.

The plants grown under 50% water stress in addition to two N regimes also showed a generally high amount of Chl 'a', Chl 'b' and total Chl contents in the polluted environment at 47 days (Table 20). WS-HN regimed plants of cv GR 3 also showed enhancement in the Chl 'a' content in the polluted conditions, while other two cultivars experienced a modest reduction in the content. The content of Chl 'b' was increased by 61, 57 and 45% in water stressed NN regime and 38, 11 and 68% under WS-HN regime of cvs CO 43, GR 3 and TKM 9 respectively. The cv GR 3 showed a marginal increase in the amount of Chl 'b' under air pollution in the WS-NN regime at 87 days. Nevertheless, others at 87 days experienced only diminution. Under the imposition of water stress the percentage of increase in the total Chl was higher in the NN regime than the HN regime of all the 3 cultivars. At the age of 87 days cv TKM 9 under NN and cv CO 43 under HN regimes showed decreased total Chl content while cv GR 3 showed

an increased content under NN, in the polluted condition. There was not much disparity between the control and test site plants, in their Chl 'a'/Chl 'b' ratio.

3.1.2.1aAscorbic Acid

It was interesting to note that most of the 42 day old plants were maintained a high amount of endogenous ascorbic acid content in the polluted environment when compared to the control (Table 21). The increase was 120 and 144 % in cvs GR 3 and TKM 9 under WN-NN regime and 90, 76 and 18% in cvs. CO 43, GR 3 and TKM 9 under HN respectively, over the control. However under WS-NN regime cvs CO 43 and GR 3 were found to accumulate 54 and 26 % higher amount than the control, and it was reduced by 13% in the cv TKM 9. On the other hand WS-HN showed high level of ascorbic acid content in all the cultivars with increase of 58, 38 and 10 % accordingly. At the age of 78 days the cv GR 3 maintained a high percentage of ascorbic acid over the control in all the regimes of polluted site plants. The cv CO 43 also showed same pattern of increase except WS-HN, where a 15% reduction was recorded.

3.1.2.1 b Free Amino acids

Air pollution exposure to rice cultivar CO 43 brought about an increase in the amount of free amino acids in their leaves at all the stages of growth when compared to the control (Table 22). The increase was marginal under WN-NN, modest under WN-HN, and it was further increased under water stress at both N regimes. However, at the early stages, cvs GR 3 and TKM 9 showed little reduction over the control under normal watered conditions and were able

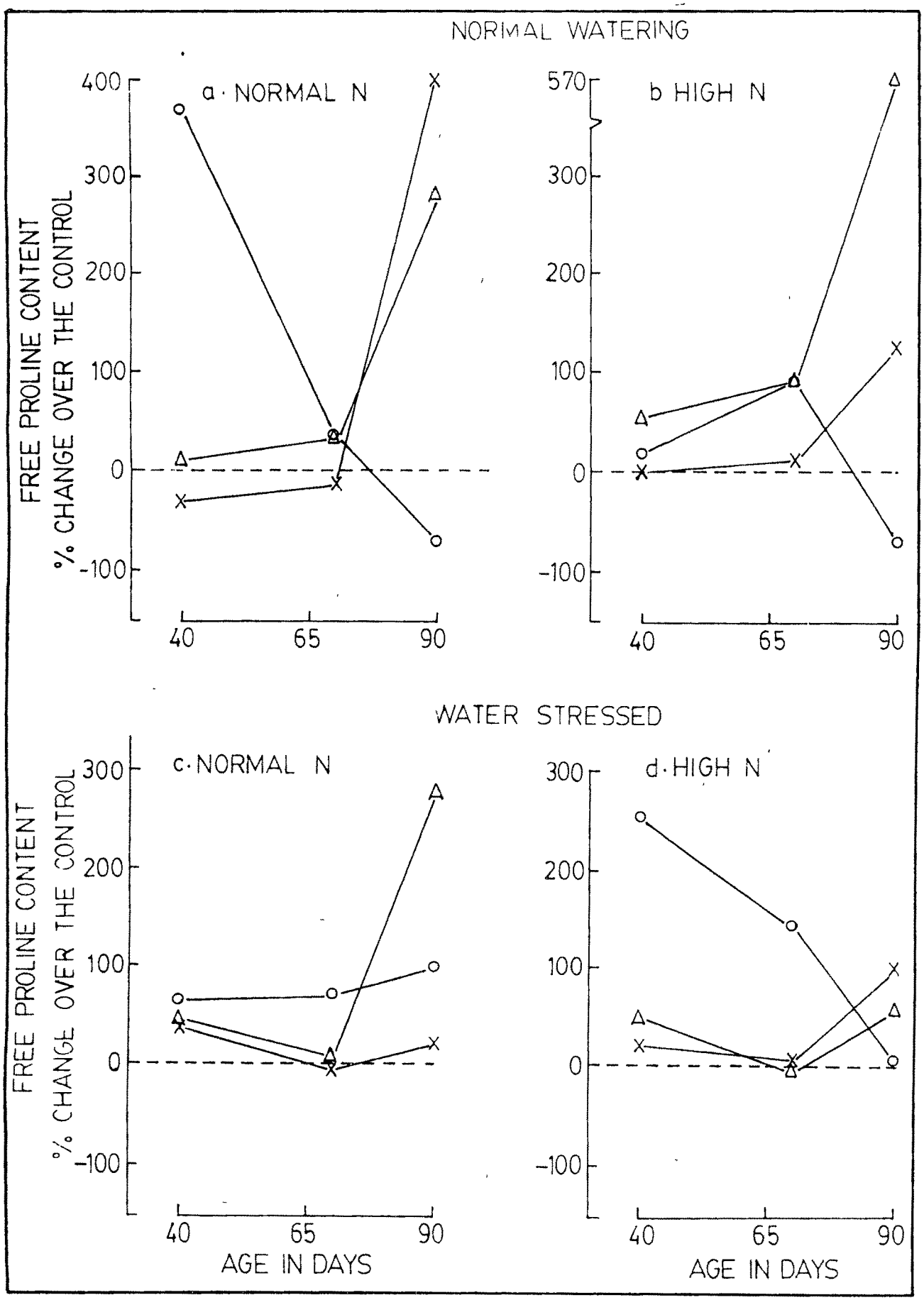

NORMAL WATERING
a · NORMAL N
b HIGH N
WATER STRESSED
c · NORMAL N
d · HIGH N
FREE PROLINE CONTENT
% CHANGE OVER THE CONTROL
400
300
200
100
0
-100
570
40
65
90
AGE IN DAYS

Table : 21 The changes in the ascorbic acid content (mg/g fresh leaves) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P) and distant from (C) a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
42	0.56	0.59	0.36	0.79	0.27	0.66	0.41	0.77	0.56	0.98	0.58	0.68
	(0.02)	(0.03)	(0.02)	(0.06)	(0.02)	(0.05)	(0.02)	(0.07)	(0.03)	(0.07)	(0.04)	(0.04)
78	0.15	0.21	0.15	0.24	0.16	0.17	0.18	0.23	0.17	0.25	0.14	0.19
	(0.01)	(0.03)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)	(0.01)
Water stressed												
42	0.58	0.89	0.52	0.66	0.77	0.68	0.40	0.62	0.58	0.79	0.48	0.53
	(0.04)	(0.08)	(0.04)	(0.05)	(0.04)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)
78	0.26	0.33	0.08	0.18	0.18	0.17	0.27	0.23	0.16	0.21	0.15	0.18
	(0.02)	(0.03)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)

Values in parentheses represent SE of three replicates.

Table : 22 The changes in the free amino acids content (mg/g fresh weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days.	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
40	2.65	2.75	3.60	3.50	4.05	3.75	3.60	3.95	3.50	2.75	3.40	2.00
	(0.10)	(0.09)	(0.10)	(0.09)	(0.15)	(0.14)	(0.15)	(0.15)	(0.17)	(0.08)	(0.11)	(0.08)
70	2.80	3.40	4.00	4.80	3.50	3.20	3.20	4.40	4.80	4.80	3.80	4.80
	(0.05)	(0.07)	(0.11)	(0.09)	(0.14)	(0.09)	(0.08)	(0.12)	(0.15)	(0.17)	(0.17)	(0.15)
90	5.70	6.80	4.20	5.70	6.80	6.80	3.50	6.10	6.80	8.10	5.30	5.90
	(0.09)	(0.12)	(0.12)	(0.13)	(0.15)	(0.14)	(0.15)	(0.19)	(0.12)	(0.17)	(0.14)	(0.18)
Water stressed												
40	2.75	4.95	2.75	3.60	5.05	5.70	2.75	4.05	2.40	4.85	4.95	5.20
	(0.09)	(0.18)	(0.09)	(0.11)	(0.14)	(0.12)	(0.09)	(0.18)	(0.12)	(0.22)	(0.15)	(0.18)
70	2.40	3.20	3.70	4.20	2.80	3.40	2.70	7.20	3.60	5.00	4.20	5.50
	(0.09)	(0.12)	(0.10)	(0.12)	(0.10)	(0.11)	(0.09)	(0.26)	(0.10)	(0.16)	(0.10)	(0.13)
90	4.80	6.40	5.30	6.10	4.80	5.50	5.70	8.10	8.10	6.40	5.50	5.00
	(0.14)	(0.18)	(0.12)	(0.14)	(0.09)	(0.11)	(0.18)	(0.24)	(0.28)	(0.18)	(0.12)	(0.11)

Values in parentheses represent SE of three replicates.

to maintain high levels of free amino acids at the polluted environment. Under WS-NN conditions all the cultivars were able to maintain a marginally high amount of free amino acids in the polluted test site. The percentage of increase was found to be high in CO 43 by 33 to 80. Under WS-HN, cv CO 43 accumulated a large amount by 42 and 167 % over the control. Though cv GR 3 showed 102 % increase over the control at 40 days, it experienced a reduction of lesser magnitude at 90 days. The cv TKM 9 showed more or less the same pattern of accumulation as observed in cv GR 3.

3.1.2.1 c Free Proline

At all the stages of growth under normal watered conditions, cv GR 3 was able to maintain a high amount of free proline in the leaves at both N regimes at the test site (Table 23). Interestingly, at 90 days, the increase was 2.8 fold under NN and 5.7 fold under HN over the control, whereas in cv CO 43 the endogenous levels of proline in the leaves registered a drastic reduction under both NN and HN regimes. Further, it was interesting to note that at early stages the per cent change over the control was high in the cv CO 43 under normal watering and it decreased in the later stages of growth under the polluted environment (Fig. 11). It was **vice versa** in the case of TKM 9 cultivar. Under water stress the percentage of increase over the control was much higher in HN regimed plants than in the NN regimed cv CO 43. The cv GR 3 was able to maintain a level high almost 2.8 fold over the control under WS-NN regime at 90 days. There was no consistent increase under WS-HN in all the three cultivars in the polluted environment upto 70 days of growth. The cv TKM 9 showed 39 and 21 % increase in the amount at 40 days and 22 and 100% at 90 days under WS-NN and WS-HN respectively.

Table : 23 The changes in the free proline content (μ moles/g fresh weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
40	0.95	4.48	2.35	2.58	3.38	2.38	3.10	3.28	1.90	2.95	4.43	4.43
	(0.05)	(0.12)	(0.08)	(0.05)	(0.12)	(0.07)	(0.05)	(0.07)	(0.08)	(0.07)	(0.05)	(0.07)
70	2.30	3.20	2.90	3.75	5.35	4.55	1.90	3.65	2.40	4.65	3.40	3.75
	(0.06)	(0.08)	(0.08)	(0.07)	(0.10)	(0.07)	(0.12)	(0.12)	(0.10)	(0.12)	(0.08)	(0.07)
90	2.50	0.75	0.30	1.15	0.40	2.00	3.65	1.20	1.05	7.05	1.20	3.90
	(0.07)	(0.04)	(0.05)	(0.07)	(0.05)	(0.07)	(0.10)	(0.06)	(0.05)	(0.21)	(0.07)	(0.10)
Water stressed												
40	2.60	4.28	1.70	2.50	2.28	3.18	1.70	6.00	2.20	3.28	3.13	3.78
	(0.04)	(0.08)	(0.03)	(0.05)	(0.04)	(0.06)	(0.04)	(0.28)	(0.08)	(0.06)	(0.07)	(0.09)
70	1.60	2.70	3.00	3.20	5.85	5.75	0.90	2.20	4.65	4.00	4.45	4.75
	(0.08)	(0.05)	(0.06)	(0.04)	(0.08)	(0.07)	(0.12)	(0.08)	(0.15)	(0.07)	(0.11)	(0.12)
90	0.40	0.80	0.80	3.00	0.90	1.10	1.40	1.50	1.70	2.60	0.80	1.60
	(0.03)	(0.04)	(0.05)	(0.12)	(0.03)	(0.04)	(0.10)	(0.10)	(0.08)	(0.09)	(0.06)	(0.05)

Values in parentheses represent SE of three replicates.

3.1.2.1 d Proteins

Forty five-day old plants of all the cultivars were able to accumulate greater amount of total and insoluble protein their leaves than the controls (Table 24). The percentage of increase in the total protein content over the control was much higher in NN regimed plants than HN regimed plants of all the cultivars in the test site. The enhancement in the insoluble protein content was greater in cv GR 3 under NN, and it was much higher in the HN regimed plants than the other two cultivars grown in the test site. Under NN conditions the soluble protein was found to be increased enormously in all the cultivars under the polluted environment at 45 days. The increase was 2.2, 1.4 and 4 fold in cvs CO 43, GR 3 and TKM 9 respectively. However, under HN regimes an increase was noted only in cv TKM 9. At the age of 90 days, a remarkable increase in the soluble protein of CO 43 under NN and HN rendered an increase in the amount of total protein to the pollution exposure. However, a modest reduction in the soluble protein content of cv GR 3 at 90 days was marked by an increase in the insoluble protein at both N levels, thereby minimising the reduction in the total protein content. On the other hand, cv TKM 9 was found to reduce its soluble protein under HN regime ultimately bringing about a reduction in the amount of total protein.

Imposition of water stress in addition to nitrogen regimes also influenced an increase in the total and insoluble protein content of all the cultivars at 45 days in the polluted environment (Table 25). The increase in the total protein content was greater under NN than under HN regimes of cvs GR 3 and TKM 9. The content of the insoluble protein appeared to be increased notably in cv

Table : 24 The changes in the protein contents (mg/g fresh leaves) of rice cvs CO 43, GR 3 and TKM 9 under two N levels when grown near to (P), and distant from (C), a fertilizer plant.

Protein	Age in days	Normal - N						High - N					
		CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
		C	P	C	P	C	P	C	P	C	P	C	P
Total	45	19.5 (1.1)	35.5 (1.6)	20.0 (0.9)	36.5 (1.9)	18.5 (1.0)	39.5 (2.1)	30.0 (1.6)	32.0 (1.6)	21.0 (1.4)	36.5 (2.4)	21.0 (1.4)	34.5 (1.7)
	90	21.0 (1.0)	24.0 (1.1)	34.5 (2.1)	33.5 (1.4)	29.5 (1.4)	25.0 (1.3)	20.0 (1.2)	30.5 (1.9)	43.5 (2.7)	36.5 (2.1)	38.5 (1.6)	32.5 (1.3)
Insoluble	45	15.0 (0.9)	21.0 (1.1)	13.5 (0.5)	21.0 (1.1)	14.5 (0.8)	20.0 (1.2)	14.0 (0.9)	17.0 (1.0)	14.0 (0.8)	30.5 (1.9)	14.0 (0.9)	23.0 (1.1)
	90	17.0 (0.8)	15.0 (0.8)	11.8 (0.7)	17.0 (0.7)	13.0 (0.5)	16.0 (0.8)	11.0 (0.6)	12.0 (0.6)	23.0 (1.2)	27.5 (1.5)	24.0 (1.3)	23.0 (0.9)
Soluble	45	4.5 (0.2)	14.5 (0.5)	6.5 (0.4)	15.5 (0.8)	4.0 (0.2)	19.5 (0.8)	16.0 (0.6)	15.0 (0.6)	7.0 (0.6)	6.0 (0.4)	7.0 (0.5)	11.5 (0.4)
	90	4.0 (0.2)	9.0 (0.3)	22.7 (1.4)	16.5 (0.7)	16.5 (0.9)	9.0 (0.5)	9.0 (0.6)	18.5 (1.3)	20.5 (1.5)	9.0 (0.5)	14.5 (0.3)	9.5 (0.4)

Values in parentheses represent SE of three replicates.

Table : 25 The changes in the protein contents (mg/g fresh leaves) of rice cvs CO 43, GR 3 and TKM 9 under two N levels with 50 % water stress when grown near to (P), and distant from (C), a fertilizer plant.

Protein	Age in Days	Normal - N						High - N					
		CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
		C	P	C	P	C	P	C	P	C	P	C	P
Total	45	17.0 (0.9)	27.5 (2.2)	18.0 (0.8)	39.5 (2.2)	22.0 (0.9)	36.5 (1.6)	24.0 (1.3)	45.5 (3.2)	20.5 (1.2)	24.0 (1.6)	19.5 (1.0)	29.0 (1.6)
	90	31.5 (1.4)	26.0 (1.3)	43.5 (1.6)	41.5 (1.9)	38.5 (1.6)	30.0 (1.4)	29.5 (1.7)	32.5 (2.0)	45.5 (3.2)	40.5 (2.4)	51.5 (2.6)	47.5 (2.2)
Insoluble	45	11.0 (0.5)	16.0 (1.9)	11.5 (0.5)	28.0 (1.9)	15.0 (0.6)	22.3 (0.9)	14.0 (0.6)	26.0 (1.9)	15.0 (0.9)	23.3 (1.3)	15.5 (0.8)	18.0 (0.9)
	90	20.0 (0.9)	15.0 (0.9)	33.5 (1.3)	27.5 (1.4)	32.0 (1.3)	18.0 (0.7)	20.0 (1.0)	18.0 (0.9)	34.5 (2.4)	26.5 (1.6)	34.5 (1.7)	36.0 (1.6)
Soluble	45	6.0 (0.4)	11.5 (0.3)	6.5 (0.3)	11.5 (0.3)	7.0 (0.3)	14.3 (0.9)	10.0 (0.7)	19.5 (1.3)	5.5 (0.3)	0.8 (0.3)	4.0 (0.2)	11.5 (0.7)
	90	11.5 (0.5)	11.0 (0.4)	10.0 (0.3)	14.0 (0.5)	6.5 (0.3)	12.0 (0.7)	9.5 (0.7)	14.5 (1.1)	11.0 (0.8)	14.0 (0.8)	17.0 (0.9)	11.5 (0.6)

Values in parentheses represent SE of three replicates.

Table : 26 The changes in the gross DNA content (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	5.00 (0.17)	4.50 (0.15)	4.00 (0.15)	4.25 (0.07)	5.00 (0.22)	5.38 (0.10)	4.38 (0.22)	5.13 (0.25)	5.75 (0.27)	4.88 (0.22)	4.75 (0.21)	5.25 (0.17)
70	5.25 (0.12)	5.00 (0.09)	5.50 (0.12)	5.90 (0.17)	4.75 (0.37)	5.75 (0.22)	4.00 (0.17)	6.00 (0.30)	4.75 (0.25)	5.38 (0.28)	5.50 (0.37)	7.13 (0.41)
85	3.50 (0.14)	3.25 (0.07)	3.50 (0.20)	3.00 (0.15)	3.25 (0.15)	3.50 (0.09)	3.63 (0.17)	3.50 (0.15)	3.50 (0.25)	3.13 (0.17)	3.25 (0.27)	3.38 (0.23)
Water stressed												
55	4.63 (0.28)	5.25 (0.21)	4.50 (0.20)	5.38 (0.32)	5.88 (0.21)	5.13 (0.11)	4.00 (0.17)	5.75 (0.29)	4.50 (0.15)	4.88 (0.28)	4.88 (0.21)	5.00 (0.24)
70	6.50 (0.30)	4.75 (0.09)	4.88 (0.21)	4.75 (0.19)	6.38 (0.17)	6.00 (0.13)	4.75 (0.12)	4.63 (0.28)	5.75 (0.37)	5.75 (0.25)	5.50 (0.40)	6.75 (0.57)
85	3.63 (0.07)	3.38 (0.15)	3.25 (0.18)	3.38 (0.17)	3.50 (0.11)	3.13 (0.10)	3.13 (0.20)	2.88 (0.25)	3.38 (0.29)	3.13 (0.28)	3.00 (0.20)	2.50 (0.22)

Values in parentheses represent SE of three replicates.

Table : 27 The changes in the gross RNA content (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	6.38 (0.32)	7.75 (0.47)	7.75 (0.37)	7.75 (0.31)	8.63 (0.40)	8.38 (0.37)	9.75 (0.81)	6.75 (0.55)	8.13 (0.42)	6.50 (0.17)	6.50 (0.37)	8.50 (0.52)
70	9.75 (0.51)	8.81 (0.56)	7.88 (0.55)	8.63 (0.42)	11.63 (1.20)	6.00 (0.60)	9.38 (0.75)	6.94 (0.60)	8.25 (0.37)	8.64 (0.25)	12.75 (1.30)	8.81 (0.71)
85	4.38 (0.37)	4.00 (0.35)	3.81 (0.25)	5.19 (0.43)	5.13 (0.47)	4.06 (0.32)	5.19 (0.42)	4.50 (0.17)	4.38 (0.25)	5.31 (0.35)	5.19 (0.37)	4.88 (0.35)
Water stressed												
55	9.63 (0.67)	9.25 (0.41)	6.88 (0.40)	6.50 (0.45)	9.50 (0.62)	8.75 (0.25)	6.75 (0.47)	8.13 (0.41)	8.63 (0.47)	5.63 (0.27)	8.75 (0.57)	9.50 (0.40)
70	8.25 (0.40)	7.50 (0.42)	7.88 (0.52)	9.75 (0.67)	10.13 (0.80)	10.50 (0.55)	7.68 (0.52)	6.20 (0.90)	10.13 (0.58)	6.00 (0.62)	9.75 (0.53)	6.38 (0.53)
85	4.81 (0.21)	4.75 (0.22)	4.50 (0.27)	4.25 (0.25)	4.88 (0.27)	4.31 (0.25)	4.81 (0.28)	3.25 (0.27)	4.25 (0.23)	4.69 (0.11)	4.57 (0.37)	3.67 (0.28)

Values in parentheses represent SE of three replicates.

old test site plants (Table 27). However, both cultivars showed only a reduction at both N levels, at later stages to varying extent. On the other hand, cv GR 3 which showed either reduction or no difference at 55 days, was able to maintain marginally high amount of RNA content at 70 and 85 days of growth at both N levels, when compared to the control. Under water stressed condition also more or less same pattern was observed in all the cultivars.

3.1.2.1 g Total QAC

The water soluble quaternary ammonium compounds (QAC) were found to be increased in all the cultivars in the polluted environment (Table 28). The percentage of increase was greater in the cvs CO 43, followed by GR 3 and TKM 9 at different stages of growth under WN-NN conditions. Under WN-HN regime cv CO 43 accumulated the same or higher amount of QAC at different stages of growth than the plants under WN-NN. The high nitrogen alone was capable of increasing the QAC content in the cv CO 43. The cvs GR 3 and TKM 9 were able to maintain a higher level of QAC than the cv CO 43 regardless of the site of growth under WN conditions. It was interesting to note that under water stress cv CO 43 had consistently accumulated a higher amount of QAC contents than the normal watered plants. This was true in plants at the polluted site particularly at later growth stage. The high endogenous level that was prevalent in the plants of cvs GR 3 and TKM 9 did not increase further as response to pollution. High N regime did not influence QAC content under water stress.

Table : 28 The changes in the amount of total quaternary ammonium compounds (μ moles/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	2.34 (0.10)	3.64 (0.14)	5.57 (0.12)	6.32 (0.14)	5.36 (0.12)	6.16 (0.15)	2.83 (0.08)	3.59 (0.10)	6.07 (0.13)	5.64 (0.10)	5.91 (0.11)	6.23 (0.14)
70	2.74 (0.12)	4.09 (0.16)	6.26 (0.10)	6.99 (0.14)	6.42 (0.18)	6.61 (0.17)	3.59 (0.09)	4.38 (0.11)	6.53 (0.14)	7.35 (0.13)	6.63 (0.19)	7.33 (0.13)
85	3.82 (0.12)	5.33 (0.13)	6.34 (0.13)	7.53 (0.16)	7.71 (0.14)	8.94 (0.13)	6.88 (0.13)	7.80 (0.11)	8.25 (0.11)	8.98 (0.14)	6.85 (0.13)	9.11 (0.16)
Water stressed												
55	3.25 (0.09)	4.22 (0.11)	4.64 (0.12)	5.76 (0.18)	5.13 (0.11)	5.70 (0.10)	3.75 (0.12)	5.20 (0.14)	4.24 (0.10)	4.91 (0.13)	5.13 (0.14)	5.70 (0.13)
70	4.22 (0.11)	4.94 (0.13)	6.01 (0.16)	6.26 (0.14)	5.17 (0.12)	6.92 (0.19)	5.97 (0.13)	6.00 (0.16)	4.36 (0.11)	5.35 (0.10)	5.17 (0.10)	6.92 (0.15)
85	7.24 (0.14)	8.77 (0.15)	7.86 (0.14)	8.40 (0.17)	6.24 (0.11)	7.83 (0.15)	6.38 (0.19)	7.18 (0.15)	8.19 (0.13)	8.19 (0.15)	6.24 (0.13)	7.84 (0.17)

Values in parentheses represent SE of three replicates.

3.1.2.1 h Total Nitrogen

The rice cv CO 43 experienced a marginal reduction in the total nitrogen content in its shoot portions at three different growth stages studied, while cv GR 3 mostly showed a marginal increase and cv TKM 9 found to have no difference at the polluted environment, over their control under WN-NN regime (Table 29). Under high N cv GR 3 was able to maintain a higher level of total nitrogen than the control at all the harvested stages. Though the cv CO 43 experienced a marginal increase at 55 and 70 days, there was no difference at 85 days, while cv TKM 9 which depicted a modest reduction at 55 and 70 days showed an increment in their shoot nitrogen content at the final harvest. In fifty five day old WS-NN plants of cvs CO 43 and GR 3 showed a marginal increase in the total nitrogen content in the shoot portions while cv TKM 9 experienced a reduction at the polluted environment. On 70 and 85 days the cv GR 3 alone was showing an increase. Under WS-HN regimes the total nitrogen of the test site plants registered a sharp reduction in the cvs CO 43 and TKM 9 at the age of 55 days, and an increase of 11% over the control in cv GR 3. There was not much difference between the control and test site plants in the accumulation of total nitrogen at the final harvest in all the water stressed cultivars.

3.1.2.2 Activities of Enymes

The air pollution had promoted the activity of peroxidase in the cvs GR 3 and TKM 9 (Table 30). The percentage of increase was higher under WN-NN than the WN-HN. However, in cv CO 43 the activity was found to be inhibited under both N levels. In contrast, under water stressed condition all the culitvars

Table : 29 The changes in the amount of total nitrogen (mg/g dry shoot) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	38.0 (1.5)	37.5 (1.4)	31.3 (1.1)	36.3 (1.2)	42.5 (1.7)	43.8 (1.5)	40.0 (1.7)	43.8 (1.4)	34.7 (1.2)	39.8 (1.1)	33.8 (1.9)	27.5 (1.7)
70	37.8 (1.2)	34.2 (0.9)	38.3 (1.0)	41.8 (1.2)	32.7 (1.9)	37.5 (1.7)	38.5 (1.2)	41.5 (1.3)	37.5 (0.9)	40.0 (1.1)	45.0 (1.8)	37.5 (1.3)
85	38.5 (1.1)	31.3 (1.0)	35.0 (0.9)	38.3 (0.9)	36.3 (1.8)	37.5 (1.7)	42.5 (1.0)	40.0 (1.5)	37.5 (0.8)	41.3 (1.2)	40.0 (1.9)	46.3 (2.7)
Water stressed												
55	32.0 (1.4)	36.0 (1.2)	27.5 (0.9)	30.0 (1.2)	41.3 (1.1)	36.3 (1.2)	37.5 (1.9)	21.8 (1.8)	41.3 (1.2)	46.3 (1.7)	40.0 (3.2)	23.2 (2.4)
70	37.5 (1.9)	37.5 (2.2)	38.8 (1.0)	42.5 (1.1)	37.5 (1.0)	35.0 (1.0)	41.3 (1.7)	38.8 (1.2)	37.5 (1.0)	40.0 (2.0)	40.2 (2.2)	41.3 (3.4)
85	32.5 (1.0)	33.3 (1.3)	36.3 (1.1)	42.5 (1.2)	35.5 (0.9)	36.0 (1.1)	32.5 (2.1)	32.8 (2.7)	41.4 (2.1)	40.0 (1.9)	40.5 (1.7)	37.5 (1.5)

Values in parentheses represent SE of three replicates.

showed a modest increase in the polluted environment under NN as well as high N regimes, when compared to the controls. The activity of polyphenol oxidase was appeared to be significantly promoted in cvs CO 43 and TKM 9 under WN-NN where as it was sharply demoted in cv GR 3 as a response to air pollution. Conversely, under WN-HN regime in cv GR 3 the leaf polyphenol oxidase activity was enormously increased while in other cultivars it showed a moderate increase in the activity. However, under the regime WS-NN, all the cultivars exhibited a remarkably accelerated activity of the above enzyme in the polluted environment over the respective control. Nevertheless, under high N the activity of the enzyme was found to be comparatively inhibited in the polluted environment. A sharp reduction in the activity of acid phosphatase under WN-NN was found to be minimised in the cv GR 3 under WN-HN. On the other hand, cv CO 43 showed a notable reduction under all the regimes except under WS-HN where it showed a modestly increased activity. The cultivar TKM 9 under NN, regardless of the water regimes typically showed an increase in the activity of acid phosphatase, whereas under high N there was a decrease in the plants grown under polluted environment when compared to the control.

The activity of enzymes-amylase, invertase and phosphorylase from the leaves of 55 day old plants are given in Table 31. The amylase activity was found to be accelerated in all the cultivars under WN-NN and WS-HN there was an increase in the amylase activity only in cv GR 3, while the cvs CO 43 and TKM 9 experienced an inhibition in the enzyme activity. Under WS-NN cv GR 3 suffered a reduction in its amylase activity, whereas cvs CO 43 and TKM 9 were depicted an increased activity in the test site when compared to the controls. The activity of invertase was found to be promoted in the cv GR 3 under all

Table : 30 Effects of air pollution on the activity of enzymes of the rice cvs CO 43, GR 3 and TKM 9, under two N and water regimes.

Enzyme	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
Peroxidase	29.0	19.0	40.0	63.0	22.0	50.0	35.0	27.0	35.0	68.0	78.0	110.0
Polyphenol-oxidase	8.5	13.5	7.5	5.0	5.4	7.0	8.4	13.1	4.3	11.3	8.1	10.6
Acid phosphatase	42.7	22.9	30.0	7.4	6.9	8.2	68.4	38.8	29.7	19.8	27.8	13.8
Water stressed												
Peroxidase	48.0	59.0	30.0	38.0	29.0	40.0	45.0	49.0	30.0	38.0	36.0	83.0
Polyphenol-oxidase	5.0	10.5	6.3	11.8	1.8	4.9	7.4	9.7	5.9	5.5	4.5	4.8
Acid phosphatase	43.0	21.6	14.9	20.6	8.4	13.7	22.2	32.2	11.3	11.0	18.5	14.5

C=control; P=polluted; Units :Peroxidase - Δ units/mg protein/minute,
Polyphenoloxidase - Δ units/mg protein/minute,
Acid phosphatase - Δ units/mg protein/10 minutes.

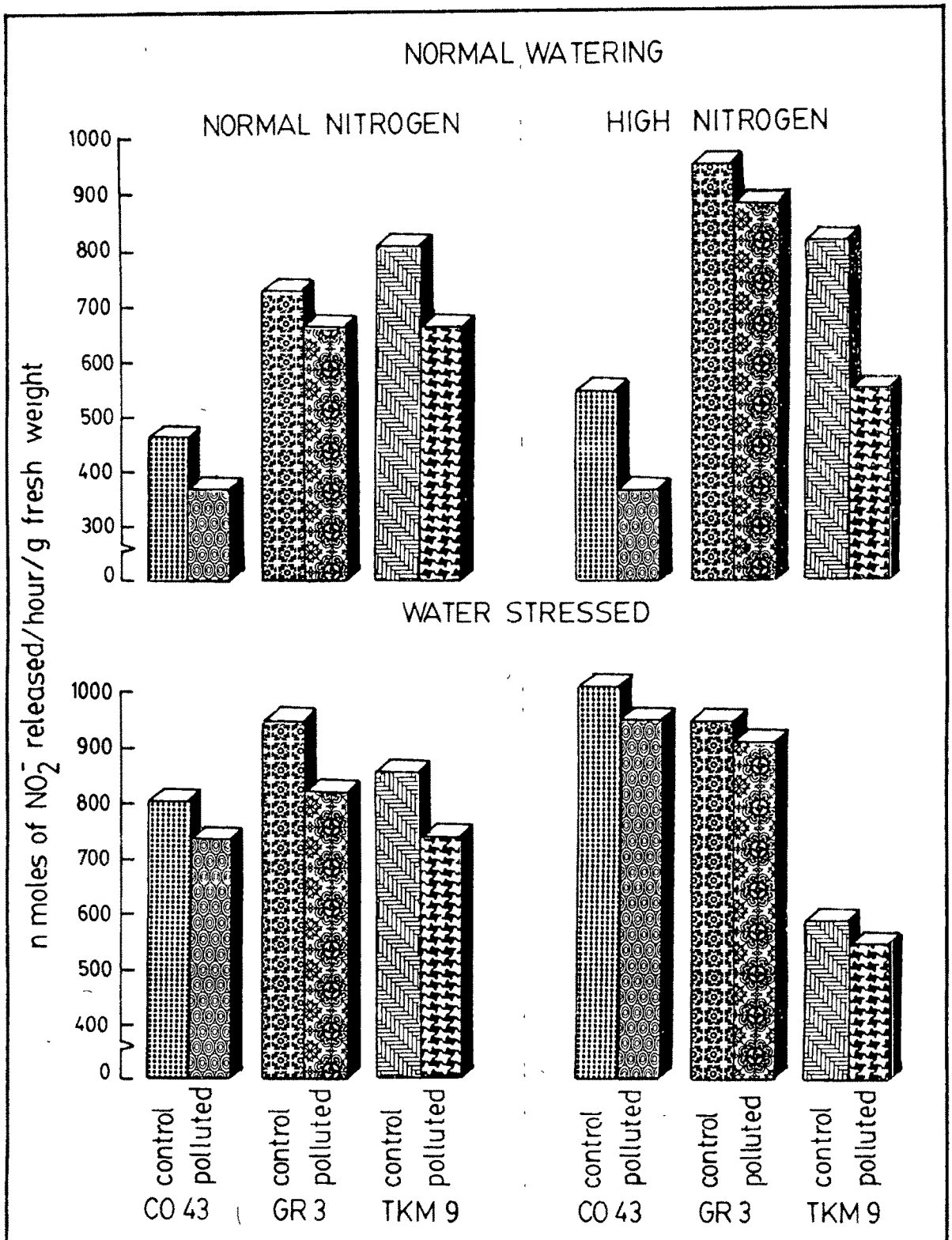
Table : 31 Effects of air pollution on the activity of enzymes from the leaves of rice cvs CO 43, GR 3 and TKM 9, under two N and water regimes.

Enzyme	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
Amylase	0.50	0.72	2.82	3.64	2.48	3.75	0.96	0.75	2.09	2.52	2.90	2.62
Invertase	1.98	2.67	1.60	3.70	1.41	1.30	2.07	3.46	1.20	3.85	1.39	1.80
Phosphorylase	0.35	0.68	0.37	0.52	0.60	1.19	0.49	0.47	0.77	0.38	0.89	0.92
Water stressed												
Amylase	0.56	0.93	2.99	2.68	2.05	2.59	0.63	0.77	2.72	3.42	1.35	3.60
Invertase	2.15	3.74	2.50	3.32	1.78	1.43	2.38	2.20	0.90	1.57	0.92	0.85
Phosphorylase	0.52	0.27	0.46	0.42	0.55	0.58	0.51	0.65	0.58	0.52	0.86	0.72

C= control; P=polluted; Units : Amylase - μ moles of maltose released/mg protein,

Invertase - μ moles of glucose released/mg protein,

Phosphorylase - μ moles of phosphate released/mg protein/10 minutes.



FIG·12: ACTIVITY OF NITRATE REDUCTASE IN RICE CULTIVARS AS AFFECTED BY AIR POLLUTION.

the regimes of polluted environment and the increase was a maximum of 2.2 fold under WN-HN. The cv CO 43 showed a higher rate in the activity of invertase except under WS-HN regime. The cv TKM 9 showed a maximum increase of 1.3 fold under WN-NN and 29% under HN regimes, over the control. However, it was reduced under water stressed conditions. The exposure of cv GR 3 to the polluted environment rendered an increase in the activity of phosphorylase under WN-NN, but decreased in other regimes. The cv CO 43 showed an increase in the activity under WN-NN and WS-HN regimes but reduced under other imposed regimes. On the other hand, the cv TKM 9 followed more or less the same pattern of activity as observed in GR 3.

The data presented in the form of Fig. 12 clearly indicated that all the regimes in the polluted environment experienced an inhibition in their leaf nitrate reductase activity when compared to the controls. The reduction was comparatively lesser in cv GR 3 under normal watering conditions than the other cultivars. Though water stressed condition brought about a decrease in the enzyme activity in the leaves of cv GR 3, it maintained a better level than the other cultivars in the polluted site.

3.1.2.3 a Glutathione

The content of glutathione was found to be increased under all the regimes of all the cultivars in the polluted environment when compared to control (Fig.13). Under WN-NN regime, though all the cultivars accumulated a higher amount of glutathione at 50 days only the cv GR 3 maintained a consistent increase till 80 days. Under WN-HN, the increase was consistently observed in the cv

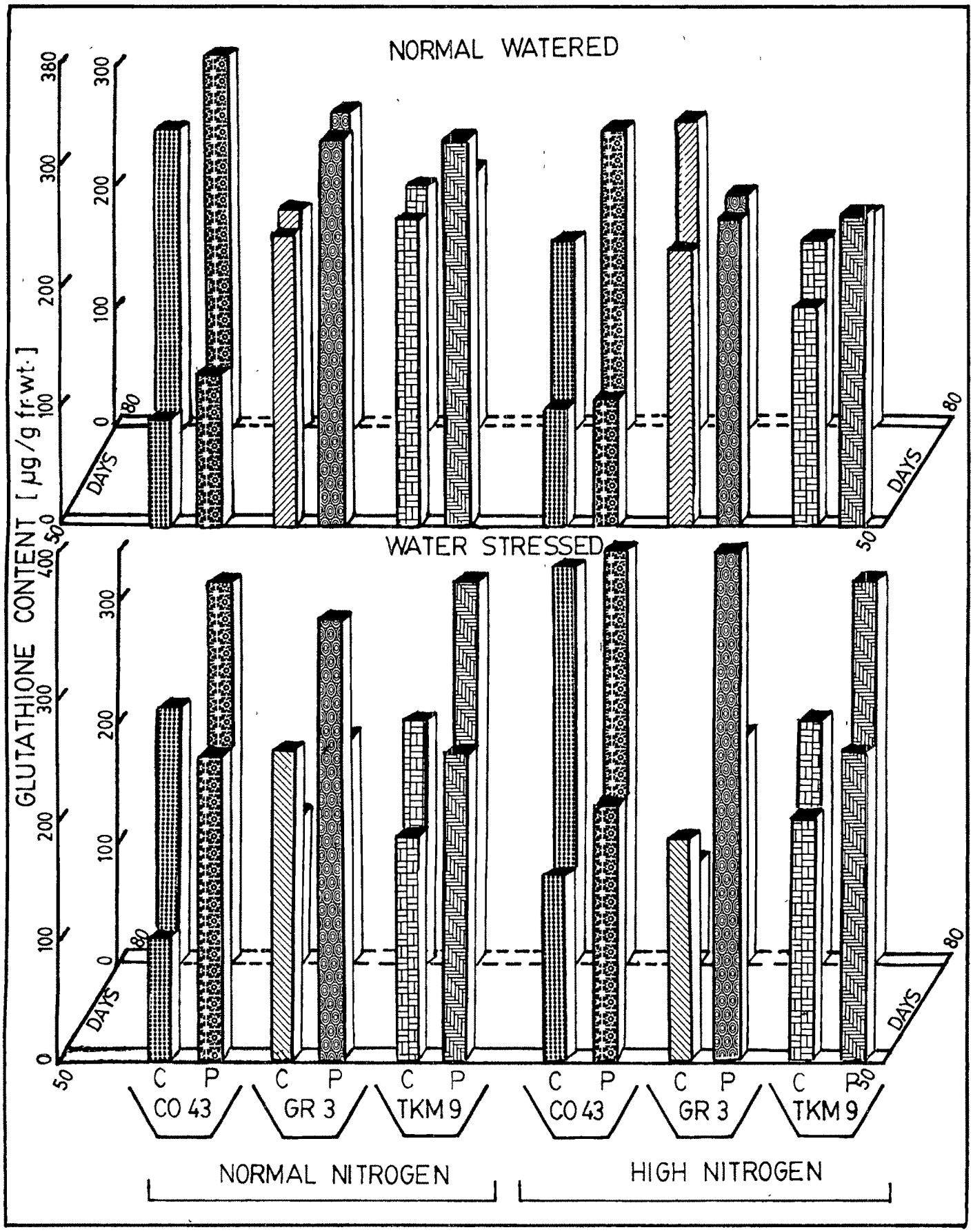

NORMAL WATERED
WATER STRESSED
GLUTATHIONE CONTENT [µg/g fr.wt.]
DAYS
C P
CO 43
GR 3
TKM 9
NORMAL NITROGEN
HIGH NITROGEN

Table : 32 The changes in the amount of total sulphur content (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	2.00 (0.10)	2.40 (0.07)	2.00 (0.06)	2.10 (0.15)	2.00 (0.09)	2.30 (0.12)	2.10 (0.05)	2.30 (0.04)	2.10 (0.15)	2.15 (0.17)	2.00 (0.05)	2.65 (0.12)
70	2.60 (0.15)	3.20 (0.14)	1.80 (0.12)	2.50 (0.15)	2.30 (0.17)	2.65 (0.09)	2.10 (0.12)	2.50 (0.07)	2.10 (0.09)	2.30 (0.08)	2.30 (0.15)	3.00 (0.32)
85	2.30 (0.08)	2.90 (0.09)	2.50 (0.13)	3.00 (0.17)	2.50 (0.20)	2.90 (0.14)	2.40 (0.07)	2.80 (0.05)	2.30 (0.17)	3.20 (0.12)	2.70 (0.14)	3.20 (0.22)
Water stressed												
55	1.80 (0.08)	3.20 (0.20)	2.40 (0.11)	2.80 (0.21)	2.45 (0.11)	2.65 (0.08)	2.20 (0.06)	2.25 (0.07)	2.60 (0.09)	2.45 (0.09)	2.40 (0.11)	2.45 (0.17)
70	2.60 (0.16)	3.40 (0.21)	2.80 (0.09)	4.85 (0.28)	2.60 (0.09)	2.85 (0.05)	2.80 (0.09)	4.00 (0.23)	3.20 (0. 1)	3.25 (0.32)	2.80 (0.15)	3.40 (0.25)
85	2.00 (0.09)	2.10 (0.10)	2.60 (0.13)	2.95 (0.12)	2.20 (0.08)	2.30 (0.07)	2.40 (0.10)	2.65 (0.12)	2.50 (0.14)	2.60 (0.17)	2.40 (0.21)	3.30 (0.34)

Figures in parentheses represent SE of three replicates.

Table : 33 The changes in the amount of fluoride content (µg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days.	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	20(2)	28(2)	17(2)	23(3)	14(1)	22(2)	13(1)	20(1)	14(1)	21(1)	14(1)	22(2)
70	19(2)	24(2)	16(1)	22(2)	19(2)	21(2)	16(2)	25(1)	21(2)	25(2)	15(1)	23(2)
85	14(1)	20(2)	18(2)	24(2)	18(2)	23(2)	21(2)	26(2)	17(1)	23(1)	16(2)	25(2)
Water stressed												
55	20(2)	24(1)	17(1)	23(1)	14(1)	20(2)	14(1)	26(2)	17(1)	23(2)	18(1)	21(1)
70	18(1)	23(2)	20(1)	25(2)	17(2)	22(1)	15(1)	29(2)	16(1)	25(2)	21(2)	25(2)
85	15(1)	23(2)	18(1)	22(1)	13(1)	24(2)	21(1)	31(2)	19(2)	27(2)	18(1)	28(2)

Figures in parentheses represent SE of three replicates.

CO 43 and GR 3 upto the age of 90 days as a response to the polluted environment. Under water stressed conditions the percentage of increase was higher than the normal watered plants. The per cent increase over the control was higher in cv CO 43 under WS-NN in 50 day old plants than in 80 day old plants, whereas it was **vice versa** in other cultivars. However, cv GR 3 could able to accumulate a remarkably higher amount of glutathione in their leaves than the other cultivars, under WS-HN, as a response to air pollution.

3.1.2.3 b Sulphur

There was always a marginal increase in the total sulphur content of the polluted site plants when compared to the non-polluted site plants (Table 32) The increase was 20 to 26 % in CO 43, 20 to 39 % in GR 3 and 15 to 16 % in TKM 9 cultivars under WN-NN regime at different stages of growth. Under WN-HN the per cent increase over the control was found to be decreased in cvs CO 43 and GR 3 but was increased in cv TKM 9. A maximum increase of 78 % was observed in cv CO 43 in 55 day old plants and 73 % in 70 day old cv GR 3 under WS-NN regime. Under WS-HN cv CO 43 showed 10 to 43 % increase at later stages of growth, while cv TKM 9 showed a marginal increase and cv GR 3 experienced no difference in the polluted environment when compared to the control.

3.1.2.3 c Fluoride

The content of fluoride in the shoots of rice was increased in all the cultivars at the polluted site (Table 33). The percentage of increase was

Table : 34 The changes in the amount of total phenolic contents (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	9.0 (0.3)	10.8 (0.3)	9.2 (0.3)	7.2 (0.4)	8.4 (0.3)	9.6 (0.4)	8.6 (0.4)	7.0 (0.3)	10.2 (0.5)	8.4 (0.6)	10.4 (0.4)	8.4 (0.4)
70	20.6 (1.0)	17.6 (0.8)	21.6 (0.9)	30.8 (1.2)	22.0 (0.8)	21.8 (1.0)	18.4 (0.8)	16.0 (0.7)	17.6 (0.7)	22.2 (1.2)	22.6 (1.0)	20.2 (0.8)
85	14.6 (1.0)	15.6 (0.6)	14.4 (0.4)	15.8 (0.4)	14.8 (0.6)	15.2 (0.5)	16.0 (0.6)	17.4 (0.5)	14.6 (0.7)	17.4 (1.0)	16.8 (0.9)	16.8 (0.8)
Water stressed												
55	8.4 (0.3)	9.2 (0.5)	9.2 (0.4)	7.6 (0.3)	10.0 (0.7)	9.6 (0.7)	9.0 (0.7)	8.4 (0.6)	10.0 (0.8)	7.4 (0.9)	9.6 (0.7)	9.6 (0.8)
70	21.2 (1.1)	16.4 (1.2)	13.4 (0.7)	22.4 (1.7)	14.6 (0.9)	26.0 (1.9)	23.6 (1.1)	21.2 (1.0)	17.4 (0.8)	20.6 (1.5)	17.4 (1.1)	23.4 (1.4)
85	15.4 (0.8)	17.0 (0.6)	14.4 (0.8)	15.0 (0.9)	11.0 (0.8)	16.4 (1.2)	16.8 (0.9)	17.0 (0.7)	14.4 (0.5)	16.4 (0.7)	14.4 (1.0)	17.6 (1.7)

Values in parentheses represent SE of three replicates.

26-43, 33-38 and 11-57 in cvs CO 43, GR 3 and TKM 9 respectively over the control at different stages of growth. The increase was 24-56 , 19-50 and 53-57 % accordingly under high N as compared to control. Under water stress the percentage of increase was less in cv GR 3 at different stages of growth under NN when compared to control. Further, under high N the cv CO 43 increased the fluoride content significantly over the control.

3.1.2.3 d Total Phenolics

Fifty day old plants of rice cv GR 3 showed a modest reduction in its total phenolic content, under all regimes in the polluted environment (Table 34). However, there was marginal increase in the levels of phenolics in 70 and 85 day old plants of cv GR 3 under all the regimes in the polluted site. It was also interesting to note that at the age of 85 days, all the cultivars more or less under all the regimes were able to maintain a higher level of phenolics than the controls. The cvs CO 43 and TKM 9 could increase the amount of phenolics at 55 days, but with a reduction at 70 days under WN-NN regime. However, under high N both the cultivars experienced a reduction at 55 and 70 days. Under water stressed conditions cv TKM 9 showed the same pattern as observed in the cv GR 3. There were either reduction or no difference under WS-HN of cv CO 43 in polluted environment when compared to the control.

3.1.2.4 a Total Soluble Sugars

The amount of total soluble sugars was found to be generally reduced in cv GR 3 in 55 day old plants in all the regimes of polluted site plants, when

Table : 35 The changes in the amount of total soluble sugars (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	23.1 (1.2)	28.8 (2.3)	28.1 (1.2)	21.9 (1.0)	27.5 (1.9)	38.8 (3.4)	19.4 (0.8)	21.9 (1.2)	32.5 (2.3)	31.3 (2.9)	34.4 (3.2)	32.5 (3.4)
70	20.6 (0.9)	23.1 (1.7)	24.4 (2.3)	22.5 (1.7)	20.6 (2.1)	26.9 (2.4)	21.9 (1.7)	20.6 (1.9)	20.6 (1.4)	26.3 (2.1)	22.5 (1.3)	21.9 (1.2)
85	18.8 (0.8)	30.0 (2.4)	17.5 (1.1)	20.6 (1.4)	20.0 (1.6)	21.9 (1.3)	17.5 (1.4)	21.9 (2.0)	16.3 (0.9)	25.0 (2.0)	23.1 (1.4)	25.6 (1.9)
Water stressed												
55	31.3 (1.7)	32.5 (1.6)	24.4 (1.7)	26.9 (1.1)	27.5 (1.8)	33.8 (2.2)	34.4 (1.2)	37.5 (1.8)	35.0 (2.0)	23.1 (1.2)	33.8 (3.2)	35.0 (2.7)
70	23.1 (2.1)	23.8 (1.9)	23.1 (1.2)	30.6 (1.9)	23.8 (2.4)	26.3 (2.1)	20.6 (1.7)	30.6 (2.8)	20.6 (1.4)	28.1 (1.3)	24.8 (2.1)	28.8 (1.4)
85	22.5 (2.1)	18.8 (1.4)	16.9 (1.1)	26.9 (1.6)	25.0 (1.2)	29.4 (2.2)	18.8 (1.4)	23.8 (2.2)	18.1 (0.9)	30.0 (2.4)	26.9 (1.9)	26.5 (2.3)

Values in parentheses represent SE of three replicates.

Table : 36 The changes in the amount of starch content (mg/g dry weight) of rice cvs CO 43, GR 3 and TKM 9 under two N and water levels when grown near to (P), and distant from (C), a fertilizer plant.

Age in days	Normal - N						High - N					
	CO 43		GR 3		TKM 9		CO 43		GR 3		TKM 9	
	C	P	C	P	C	P	C	P	C	P	C	P
Normal watered												
55	8.6 (0.7)	13.5 (1.1)	8.1 (0.5)	10.4 (0.4)	8.8 (0.5)	15.8 (1.3)	7.4 (0.6)	11.5 (0.9)	9.5 (0.6)	13.5 (0.9)	8.8 (0.6)	13.1 (0.8)
70	14.2 (1.2)	17.1 (1.3)	13.7 (1.3)	14.6 (1.2)	14.4 (1.1)	18.3 (1.8)	14.2 (0.6)	16.4 (1.2)	14.2 (0.7)	17.6 (1.4)	14.6 (0.6)	24.5 (1.2)
85	15.8 (1.1)	25.5 (2.4)	9.9 (0.6)	8.8 (0.7)	16.2 (0.9)	17.9 (2.1)	14.1 (0.7)	27.5 (1.5)	11.4 (0.4)	9.0 (0.3)	10.3 (0.5)	11.9 (0.4)
Water stressed												
55	8.1 (0.3)	9.9 (0.6)	8.5 (0.5)	11.5 (0.6)	7.7 (0.6)	11.7 (1.1)	8.6 (0.5)	14.0 (1.1)	8.6 (0.4)	9.5 (0.4)	8.6 (0.4)	15.0 (1.1)
70	13.5 (0.5)	14.9 (0.8)	14.9 (0.9)	18.9 (1.3)	16.2 (1.9)	24.2 (1.4)	14.0 (0.8)	14.9 (0.9)	14.5 (0.9)	18.9 (1.1)	16.7 (1.3)	18.0 (1.6)
85	17.6 (1.2)	29.5 (2.5)	9.5 (0.5)	9.0 (0.4)	17.1 (1.5)	15.5 (1.1)	13.4 (0.4)	23.9 (1.9)	8.6 (0.6)	12.1 (0.7)	9.9 (0.7)	11.7 (0.6)

Values in parentheses represent SE of three replicates.

compared to the controls (Table 35). However, there was high amount of total soluble sugars at later stages in the polluted site plants of cv GR 3. Under both N levels of normal watered condition the cv CO 43 showed a high level of total soluble sugars at 55 and 85 days but showed no difference at 70 days. Under water stress the cv CO 43 showed a mixed effect at different stages of growth. The cv TKM 9 experienced a consistent increase in the amount of total soluble sugars in the NN regimes of polluted site plants, when compared to the controls.

3.1.2.4 b Starch

The contents of the starch was mostly high in all the cultivars in the shoot of polluted test site plants (Table 36). The per cent increase over the control was much higher in all the cultivars and regimes at 55 days, than in the later stages of growth, when compared to the unpolluted site plants. However, at all the stages of growth, all the cultivars were able to maintain a moderately higher amount of starch in their shoot portions than the controls, regardless of the imposed regimes. The amount of accumulation generally appeared to be greater in cv CO 43 followed by GR 3 and TKM 9 cultivars. Nevertheless, WN-HN the cv GR 3 showed a 22 % reduction in the polluted site under WN-HN, whereas cvs CO 43 and TKM 9 were able to maintain a higher amount of 96 and 16 % than the controls, at the age of 85 days respectively.

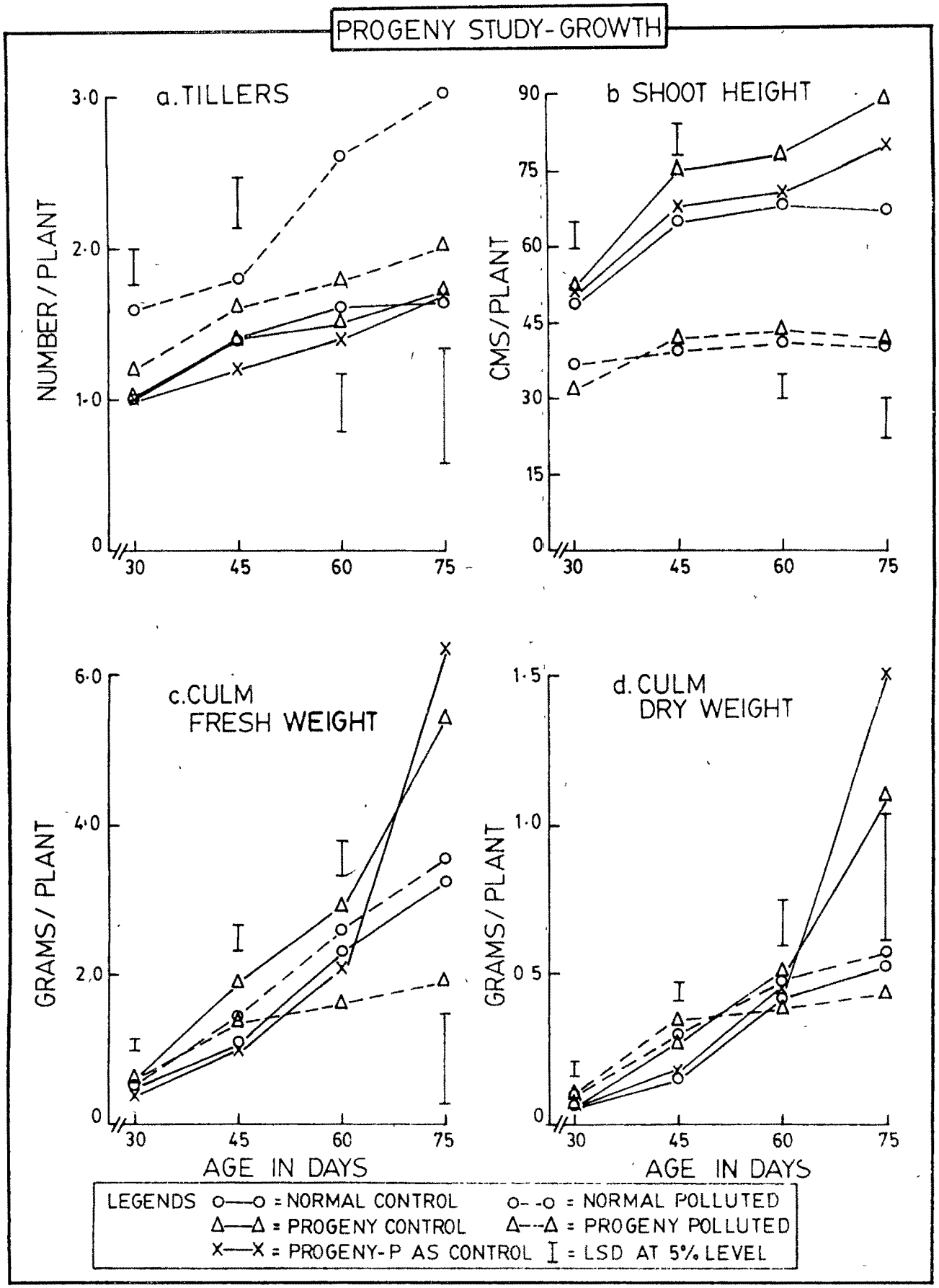
3.2.0 SECOND YEAR STUDY

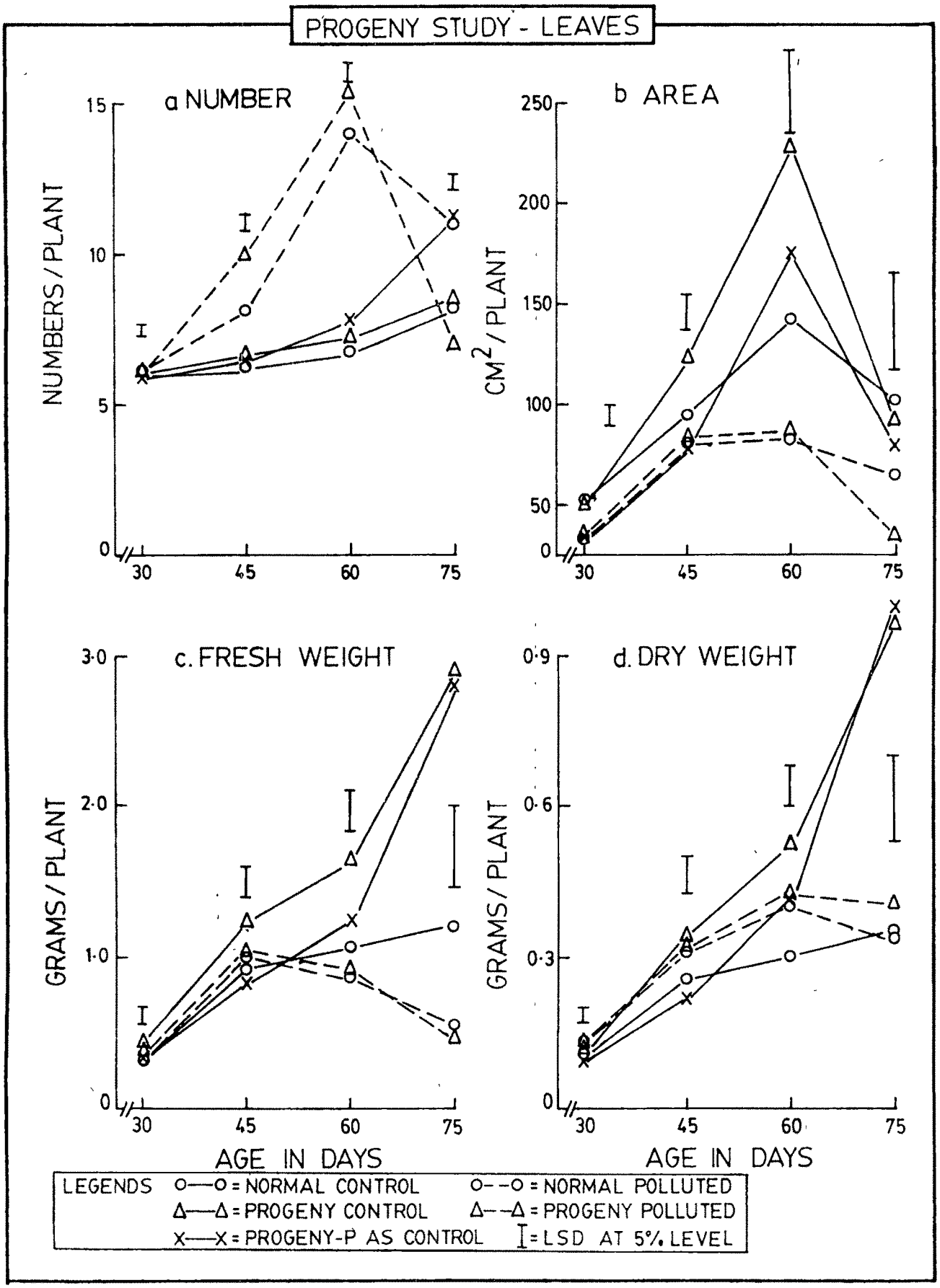
3.2.1 Studies on Progeny

3.2.1.1 Growth

The growth studies on the progeny of cv GR 3 under high N regime are depicted in Fig. 14 and 15. The plants raised from the seeds obtained from the Rice Research Station, Navagam, Gujarat (hereafter mentioned as normal plants), when grown under the polluted environment produced always increased number of tillers per plant (Fig. 14 a). The increase was 2.5 fold at the final harvest. However, the progeny plants (seeds harvested from the previous crop) did not shown any significant effect over the control. The height of the plants was invariably affected by air pollution. At all the time of growth the reduction was significant by 25 to 43 % in the polluted environment (Fig. 14 b). The progeny plants showed a high reduction of 40 to 64 % in their height. The fresh weight and dry weight of culm appeared to be always high in the polluted site plants. However, after 45 days fresh weight and dry weight of culm were reduced in the progeny plants when compared to their respective controls. Remarkably, PPYPC plants exhibited a maximum increase in both fresh as well as dry weight at the final stage (Fig. 14 c and d).

The number of leaves, leaf area, fresh and dry weight of leaves are shown in Fig. 15. The number of leaves in the plants from the polluted site seemed to be significantly high at all the time of growth. However, in 75 day old plants there appeared to be a sharp decline in the polluted progeny plants


PROGENY STUDY-GROWTH
a. TILLERS
NUMBER / PLANT
3·0
2·0
1·0
0
30
45
60
75
b SHOOT HEIGHT
CMS/PLANT
90
75
60
45
30
15
0
c. CULM FRESH WEIGHT
GRAMS / PLANT
6·0
4·0
2,0
0
AGE IN DAYS
d. CULM DRY WEIGHT
GRAMS / PLANT
1·5
1·0
0 5
0
AGE IN DAYS
LEGENDS o—o = NORMAL CONTROL
o- -o = NORMAL POLLUTED
Δ—Δ = PROGENY CONTROL
Δ--Δ = PROGENY POLLUTED
x—x = PROGENY-P AS CONTROL
I = LSD AT 5% LEVEL


PROGENY STUDY - LEAVES
a NUMBER
NUMBERS / PLANT
15
10
5
0
30
45
60
75
b AREA
CM² / PLANT
250
200
150
100
50
0
c. FRESH WEIGHT
GRAMS / PLANT
3·0
2·0
1·0
0
AGE IN DAYS
d. DRY WEIGHT
0·9
0·6
0·3
AGE IN DAYS
LEGENDS
o—o = NORMAL CONTROL
o--o = NORMAL POLLUTED
Δ—Δ = PROGENY CONTROL
Δ--Δ = PROGENY POLLUTED
x—x = PROGENY-P AS CONTROL
I = LSD AT 5% LEVEL

when compared to its control (Fig. 15 a). The photosynthetic leaf area was dramatically decreased in the polluted site plants at all the time of growth (Fig. 15 b). It was interesting to note that the progeny plants at the control site showed a tremendous increase in its fresh as well as dry weight of leaves. However, polluted site plants showed a reduction in their fresh weight of leaves after 45 days. The dry weight accumulation was also very low in the plants exposed to the polluted environment.

3.2.1.2 Yield and Yield Attributes

There were significant reductions in the panicle length and spikelet numbers of the polluted site plants of the cultivar GR 3 when compared to the control (Table 37). The number of panicles was markedly increased in the polluted site normal plants. The sterility percentage of grains was found to be 87 or 98 in the polluted plants as against a 45 of the cotrol and also the dry weight of filled grains (economic yield) was drastically reduced when compared to the control. It was interesting to note that the dry weight of unfilled grains was also found to be reduced in the progeny plants of polluted site. The straw weight was significantly increased in the normal plants of the test site. However, the progeny plants were able to maintain a high straw yield when compared to the control. Their sharp reduction in their economic yield rendered to reduce the harvest index in the test site plants.

3.2.1.3 Physiological and Biochemical Responses

(a) Pigments

The concentrations of pigments are given in Fig. 16. The concentrations of Chl 'a', Chl 'b' and total Chl in the leaf of the plants from polluted site

Table : 37 Yield and Yield attributes of cv GR 3 of rice grown near to, and distant from, a fertilizer plant.

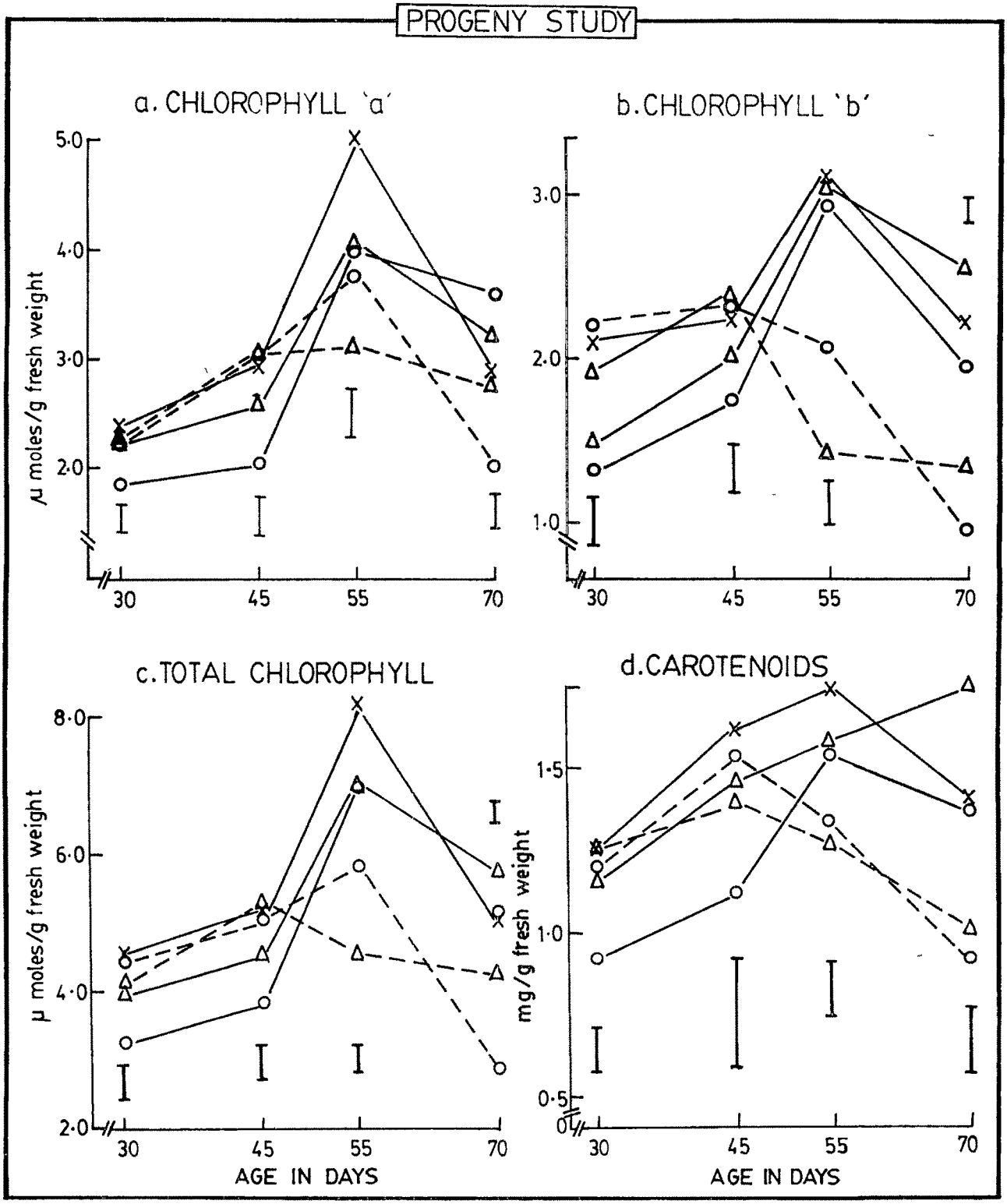
Characters	Normal		Progeny			LSD at
	Control	Polluted	PPYCC	PPYPC	PPYPP	5 %
Panicle length (cm)	21.4	11.7*	18.2	18.6	12.6*	2.7
Spikelets/panicle	7.2	4.0*	6.8	6.4	5.2*	0.3
Panicles (number)	1.0	5.2*	2.0	2.2	2.2	1.6
Sterility index (%)	45.0	87.0*	41.0	68.0	98.0*	19.0
Dry filled grains (g) (Economic yield)	0.62	0.24*	1.30	0.70	0.02*	0.2
Dry unfilled grains (g)	0.18	0.37	0.25	0.54	0.14*	0.3
Straw yield (g)	1.07	2.40*	2.10	2.34	2.82	0.9
100 grains (g)	1.60	1.28	1.80	1.75	1.30	0.5
Biological yield (g)	1.88	2.81	3.66	3.60	2.97	1.2
Harvest index	0.36	0.02*	0.34	0.23	0.02*	0.07

(*) = significant over the control at 5 % level;

PPYCC = Progeny of previous year control site plant grown at control.

PPYPC = Progeny of previous year test site plant grown as control.

PPYPP = Progeny of previous year test site plant grown at test site.


PROGENY STUDY
a. CHLOROPHYLL 'a'
b. CHLOROPHYLL 'b'
c. TOTAL CHLOROPHYLL
d. CAROTENOIDS
μ moles/g fresh weight
mg/g fresh weight
AGE IN DAYS
AGE IN DAYS
LEGENDS: o—o = NORMAL CONTROL
o--o = NORMAL POLLUTED
Δ—Δ = PROGENY CONTROL
Δ--Δ = PROGENY POLLUTED
X—X = PROGENY-P AS CONTROL
I = LSD AT 5% LEVEL

were higher than the control upto 45 days of growth, and thereafter, they were drastically reduced in 55 and 70 day old plants. Among the control plants, the progeny of the previous year from the polluted site was able to show high level of pigments upto 55 days (Fig. 16 a to c). The pigment carotenoids was also high as compared to control upto 45 days in the polluted environment. However, progeny plants at the test site started showing reduction after 30 days. At the age of 55 and 70 days the content was dramatically reduced. On the other hand, among the controls, the progeny of the previous year control plants showed a high level of carotenoids content at 70 days (Fig. 16 d).

There was an increase in the content of phaeophytin 'b' after the acid conversion indicating the presence of initial phaeophytin in the progeny plants only in the polluted site. There was no initial phaeophytin in the rest of the plants (Fig. 17 b and d).

(b) Relative Water Content (RWC)

At the age of 55 days the RWC of the rice plants were 8 and 29 % less in the polluted environment when compared to their respective controls of normal and progeny ones (Table 38). However, the decrease was found to be insignificant in the polluted environment in 75 day old plants.

(c) Protein

An increase of 67 % and decrease of 16 % were observed in the total protein content of normal and progeny plants of polluted site as compared to the controls at the age of 40 days. However, insoluble protein appeared to

Table : 38 Biochemical responses and foliar injury of cv GR 3 of rice grown near to, and distant from, a fertilizer plant.

Parameter	Age in days	Normal		Progeny		
		Control	Polluted	PPYCC	PPYPC	PPYPP
Relative water content (%)	55	86.00 (2.00)	79.00 (2.00)	89.00 (3.00)	91.00 (3.00)	65.00 (4.00)
Proteins (mg/g fr.ls.)						
Total	40	40.2 (1.9)	67.3 (6.1)	52.7 (3.9)	31.2 (2.7)	44.0 (2.9)
	55	41.5 (1.5)	34.9 (1.6)	- -	38.3 (1.8)	33.2 (2.3)
Insoluble	40	25.5 (2.7)	49.3 (2.5)	22.3 (1.9)	18.2 (2.3)	33.0 (1.7)
	55	29.8 (1.6)	26.5 (0.6)	- -	30.2 (0.3)	23.2 (0.8)
Soluble	40	14.7 (0.8)	18.0 (3.6)	30.4 (2.6)	13.0 (0.8)	11.0 (0.9)
	55	11.7 (0.5)	8.4 (0.9)	- -	8.1 (0.6)	10.0 (0.4)
Free proline (μ moles/g dr.wt.)	40	80.0 (2.3)	457.0 (16.2)	98.3 (3.6)	90.0 (2.6)	332.0 (17.1)
	55	70.0 (3.5)	115.0 (5.6)	50.0 (2.3)	50.0 (3.1)	333.0 (28.1)
Ascorbic acid (mg/g fr. wt.)	30	0.84 (0.04)	1.39 (0.03)	0.99 (0.06)	1.06 (0.05)	1.55 (0.12)
	45	1.04 (0.09)	1.20 (0.05)	0.99 (0.08)	0.82 (0.04)	1.41 (0.09)
	60	0.62 (0.09)	0.42 (0.09)	0.70 (0.08)	1.21 (0.05)	0.44 (0.11)
Foliar injury (%)	75	- -	40.7 (8.6)	- -	- -	55.3 (14.4)

Values in parentheses represent SE of three replicates; PPYCC = Progeny of previous year control site plant grown at control; PPYPC = Progeny of previous year test site plant grown as control; PPYPP = Progeny of previous test site plant grown at test site.

be increased by 93 and 48 % in both the sets of polluted plants, over their respective controls. An increase of 22 % in soluble protein content in normal polluted site plant and 64 % reduction in the progeny plants were also observed. However, at the age of 55 days both the set of plants showed only reduction in the total, insoluble and soluble protein content in the polluted environment.

(d) Free Proline

There was an enormous increase in the free proline content of polluted site plants (Table 38). The increase was 4.7 fold and 2.4 fold in the normal and progeny plants over the respective controls in 40 day old plants. Further, the increase was 0.64 fold and 5.7 fold over the control of both the sets of plants respectively in the polluted environment at the age of 55 days.

(e) Ascorbic acid

The endogenous levels of ascorbic acid seemed to be increased in the polluted site plants at the age of 30 and 45 days but it was reduced at 60 days (Table 38). The increase was 65 and 57 % at 30 days, 15 and 42 % at 45 days while the decrease was 32 and 37 % at 60 days in the normal and progeny plants in the test site respectively.

(f) Total Nitrogen, Sulphur and Fluoride

The polluted environment brought about a marginal decrease in the total nitrogen content of normal rice plants at the age of 30 days, (Table 39).

Table : 39 Response of rice cv GR 3 on the total nitrogen, sulphur and fluoride contents in their shoot grown near to, 10 km distant from, fertilizer plant.

Parameter	Age in days	Normal		Progeny		
		Control	Polluted	PPYCC	PPYPC	PPYPP
Total nitrogen (mg/g dry wt.)	30	25.21 (0.17)	22.52 (0.56)	26.78 (0.58)	26.17 (0.62)	30.83 (0.68)
	50	23.50 (0.41)	28.58 (0.37)	21.46 (0.17)	24.67 (0.14)	37.08 (0.34)
	60	26.79 (0.12)	29.38 (0.51)	28.54 (0.61)	27.38 (0.39)	33.33 (0.34)
	75	27.17 (0.25)	29.79 (0.74)	26.83 (0.27)	27.17 (0.27)	22.92 (0.34)
Total sulphur (mg/g dry wt.)	30	2.12 (0.11)	2.60 (0.15)	2.06 (0.08)	2.10 (0.07)	2.42 (0.11)
	50	2.44 (0.13)	2.80 (0.27)	2.24 (0.14)	2.12 (0.13)	2.64 (0.14)
	60	2.60 (0.11)	2.96 (0.13)	2.44 (0.13)	2.40 (0.12)	2.78 (0.11)
	75	2.60 (0.13)	3.04 (0.14)	2.80 (0.14)	2.60 (0.17)	2.96 (0.15)
Fluoride (µg/g dry wt.)	30	12.0 (1.0)	18.0 (1.0)	13.0 (1.0)	14.0 (1.0)	21.0 (2.0)
	50	15.0 (1.0)	22.0 (2.0)	17.0 (1.0)	14.0 (2.0)	23.0 (1.0)
	60	13.0 (1.0)	19.0 (1.0)	19.0 (2.0)	16.0 (2.0)	27.0 (2.0)
	75	14.0 (1.0)	21.0 (2.0)	15.0 (1.0)	14.0 (1.0)	24.0 (2.0)

Values in parentheses represent SE of three replicates; PPYCC = Progeny of previous year control site plant grown at control; PPYPC = Progeny of previous year test site plant grown as control; PPYPP = Progeny of previous test site plant grown at test site.

However, at the later stages they were able to maintain a marginally high amount of total N in their shoot portions in the polluted environment. Conversely, the progeny plants at the polluted site accumulated a high amount of total N in their shoot portion than the controls upto 60 days, but at 75 days experienced a marginal decrease.

The amount of total sulphur content in the rice shoot portion of plants grown under the polluted environment showed a marginally high amount of total sulphur at all the stages of growth. The accumulation was marginally higher in the normal plants than the progeny plants at the polluted site.

The polluted environment near the fertilizer plant brought about a marginal increase by 46-50 % in the fluoride content of rice cv GR 3 at different stages of growth. In the progeny plants the percentage increase was slightly high at a range of 35-62 at different stages at the test site.

3.2.2.0 Treatments with Chemical Protectants

3.2.2.1 Growth

The height of the plants and leaf area at the age of 60 and 75 days as a response to treatment with chemical protectants under polluted and non-polluted environment are shown in the Fig. 18. The plant height was sharply reduced in the polluted environment in all the cultivars and the chemical treatments provided no significant effect on the plant height under polluted environment. The reduction range was from 40 to 48 % in 60 day old plants and it was 40

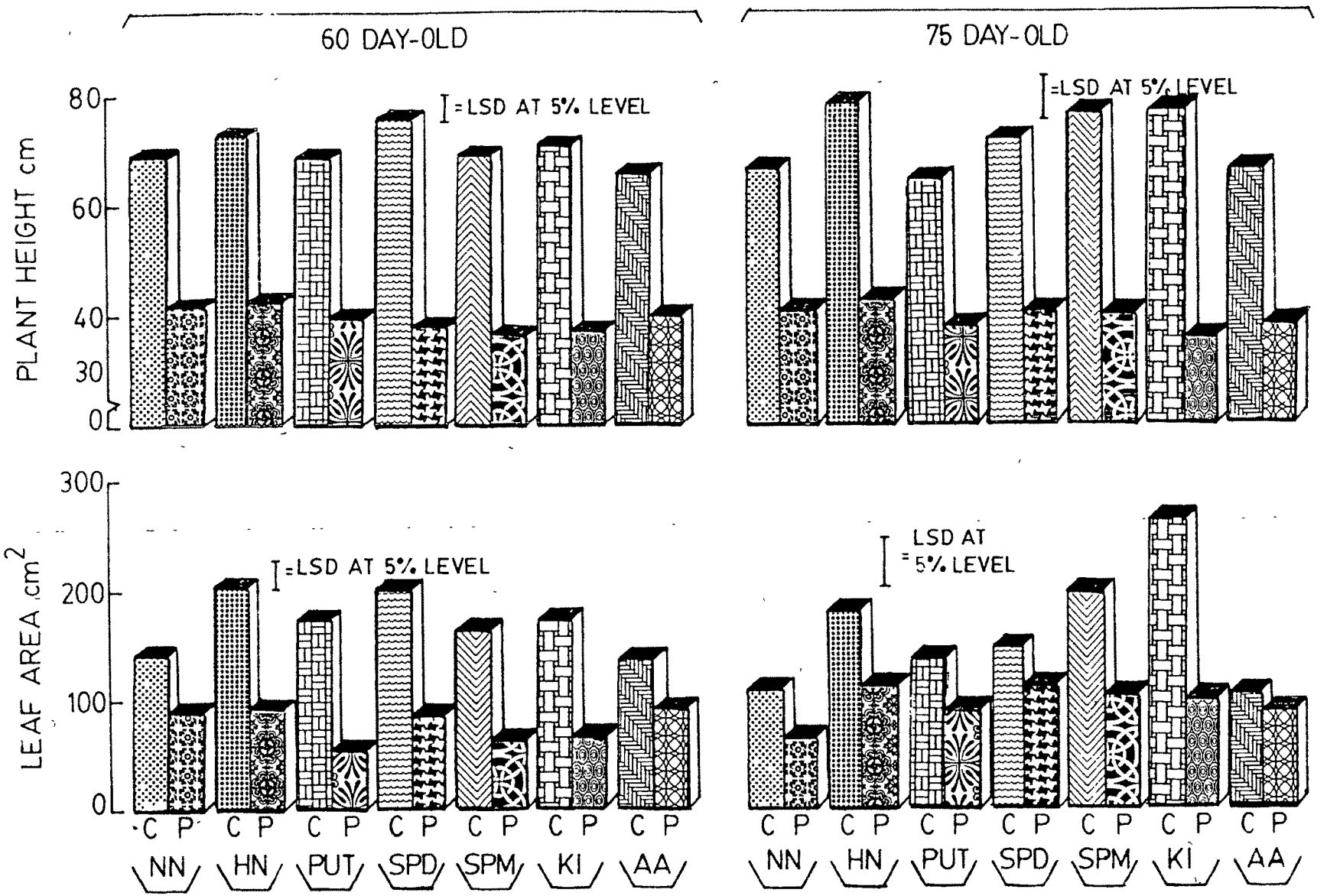


Fig. 18 Effects of ambient air pollution on the plant height and photosynthetic leaf area of rice cv GR 3, under the application of high N, polyamines, kinetin and ascorbic acid when grown near to, and distant from, a fertilizer plant.

to 56 % in 75 day old plants of all the treatments. Only high N applied plants showed slight improvement (not significant) over the normal plants at the polluted site. Though there were highly significant reductions in the photosynthetic leaf area of plants in 60 day old plants, their reductions were minimised in 75 day old plants. Application of HN had minimised the reduction from 55 to 28 %, putrescine 67 to 34 %, spermidine 57 to 23 %, spermine 66 to 49 % and ascorbic acid from 41 to 19 %. However, the reduction in kinetin sprayed one was increased from 60 to 64 % due to a vigorous growth in the control plants. The foliar injury was found to be minimised by 12, 23, 31, 32, 33 and 34 % in kinetin, ascorbic acid, high N, putrescine, spermidine and spermine treated plants respectively as against 41 % in normal plants at the age of 75 days (Table 41 and 38).

The fresh weight and dry weight of leaves as a response to chemical treatments under polluted and nonpolluted site are shown in the Fig.19. The fresh weight of leaves was found to be reduced by 20 % in 60 day old plants and 53 % at the age of 75 days in the polluted environment. High N regimed plants also showed a reduction of 37 to 57 % in their fresh weight of leaves. At the age of 60 days the leaf fresh matter was significantly affected under all the chemical treatments. In the polluted site-normal plants no significant difference was evident in the dry matter of leaves when compared to the control. However, there were significant reductions under high N application and putrescine, spermidine, spermine and kinetin spray treatments when the plants were at the age of 60 days. Interestingly, ascorbic acid treated plants showed an increase of 27 and 21 % in their leaf dry matter at 60 and 75 days respectively. This was due to the fact that ascorbic acid itself brought about a decrease in dry

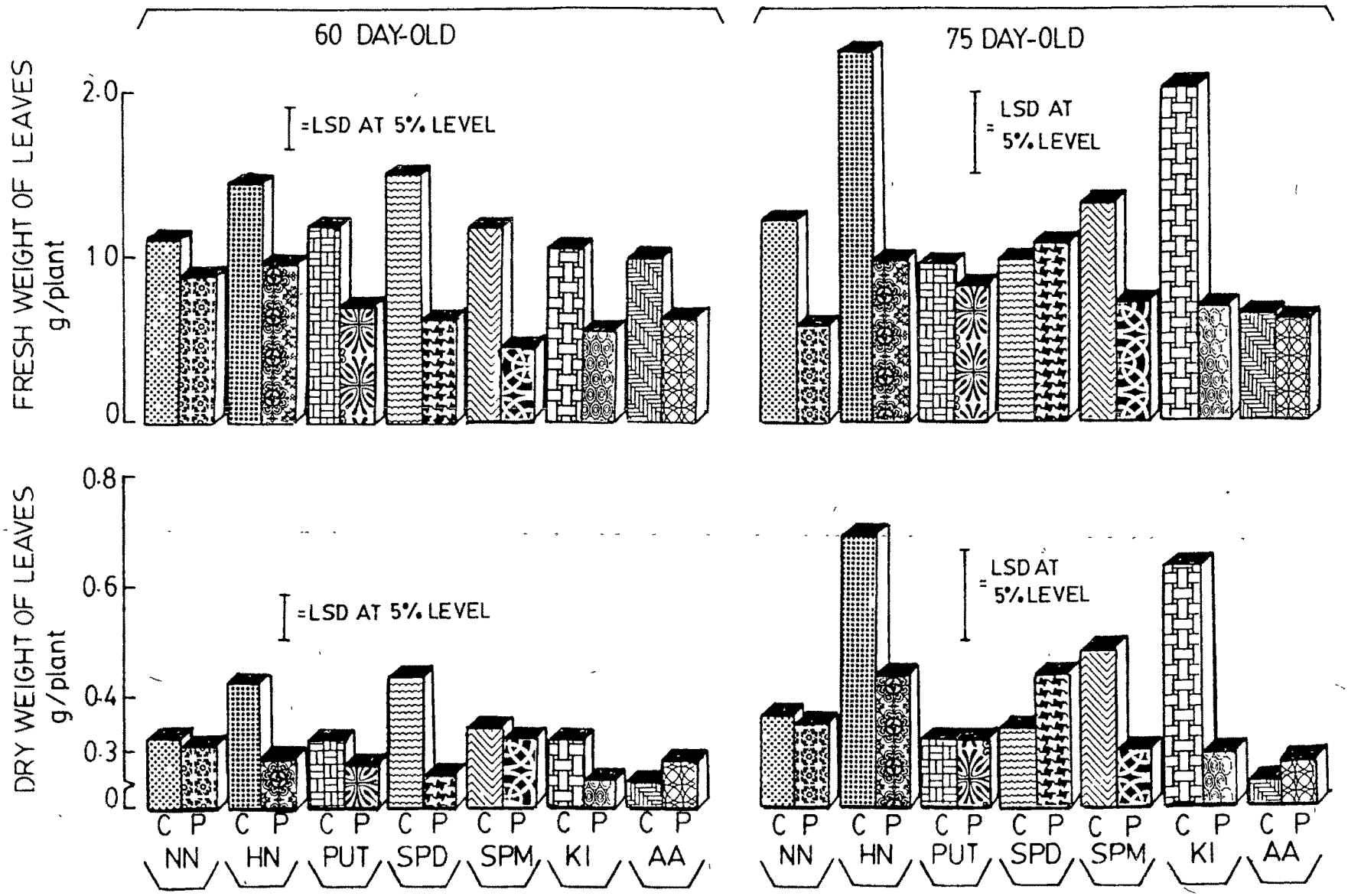


Fig. 19 Effects of ambient air pollution on the fresh and dry weight of leaves of rice cv GR 3, under the application of high N, polyamines, kinetin and ascorbic acid when grown near to, and distant from, a fertilizer plant.

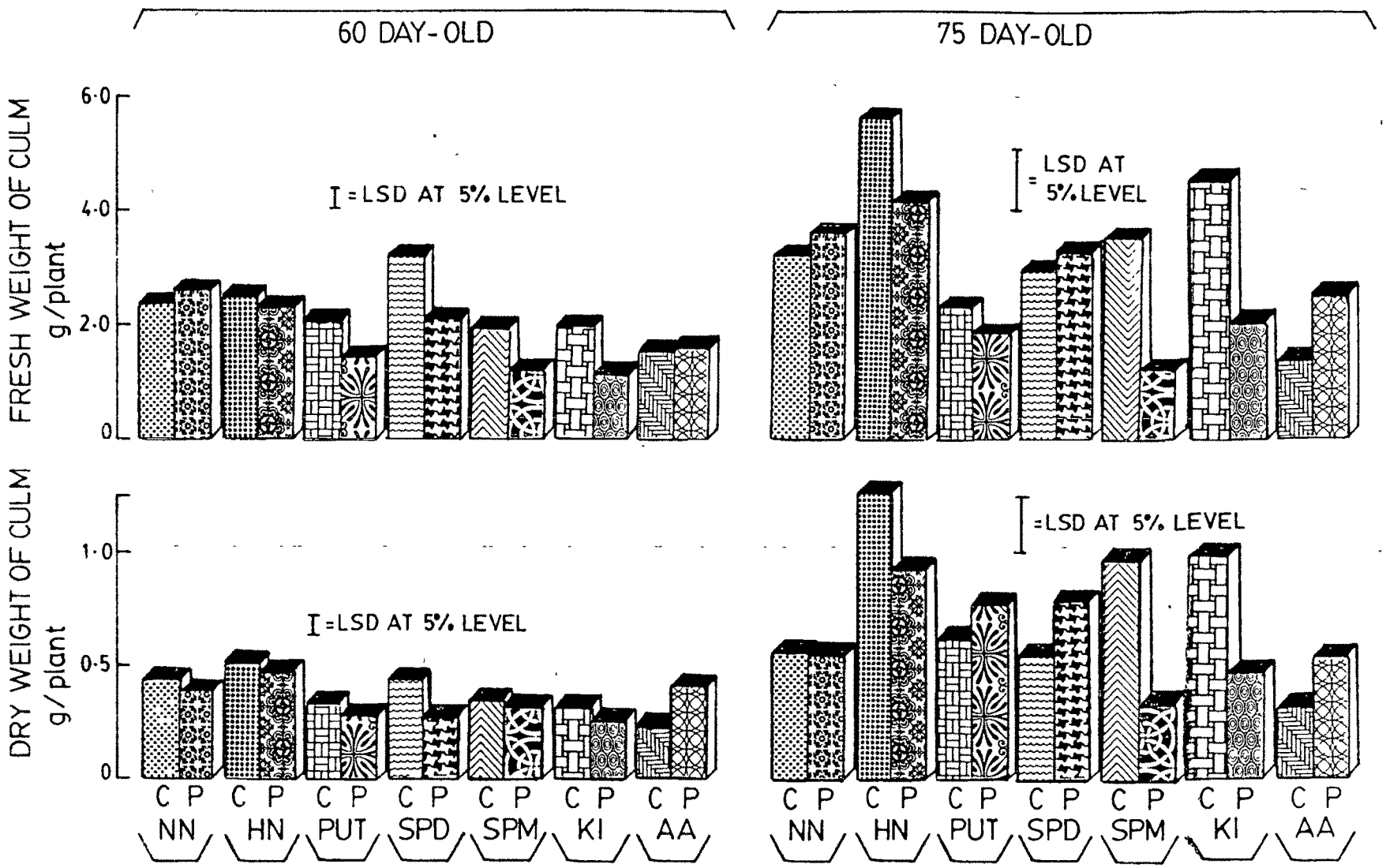


Fig. 20 Effects of ambient air pollution on the fresh and dry weight of culm of rice cv GR 3, under the application of high N, polyamines, kinetin and ascorbic acid when grown near to, and distant from, a fertilizer plant.

matter accumulation of control plants and this decrease was less under the polluted environment. Spermidine spray also rendered in an increased dry matter whereas other treatments showed no increase.

Air pollution had affected the fresh and dry weight of rice culms to varying extent (Fig.20). The plants grown without treatment in the polluted site showed a marginal increase in the fresh weight of culm when compared to the control. Under high-N there was a marginal reduction at 60 and 75 day old plants, however, it was interesting to note that in 75 day old HN regimed plants the accumulation of fresh matter was high when compared to the rest of the polluted plants. The foliar application of ascorbic acid and spermidine produced an increase in the fresh matter of culm in 60 and 75 day old plants. On the other hand polyamines and kinetin sprayed plants showed only reduction in 60 day old plants. The dry matter accumulation of the culm was found to be reduced in the polluted site plants but were not significant. It was interesting to note that HN regimed and ascorbic acid sprayed plants showed a high amount of dry matter accumulation among the polluted site plants, over their respective control. In 75 day old plants an increase was also observed in putrescine and spermidine sprayed ones while rest of the treatments experienced only reduction.

3.2.2.2 Yield and Yield Attributes

The air pollution of the fertilizer factory had affected the yield and yield attributes of cv GR 3 to varying extent, inspite of the treatments with various chemical protectants (Table 40). The length of the panciles and number of spikelets per panicle were significantly reduced in all the treated plants when

Table : 40 Yield and Yield attributes of GR 3 rice cultivar to chronic air pollution under various chemical treatements.

Parameters	Putrescine		Spremidine		Spermine		Kinetin		Ascorbic acid		High-N		LSD at
	C	P	C	P	C	P	C	P	C	P	C	P	5%
Panicle length (cm)	20.9	8.2*	21.5	11.8*	21.0	12.0*	17.3	11.5*	16.7	11.9*	18.4	12.4*	2.9
Spikelets/panicle	7.4	3.3*	7.0	5.1*	7.4	4.5*	5.6	4.6*	5.4	4.6*	5.4	4.7*	0.2
Panicles (number)	1.0	3.5*	1.4	3.4*	1.0	4.2*	1.0	4.4*	1.0	6.6*	1.0	6.8*	1.4
Sterility (%)	36.0	97.0*	28.0	93.0	33.0	98.0*	34.0	98.0*	37.0	97.0*	42.0	91.0*	15.7
Dry filled grains(g) (Economic yield)	0.73	0.02*	1.08	0.08*	0.82	0.02*	0.50	0.02*	0.37	0.07*	0.40	0.31	0.14
Dry unfilled grains(g)	0.15	0.16	0.10	0.25	0.14	0.24	0.15	0.26	0.11	0.51*	0.14	0.69*	0.32
Straw weight(g)	1.00	1.71	1.32	2.40*	1.03	2.10	0.73	2.59*	0.38	2.42*	1.01	3.13*	0.9
100 grains (g)	1.77	1.07*	1.78	1.07*	1.72	1.06*	1.70	1.19*	1.61	1.13*	1.62	1.33	0.4
Biological yield	1.88	1.89	2.50	2.73	1.99	2.36	1.38	2.87	0.86	3.00*	1.54	4.06	1.4
Harvest index	0.38	0.02*	0.44	0.03*	0.40	0.03*	0.35	0.01*	0.44	0.03*	0.26	0.05*	0.08

C = control, P = polluted;* = significant difference over the control at LSD 5 % level.

compared to their controls. Interestingly, all the treated plants of polluted environment had a marked increase in the number of panicles per plant. However, all experienced a 91 to 98 % sterility in their grains as against the 28 to 42 % of the respective controls. The dry weight of filled grains (economic yield) was also significantly reduced in the treated plants. It was interesting to note that under the polluted environment the high N regimed plants showed no significant reduction when compared to its control, which was not so in rest of the treatments. Moreover, under ascorbic acid and high N regimed plants there was a significant increase in the amount of dry unfilled grains over their control. Straw weight was found to be increased in most of the treatments and the biological yield was significantly high only under ascorbic acid and high N regimed plants in the polluted conditions. The 100 grains weight (quality) was also not affected under high N regimed plants, however, it was decreased considerably in the rest of the treatments. The loss in their economic yield rendered a reduction in the harvest index of polluted site plants.

3.2.2.3 Physiological and Biochemical Responses

(a) Pigments

The changes in the concentration of pigments-Chl 'a', Chl 'b', total Chl and carotenoids were depicted in the Fig. 21 and 22. Fifty five day-old plants experienced a reduction in the Chl 'a' content in the test site, however, spermidine and ascorbic acid treated plants showed an increase of 7 % over the control. Nevertheless, at the age of 70 days except the spermidine sprayed plants all the others showed a sharp reduction ranging from 21 to 46 %. Ascorbic acid treated plants showed no difference to the control.

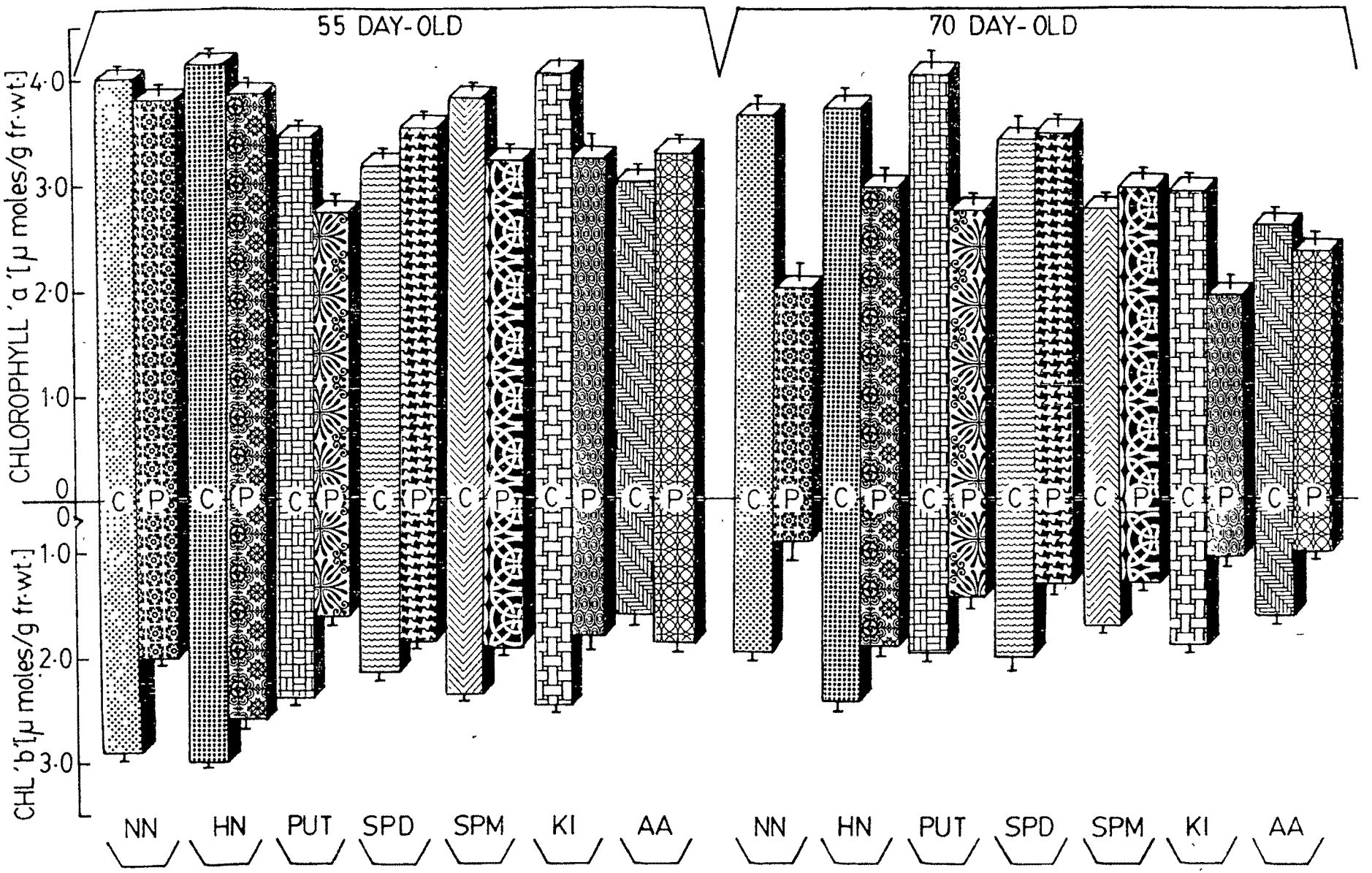


Fig. 21 Effects of ambient air pollution on the chlorophyll 'a' and chlorophyll 'b' contents of rice cv GR 3, under the application of high N, polyamines, kinetin and ascorbic acid when grown near to, and distant from, a fertilizer plant. Vertical bars represent SE of three replicates.

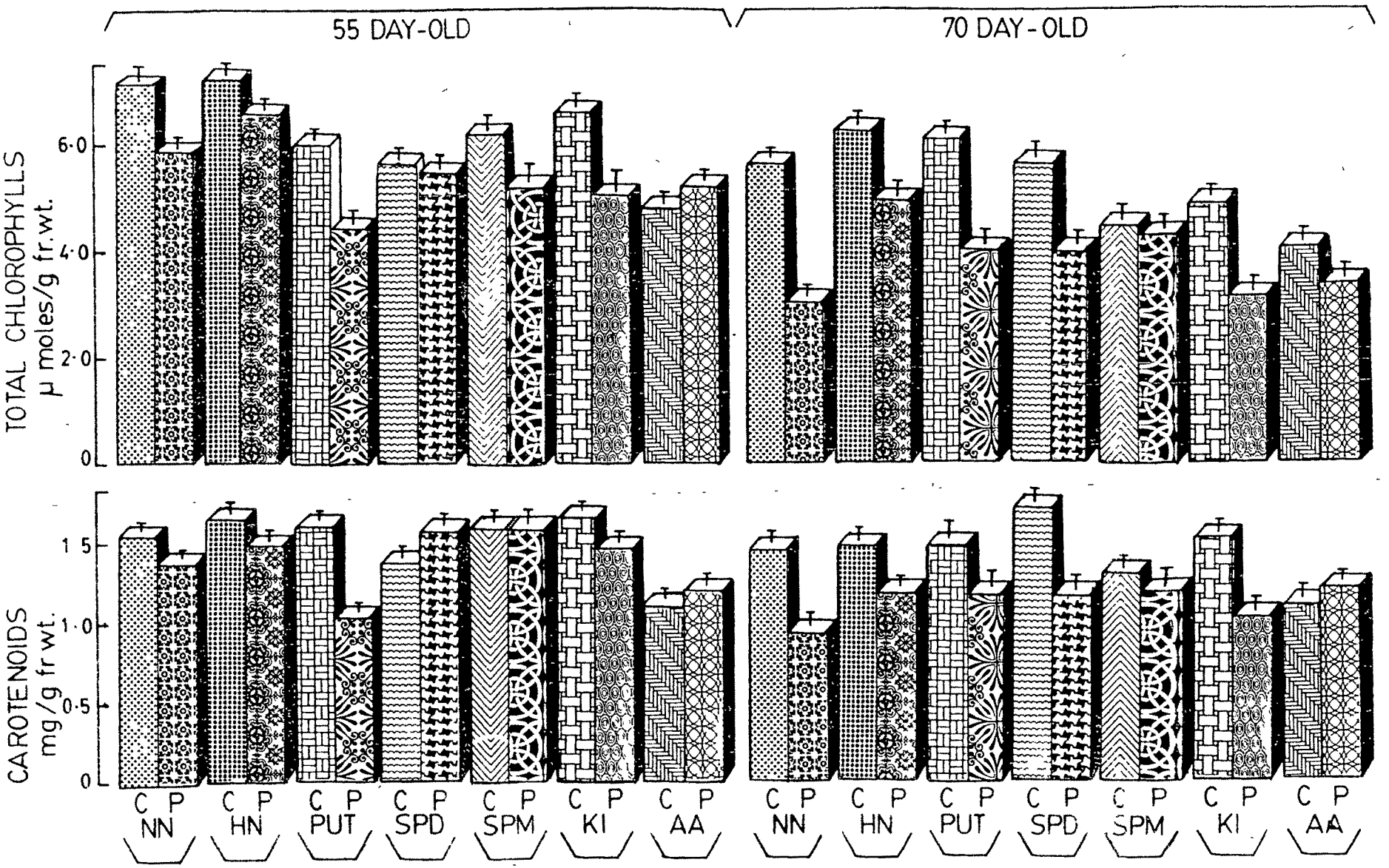


Fig. 22 Effects of ambient air pollution on the total chlorophylls and carotenoids contents of rice cv GR 3, under the application of high N, polyamines, kinetin and ascorbic acid when grown near to, and distant from, a fertilizer plant. Vertical bars represents SE of three replicates.

The Chl 'b' content also seemed to be affected to varying extent (Fig. 21). The reduction was 29, 13, 33, 16, 19 and 28 % in 55 day old plants and 53, 20, 31, 34, 23 and 43 % in 70 day old plants under normal, high N, putrescine, spermidine, spermine and kinetin treated plants in the polluted conditions, respectively. Though there was an increase in the Chl 'b' content by 12 % in the ascorbic acid treated plants at 55 days, it got reduced by 38 % at the age of 70 days, as compared to control.

The amount of total Chl appeared to be reduced by 16 and 48 % at 55 and 70 day old normal plants when compared to the control (Fig.22). Under high N regimed plants the reduction was 10 and 21 % respectively. In other treatments the reduction ranged from 2 to 38 % at both the periods. Interestingly, there was an increase in the total Chl content of polluted site plants by 9 % in 55 day old plants sprayed with ascorbic acid, however, it was reduced by 5 % at 70 days.

The carotenoids content also showed varying degree of response to the polluted environment (Fig.22). In the normal plants (without any treatment) there was a reduction of 13 and 34 % at the age of 50 and 70 days respectively. The reduction under high N was 7 and 18 % (half of the normal N) accordingly. It was interesting to note that in the spermidine sprayed plants there was an increase by 14 % at 55 days and decrease by 23 % in 70 day old plants. Further, ascorbic acid sprayed plants showed a marginal increase in their carotenoids content when compared to control. However, rest of the treatments experienced only reduction in the polluted conditions.

(b) RWC

The relative water content of 55 day old rice plants was appeared to be increased under high N by 6 % (Table 41). However, it was decreased in spermidine, spremine, and kinetin treated plants at a range of 6 to 8 % when compared to the control.

(c) Protein

The treatments of ascorbic acid had brought about an increase in the total protein content by 35 % due to the increase of 68 % in the soluble protein. Among the polyamines treated plants, spermidine increased the insoluble protein content by 43 % and minimised the reduction in the total protein. However, other treatments showed only reduction by 4 to 29 % in all the protein contents. Kinetin sprayed plants also showed a reduction of 14 to 27 % in the different proteins (Table 41).

(d) Free Proline

It was interesting to note that under the polluted environment the 55 day old plants under all treatments showed an enormous increase in free proline content when compared to their control (Table 41). The increase was 2.88 fold, 2.05 fold and 2.03 fold in the spermine, kinetin and high N regimed plants over the respective controls. However, the increase was only 80, 22 and 37 % in putrescine, spermidine and ascorbic acid treated plants respectively.

Table : 41 Biochemical responses (at 55 days) and foliar injury (at 75 days) of rice cv GR 3 to chronic air pollution, under various chemical treatments.

Treatments :	Putrescine		Spermidine		Spermine		Kinetin		Ascorbic acid		High-N	
Parameters	C	P	C	P	C	P	C	P	C	P	C	P
RWC (%)	90.0 (3.0)	93.0 (2.0)	94.0 (2.0)	86.0 (3.0)	89.0 (3.0)	84.0 (2.0)	93.0 (2.0)	87.0 (4.0)	84.0 (2.0)	81.0 (3.0)	86.0 (2.0)	91.0 (2.0)
Protein (mg/g fr. wt.)												
Total	38.3 (0.8)	33.5 (1.7)	33.8 (1.1)	32.2 (1.5)	33.5 (1.4)	30.2 (1.3)	32.8 (1.6)	26.5 (0.9)	23.5 (1.7)	31.8 (2.2)	42.5 (1.9)	44.3 (1.8)
Insoluble	21.5 (0.4)	18.3 (0.8)	11.3 (0.2)	16.2 (0.8)	15.8 (0.5)	13.3 (0.4)	13.3 (1.1)	9.7 (0.5)	11.7 (0.8)	12.0 (0.9)	34.5 (1.5)	36.2 (1.3)
Soluble	16.8 (0.4)	15.2 (0.9)	22.5 (0.9)	16.0 (0.7)	17.7 (0.9)	16.9 (0.9)	19.5 (0.5)	16.8 (0.4)	11.8 (0.9)	19.8 (1.3)	8.0 (0.4)	8.1 (0.5)
Free Proline (μ moles/g fr.wt.)	50.0 (2.9)	90.0 (4.2)	105.0 (2.7)	128.0 (4.7)	52.5 (3.2)	172.0 (7.1)	58.3 (3.3)	178.0 (6.4)	63.3 (4.4)	87.0 (7.2)	65.0 (2.4)	197.0 (5.9)
Ascorbic acid (μg/g fr.wt.)	832.0 (10.8)	433.0 (9.9)	720.0 (8.5)	606.0 (6.4)	928.0 (11.8)	696.0 (7.8)	1166.0 (31.0)	654.0 (15.7)	864.0 (9.8)	672.0 (6.4)	506.0 (6.5)	594.0 (4.9)
Foliar injury (%)	-	32.3 (5.5)	-	32.7 (14.0)	-	33.7 (10.1)	-	11.9 (5.8)	-	23.0 (8.5)	-	31.0 (6.8)

C = control, P = polluted; values in parentheses represent SE of three replicates.

(e) Ascorbic acid

The endogenous level of ascorbic acid appeared to be increased only under high N regimed polluted site plants (Table 41). In the rest of the treatments, it was invariably reduced. Exogenous application of ascorbic acid did not produce any increase in its endogenous levels in the plants at the polluted environment.

(f) Polyamines

The contents of the polyamines - putrescine, spermidine and spermine are depicted in the Fig. 23 along with the plant height at the age of 60 days. The magnitude of inhibition in the plant height of the test site plants was apparently minimised after the polyamines treatment. Nevertheless, the endogenous levels of putrescine, spermidine and spermine showed a sharp reduction of more or less 60 % in the polluted site plants when compared to the control plants. An attempt to correlate the total endogenous levels of polyamines with the height of the plants and leaf area showed the levels significant at 1 % (r= 0.891) and 5 % (r=0.687), respectively (Fig. 24).

(g) Total Nitrogen

Fifty day-old plants at the polluted environment showed higher amount of total N content in their shoots under all the treatments (Table 42). The increase was between 8 and 55 % over the controls. However, at the age of 60 days the levels were below the control or percentage of increase was much lesser

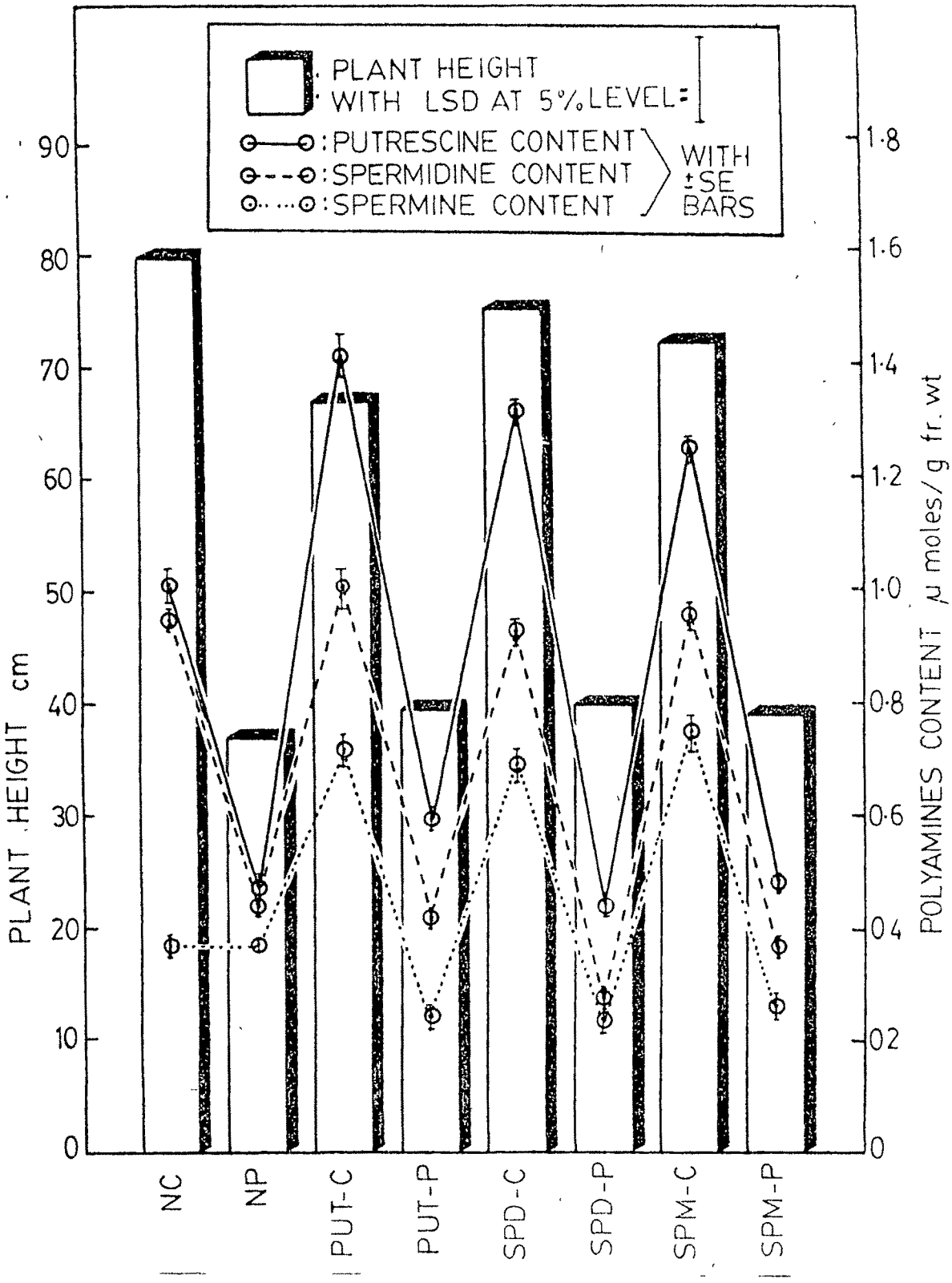


Fig. 23 The plant height and endogenous levels of polyamines in rice cv GR 3 as affected by air pollution.

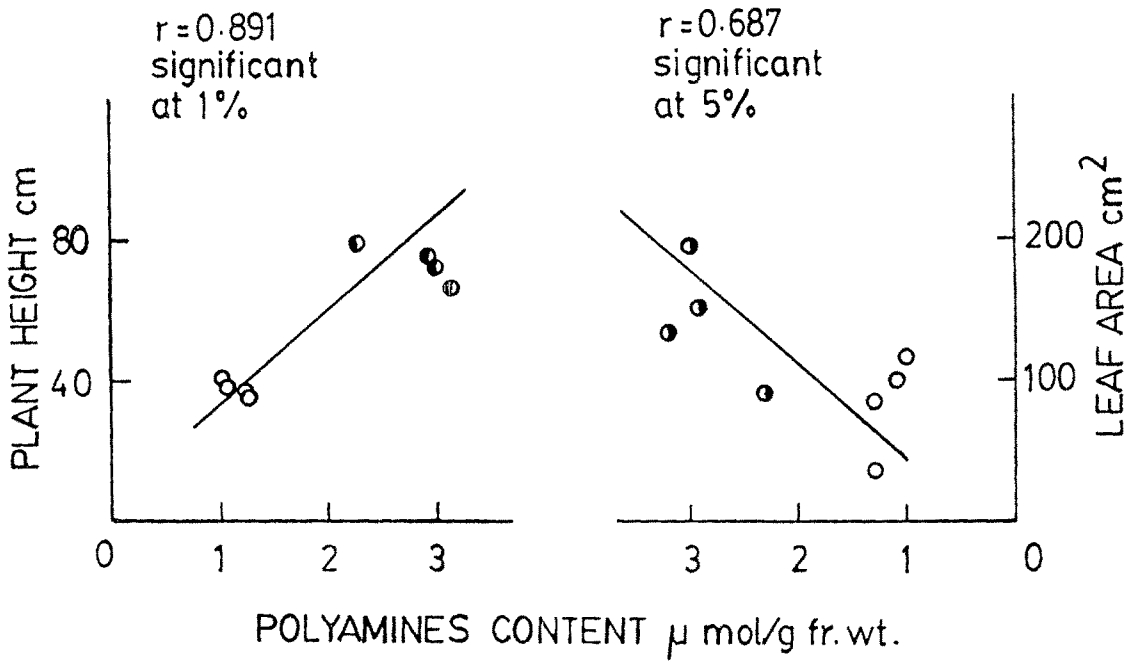


Fig. 24 Correlation of total polyamines content of rice cv GR 3 with the plant height and leaf area as affected by air pollution.

Table : 42 Response of GR 3 rice cultivar on the total nitrogen and sulphur contents in their shoots, grown near to (P), and 10 km distant from (C) the fertilizer plant with different chemical treatments.

Age in days	Putrescine		Spermidine		Spermine		Kinetin		Ascorbic acid		High-N	
	C	P	C	P	C	P	C	P	C	P	C	P
	Total nitrogen (mg/g dry weight)											
50	17.50 (1.18)	24.00 (0.80)	18.00 (0.74)	19.50 (0.52)	19.17 (0.84)	25.42 (1.34)	19.38 (0.51)	28.75 (1.51)	19.00 (1.20)	29.38 (2.51)	20.42 (0.34)	30.25 (0.42)
60	28.13 (1.16)	20.21 (0.97)	24.58 (2.68)	16.98 (0.98)	22.92 (0.84)	25.63 (0.91)	21.67 (0.45)	24.58 (0.84)	24.67 (0.14)	26.88 (0.78)	25.71 (0.36)	29.38 (0.51)
75	18.75 (0.27)	24.17 (1.34)	20.63 (0.19)	23.13 (1.51)	18.13 (0.51)	24.38 (1.30)	17.5 (0.51)	24.79 (2.17)	19.38 (0.34)	27.50 (1.35)	24.00 (1.20)	31.04 (1.45)
	Total sulphur (mg/g dry weight)											
50	2.83 (0.14)	2.65 (0.18)	2.65 (0.12)	2.62 (0.15)	2.79 (0.21)	2.61 (0.14)	2.62 (0.11)	2.98 (0.23)	2.50 (0.16)	2.65 (0.28)	2.24 (0.21)	2.44 (0.19)
60	2.75 (0.15)	2.85 (0.14)	2.84 (0.17)	2.75 (0.11)	2.88 (0.17)	2.89 (0.19)	2.61 (0.09)	2.81 (0.15)	2.85 (0.24)	2.98 (0.31)	2.30 (0.13)	2.66 (0.12)
75	2.75 (0.10)	2.81 (0.09)	2.88 (0.21)	2.82 (0.14)	2.94 (0.22)	3.02 (0.27)	2.87 (0.21)	2.82 (0.13)	2.64 (0.21)	2.92 (0.25)	2.60 (0.17)	3.12 (0.21)

C = control, P = polluted; values in parentheses represent SE of three replicates.

Table : 43 Response of GR 3 rice cultivar on the total fluoride content (µg/g dry weight) in their shoots, grown near to (P), and 10 km distant from (C), the fertilizer plant with different chemical treatments.

Age in days	Putrescine		Spermidine		Spermine		Kinetin		Ascorbic acid		High-N	
	C	P	C	P	C	P	C	P	C	P	C	P
50	14(1)	22(2)	15(1)	22(2)	13(1)	21(2)	14(1)	20(2)	17(2)	20(2)	17(2)	19(2)
60	18(2)	22(2)	13(1)	28(2)	16(2)	26(2)	15(1)	24(2)	15(1)	22(2)	14(1)	22(2)
75	15(1)	26(2)	18(2)	26(2)	15(1)	28(2)	12(1)	21(2)	12(1)	19(1)	15(2)	24(2)

Values in parentheses represent SE of three replicates.

than the reported values at 50 days. The increase in total N content was further improved at 75 days.

(h) Total Sulphur

In 50 day-old plants the total sulphur content in the shoot systems was found to be marginally increased in the kinetin, ascorbic acid and high N treated polluted site plants (Table 42). However, it appeared to decrease marginally in the polyamine sprayed polluted site plants. At the age of 60 and 75 days only high N and ascorbic acid treated plants showed an increase of 16 to 20 % and 5 to 11 % over their respective controls. In the rest of the treatments there was no marked change in the sulphur content of plants grown near the fertilizer plant.

(i) Fluoride

The high nitrogen treatment found to reduce the fluoride content of rice cultivars at 50 days and later the increase was upto 60 % over the control (Table 43). At the age of 60 days spermidine treated plants showed 115 % increase in the fluoride content over the control. The ascorbic acid treated plants also showed a lesser increase as observed in high N, while other treatments experienced an increase above 60 % at one time or other.

3.3.0 FUMIGATION STUDIES

3.3.1.0 Growth Responses

3.3.1.1 Shoot Length

The artificial fumigation of gaseous air pollutants on the rice seedlings between 21 and 30 days had invariably affected their shoot length, as recorded in 31 day-old plants (Table 44). To the individual fumigation of SO_2 and NH_3 the shoot length of cv CO 43 was significantly inhibited. However, a highly significant increase was observed in the cv GR 3 to NH_3 fumigation, under HN. The fumigation of NO_2 had increased the shoot length of cv TKM 9 under NN. The cvs CO 43 and TKM 9, grown under low N were adversely affected by the individual fumigation of NH_3 and SO_2. Conversely, the shoot length of cv GR 3 was found to be increased to NH_3 fumigation. The SO_2 fumigation showed an adverse effect as shown by reduced shoot length in cvs GR 3 and TKM 9 under high N, while NH_3 fumigation effected only reduction in cv TKM 9. Interestingly, all the three cultivars fumigated with NO_2 significantly increased their shoot length and it was greater in cv GR 3 followed by TKM 9 and CO 43 under HN.

The effect of the mixture of $SO_2$and NH_3 appeared to be adverse to cv CO 43 and favourable to cv GR 3 as depicted by their shoot length, under NN. The mixture of SO_2 + NO_2 found to be toxic to all the three cultivars as represented by the reduction in shoot length. The mixture of SO_2, NH_3 and NO_2 produced significant reduction in the shoot length of the cv CO 43 and there was no marked effect in other cultivars. Under low N the inhibition was evident in cv CO 43

Table : 44 Individual and combined effects of SO_2, NH_3 and NO_2 on the shoot length (cm) of rice cvs CO 43, GR 3 and TKM 9 under three N regimes.

	Normal N			Low N			High N			
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	Mean of Regimes
Individual fumigations										
Control	16.1	16.6	15.5	14.7	16.4	15.2	18.3	20.6	19.7	17.0
SO_2	13.7*	17.4	15.7	14.6	14.8	13.2*	19.2	17.7**	17.3*	16.0
NH_3	14.0*	20.3**	14.0	12.8*	19.8**	14.3	18.5	19.9	16.1**	16.6
NO_2	14.8	15.3	17.5*	15.4	15.9	14.3	20.9*	23.9**	21.9*	17.6
Mean of treatments	14.2	17.7	15.3	14.3	16.8	13.9	19.5	20.5	18.4	
	LSD at 1 % = 2.74 (**)and 5 % = 1.94 (*)									
Mixed fumigations										
Control	16.2	16.6	15.4	14.5	16.3	15.3	18.2	20.8	19.4	17.0
$SO_2 + NH_3$	13.6**	17.8*	15.7	13.5	16.2	14.3	14.3**	21.4	18.3	16.1
$SO_2 + NO_2$	13.7**	13.1**	14.1*	11.8**	17.4	14.3	17.6	21.6	21.7**	16.1
$SO_2 + NH_3 + NO_2$	14.3**	16.1	16.2	12.5*	17.9*	13.1**	21.6**	20.0	21.7**	17.0
Mean of treatments	13.9	15.7	15.3	12.6	17.2	13.9	17.8	21.0	20.6	
	LSD at 1 % = 1.72 (**)and 5 % = 1.22 (*)									

Table : 45 Individual and combined effects of SO_2, NH_3 and NO_2 on the root length (cm) of rice cvs CO 43, GR 3 and TKM 9 under three N regimes.

	Normal N			Low N			High N			Mean
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	of Regimes
Individual fumigations										
Control	7.0	6.3	7.5	8.1	7.4	7.4	8.7	6.5	6.6	7.28
SO_2	5.1**	4.9*	6.0*	7.1	6.6	6.3	8.3	7.0	5.2*	6.28
NH_3	5.3*	6.1	6.0*	7.1	7.3	6.5	7.3*	6.4	5.5	6.39
NO_2	7.8	5.4	8.4	6.8	7.2	6.8	8.4	6.8	4.9*	6.94
Mean of treatments	6.1	5.5	6.8	7.0	7.0	6.5	8.0	6.7	5.2*	
LSD 1 % = 1.9 (**) and 5 % = 1.4 (*)										
Mixed fumigations										
Control	7.0	6.4	7.4	8.0	7.3	7.3	8.4	6.3	6.2	7.14
SO_2 + NH_3	6.1	6.7	7.3	6.8	5.9*	7.7	8.8	6.7	6.4	6.93
SO_2 + NO_2	7.4	6.0	7.3	6.6*	7.6	7.7	8.1	6.4	6.0	7.00
SO_2 + NH_3 + NO_2	7.4	5.3	7.8	7.1	7.5	6.6	8.5	6.6	5.7	6.94
Mean of treatments	7.0	6.0	7.5	6.8	7.0	7.3	8.5	6.6	6.0	
LSD at 1 % = 1.8 (**) and 5 % = 1.3 (*)										

to SO_2 + NO_2 mixture. The mixture of SO_2, NH_3 and NO_2 rendered a reduction in the shoot length of the cvs CO 43 and TKM 9, while it increased in the cv GR 3. Under high N the mixture of SO_2 and NH_3 inhibited the shoot length of cv CO 43. The cv TKM 9 appeared to increase its shoot length to the fumigation of SO_2 + NO_2. The mixture of all the three pollutants significantly increased the shoot length in the cvs CO 43 and TKM 9 while it produced no effect on the cv GR 3 when compared to control.

3.3.1.2 Root Length

The individual fumigation of SO_2 brought about a significant reduction in the root length of all the cultivars under NN (Table 45). The inhibition was also significant to NH_3 fumigation in cvs CO 43 and TKM 9. NO_2 produced no significant effect. Under low N regime no considerable variation was occurred in the root length of the cultivars. Under high N a sharp reduction was evident in the cv TKM 9 to the individual fumigation of SO_2 and NO_2. NH_3 fumigation rendered a reduction in the root length of cv CO 43. The mean effect of individual treatments under HN regimed plants cv TKM 9 also showed a significant reduction. Under LN regime the exposure of SO_2 + NH_3 to cv GR 3 and SO_2 + NO_2 mixture to cv CO 43 were reduced the root length significantly.

3.3.1.3 Shoot Dry Matter

To the individual fumigation of SO_2 and NH_3 the cvs CO 43 and TKM 9 experienced a significant reduction under NN, while cv GR 3 showed a significantly increased shoot dry matter production (Table 46). NO_2 fumigation reduced the

Table : 46 Effects of individual and mixed fumigation of SO_2 , NH_3 and NO_2 on the shoot dry weight (mg) of three rice cultivars under three N regimes.

	Normal N			Low N			High N			
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	Mean of Regimes
Individual fumigations										
Control	21.3	24.0	26.0	18.0	22.0	25.0	25.0	33.0	29.5	24.9
SO_2	17.0**	25.8*	23.4**	18.0	16.7**	27.5**	25.0	26.7**	23.3**	22.6
NH_3	15.3**	38.3**	23.3**	13.0**	28.2**	19.0**	14.0**	33.3	23.6**	23.1
NO_2	19.2*	13.5**	25.7	18.0	22.0	20.8**	28.0**	35.6**	29.5	23.6
Mean of treatments	17.2	25.9	24.1	16.3	22.3	22.4	22.3	31.9	25.5	
	LSD at 1 % = 2.18 (**)and 5 % = 1.55 (*)									
Mixed fumigations										
Control	20.0	25.0	23.0	17.0	21.0	24.0	23.0	32.0	27.5	23.6
SO_2 + NH_3	21.2	29.0*	21.2	16.9	26.4**	24.3	21.5	37.3**	28.0	25.1
SO_2 + NO_2	13.9**	17.3**	18.5**	18.0	20.5	28.3**	21.8	29.0*	39.2**	22.9
SO_2 + NH_3 + NO_2	19.1	23.0	23.4	18.9	29.0**	22.3	28.5**	33.0	27.7	24.9
Mean of treatments	18.1	23.1	21.0	17.9	25.3	24.9	23.9	33.1	31.6	
	LSD at 1 % = 4.14 (**)and 5 % = 2.93 (*)									

amount of dry matter in the cv CO 43 and the reduction was highly significant in the cv GR 3. Under low N regimed plants, SO_2 decreased the dry matter in the cv GR 3 and increased in the cv TKM 9. NH_3 fumigation sharply decreased the accumulation in the cvs CO 43 and TKM 9 while it increased in cv GR 3. Under high N cultivars GR 3 and TKM 9 were sharply affected by SO_2 fumigation and cvs CO 43 and TKM 9 were affected by NH_3 fumigation. NO_2 increased the shoot dry matter in the cvs CO 43 and GR 3 under HN. Interestingly, NH_3 fumigation reduced the amount in the cv TKM 9 under all the N regimes.

The mixture of SO_2 and NH_3 brought about a significant increase in the cv GR 3 in their shoot dry weight. The mixture of SO_2 and NO_2 reduced the dry matter sharply in all the cultivars under NN. LN regimed plants of cv GR 3 when exposed to the mixture of SO_2 + NH_3 and SO_2 + NH_3 + NO_2 and the cv TKM 9 to the mixture of SO_2 + NO_2 showed a significant increase in their shoot dry matter. Under HN, SO_2 + NH_3 rendered a significantly high dry matter accumulation in the cv GR 3, however, it was reduced in plants exposed to the SO_2 + NO_2 mixture, Nevertheless, cv TKM 9 showed significant increase in the presence of SO_2 + NO_2. To the mixture of the three pollutants, cv CO 43 experienced a significant increase while others showed no effect.

3.3.1.4 Root Dry Matter

Individual fumigation of SO_2 and NH_3 significantly increased the root dry matter accumulation in the cv TKM 9 (Table 47). Under deficient N SO_2 and NH_3 fumigation brought about significant increase in the root dry matter in cv GR 3. The mean of all the treatments in NN and LN regimes also showed corresponding

Table : 47 Individual and combined effects of SO_2, NH_3 and NO_2 pollutants on the root dry weight (mg) of three rice cultivars under three N regimes.

	Normal N			Low N			High N			
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	Mean of Regimes
Individual fumigations										
Control	6.0	8.0	6.7	6.0	10.0	9.0	7.0	8.0	7.0	7.52
SO_2	5.1	8.0	8.4*	5.7	11.7*	10.4	6.5	9.0	7.3	8.01
NH_3	5.7	8.0	8.4*	6.0	11.7*	10.4	6.5	9.0	7.3	8.11
NO_2	5.3	6.8	7.7	6.5	11.0	8.6	7.3	8.0	6.3	7.50
Mean of treatments	5.4	7.6	8.2*	6.1	11.5*	9.8	6.8	8.7	7.0	
	LSD at 1 % = 2.09 (**)and 5 % = 1.48 (*)									
Mixed fumigations										
Control	6.0	8.0	6.6	6.1	10.1	8.9	6.9	8.2	7.2	7.56
$SO_2 + NH_3$	6.3	8.4	6.5	6.2	10.0	7.8	7.2	9.6*	8.1	7.79
$SO_2 + NO_2$	6.0	6.8*	5.7	6.0	11.5*	10.3*	6.4	6.9*	7.9	7.50
$SO_2 + NH_3 + NO_2$	6.0	9.2*	7.0	7.2*	10.0	8.7	7.4	7.7	7.0	7.80
Mean of treatments	6.1	8.1	6.4	6.5	10.5	8.9	7.0	8.1	7.7	
	LSD at 1 % = 1.6 (**)and 5 % = 1.14 (*)									

increase. To the mixture of SO_2 and NO_2 the root dry weight was sharply reduced in the cv GR 3. However, it was increased as a response to the fumigation mixture of SO_2 + NH_3 + NO_2. Low N regime brought about considerable increase in the root dry weight of cvs GR 3 and TKM 9 towards SO_2 and NO_2 mixture. The cv CO 43 increased its root dry matter under SO_2 + NH_3 + NO_2 fumigation, under HN, SO_2 + NH_3 mixture produced tremedous increase in the cv GR 3 while it was decreased towards SO_2 + NO_2 mixture.

3.3.1.5 Total Leaf Area (TLA)

The individual fumigation of SO_2 brought about a decrease in the total leaf area of the cv CO 43 and a significant increase in the cv GR 3 (Table 48). NH_3 fumigation also produced an increase in the TLA of the cv GR 3 but sharply decreased in the cv TKM 9. However, TLA was appeared to increase in the cv TKM 9 to NO_2. Under deficient N the TLA of cv TKM 9 was sharply reduced to SO_2 and NH_3 fumigations whereas in cv GR 3 it was increased under NH_3 fumigation. The same pattern of effects were evident under high N regimed plants. Besides that NO_2 fumigation also increased the TLA of cvs GR 3 and TKM 9.

The fumigation mixture of SO_2 and NH_3 effected an increase in the TLA of the cv GR 3 under NN. But, the mixture of SO_2 + NO_2 produced a reduction in the cvs GR 3 and TKM 9. The mixture of all the three pollutants rendered a marked reduction in the TLA of the cv CO 43. Under low N the mixture of SO_2, NH_3 and NO_2 produced a significant increase in the TLA of the cv GR 3 while the TLA was decreased in TKM 9. Under HN regime the cv GR 3 had an increased TLA to the mixture of SO_2 + NH_3 and cv TKM 9 had a decreased one.

Table : 48 Individual and combined effects of SO_2, NH_3 and NO_2 on the total leaf area (cm^2) of three rice cultivars under three N regimes.

	Normal N			Low N			High N			Mean of Regimes
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	
Individual fumigations										
Control	7.2	8.5	8.2	6.3	6.4	7.4	10.5	12.9	11.3	8.7
SO_2	6.2*	9.5*	8.9	5.7	6.0	6.0**	11.1	12.4	9.7**	8.4
NH_3	6.8	9.6*	5.9**	6.0	7.3*	6.1**	11.1	13.8*	9.8**	8.5
NO_2	7.2	7.9	9.3*	5.9	6.5	7.3	10.9	13.8*	12.3*	9.0
Mean of treatments	6.7	9.0	8.0	5.9	6.6	6.5	11.0	13.3	10.6	
	LSD at 1 % = 1.35 (**) and 5 % = 0.9 (*)									
Mixed fumigations										
Control	7.1	8.6	8.2	6.2	6.4	7.4	10.2	12.7	11.1	8.7
$SO_2 + NH_3$	6.9	9.6*	8.2	7.1*	6.5	6.5*	9.9	16.3**	9.8*	9.0
$SO_2 + NO_2$	6.6	7.8*	6.9**	5.8	6.9	8.1	12.4**	13.7*	12.1*	8.9
$SO_2 + NH_3 + NO_2$	6.0*	9.1	8.0	6.5	7.3*	5.9*	11.1*	12.6	12.4**	8.8
Mean of treatments	6.5	8.8	7.7	6.5	6.9	6.8	11.1	14.2	11.4	
	LSD at 1 % = 1.3 (**) and 5 % = 0.8 (*)									

It was interesting to note that the TLA of all the cultivars were significantly increased to SO_2 and NO_2 mixture. To the mixture of all the three pollutants the cvs CO 43 and TKM 9 experienced an increase while cv GR 3 showed no effect on their TLA. No significant visible injury symptoms were observed except few indications of marginal decolouration in the older leaves of rice plants to SO_2 alone and its combinations with the other pollutants, 8 days after the commencement of fumigations.

3.3.1.6 Leaves Dry Matter

The dry matter of leaves was found to be considerably reduced in the cv CO 43 towards SO_2 fumigation, while it was significantly increased in the cvs GR 3 and TKM 9 (Table 49). NH_3 fumigation brought about a highly significant increase in leaves dry matter in the cv GR 3, though, it sharply decreased in the leaves dry matter of the cv TKM 9, under NN. In low N regimed plants of cv GR 3 the dry matter was sharply reduced by SO_2 fumigation but was significantly increased under NH_3 fumigation. A significant decrease was also evident in the cv CO 43 to NH_3 and in the cv TKM 9 to NO_2 fumigation. High N regimed plants of GR 3 cultivar showed a significant reduction to SO_2 and an increment to NH_3 fumigation, as observed in the LN regime. Nevertheless, the cv TKM 9 which experienced a sharp reduction in the leaves dry matter under low N, significantly increased the same under high N to NO_2 fumigation.

The fumigation mixture of SO_2 and NH_3 brought about a highly significant increase in the dry matter of leaves in the cv GR 3 while the dry matter accumulation was sharply reduced in the cv TKM 9, under NN. However, both the

Table : 49 Changes in the leaves dry weight (mg/plant) of three rice cultivars due to SO_2, NH_3 and NO_2 individual and in combinations under three N regimes.

	Normal N			Low N			High N			
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	Mean of Regimes
Individual fumigations										
Control	11.0	14.0	15.0	10.0	13.0	15.0	14.0	19.0	15.0	14.0
SO_2	9.6*	15.8*	16.5*	10.0	11.2*	13.7	14.3	17.3*	16.0	13.8
NH_3	10.7	16.1**	13.5*	8.7*	14.8*	14.0	14.0	21.3**	13.9	14.1
NO_2	11.0	13.4	14.1	9.0	12.0	13.4*	14.7	20.1	18.2**	14.0
Mean of treatments	10.4	15.1	14.7	9.2	12.7	13.7	14.3	19.6	16.0	
LSD at 1 % = 2.0 (**) and 5 % = 1.4 (*)										
Mixed fumigations										
Control	10.7	13.0	16.0	9.0	13.3	15.0	13.7	20.0	14.0	13.9
$SO_2 + NH_3$	12.0	16.9**	12.2**	10.0	13.0	15.0	14.8	22.0*	13.6	14.4
$SO_2 + NO_2$	9.4	11.1*	12.0**	12.2**	13.4	16.5*	13.3	19.0	16.8*	13.7
$SO_2 + NH_3 + NO_2$	9.1*	14.0	14.0*	9.5	14.8*	13.1*	14.7	19.0	17.0*	13.9
Mean of treatments	10.2	14.0	12.7	10.6	13.7	14.9	14.3	20.0	15.8	
LSD at 1 % = 2.2 (**) and 5 % = 1.5 (*)										

cultivars experienced a reduction towards the fumigation mixture of SO_2 and NO_2. The mixture of all the three pollutants produced a significant reduction in the leaves dry matter accumulation in the cvs CO 43 and TKM 9, while the cv GR 3 showed no significant effect. Under low N regimed plants cvs CO 43 and TKM 9 showed a considerable increase in the leaves dry matter accumulation to SO_2 and NO_2 mixture. Combination of all the three pollutants brought about an increase in the cv GR 3 but dry matter accumulation in the leaves was decreased in the cv TKM 9. Under high N cv GR 3 produced significantly high amount of leaves dry matter to SO_2 and NH_3 mixture. The cv TKM 9 showed significant increase towards SO_2 + NO_2 mixture and to the mixture of all the pollutants.

3.3.1.7 Specific Leaf Area, (SLA)

The cv TKM 9 experienced a significant reduction in the SLA to NH_3 fumigation and it was increased to NO_2 fumigation (Table 50). The low N regimed plants of cv CO 43 showed a sharp reduction in the SLA to SO_2 and increment to NH_3 fumigation. High N regime rendered a sharp reduction in the SLA of cv TKM 9 towards SO_2 fumigation. The mixture of SO_2 and NH_3 produced an inhibition in the SLA of the cv CO 43. On the other hand SO_2 and NO_2 mixture had significantly increased the SLA of the cv GR 3. Low N regimed plants of cv CO 43 showed increased SLA to SO_2 and NH_3 mixture but reduced to SO_2 and NO_2 mixture. Under high N also cv CO 43 showed same pattern of reduction to SO_2 and NO_2 mixture but increased to the mixture of all the three pollutants. The cv GR 3 increased the SLA to the fumigation of SO_2 and NH_3 mixture, however, the SLA was reduced in the cv TKM 9.

Table : 50 Individual and combined effects of SO_2, NH_3 and NO_2 on the specific leaf area (cm^2/g dry weight) of three rice cultivars, under three N regimes.

	Normal N			Low N			High N			Mean of Regimes
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	
Individual fumigations										
Control	655	607	547	630	492	493	750	679	706	618
SO_2	646	601	542	567*	536	439	773	720	509**	604
NH_3	650	583	444**	699*	497	434	795	645	699	605
NO_2	681	589	656**	655	541	547	743	686	671	641
Mean of treatments	659	591	547	640	525	473	770	684	660	
LSD at 1 % = 88.5 (**)and 5 % = 63 (*)										
Mixed fumigations										
Control	648	610	547	625	492	490	738	675	701	614
SO_2 + NH_3	576**	565	574	712*	502	434	675	754*	530**	591
SO_2 + NO_2	707	710**	574	473**	510	494	645**	720	720	617
SO_2 + NH_3 + NO_2	648	649	635	617	492	463	833**	665	727	637
Mean of treatments	644	641	594	601	501	463	718	713	659	
LSD at 1 % = 97 (**)and 5 % = 69 (*)										

3.3.2.0 Physiological and Biochemical Responses

3.3.2.1 (a) Chlorophyll 'a'

The content of Chl 'a' appeared to be invariably affected in the cultivars of rice under the fumigation of gaseous air pollutants (Table 51). A marginal reduction was evident in the cv GR 3 under NN and LN regimes to SO_2 fumigation. Though cv TKM 9 showed an increase to SO_2 under NN, LN regime brought about reduction in Chl 'a' resembling the cv CO 43 whereunder the level was decreased. Interestingly, cv GR 3 increased the amount of Chl 'a' to NH_3 fumigation under NN and LN regimes. The level of Chl 'a' was found to be reduced in cv CO 43 under NN. The fumigation of NO_2 rendered a reduction in the Chl 'a' of cv GR 3 but the content was enhanced under LN of the cv TKM 9 . The content of Chl 'a' seemed to be high to the mixture of SO_2 and NH_3 in the cv GR 3 in general. Typically the mixture of SO_2 and NO_2 was found to be highly sensitive in all the regimes of rice cultivars showing mostly inhibition under NN. The mixture of all the three pollutants produced a considerable reduction in the cv CO 43 under NN, however, the content was increased in cv GR 3 under NN and LN regimes.

(b) Chlorophyll 'b'

The content of Chl 'b' was found to be reduced under NN in cv TKM 9 and there was no significant effect in others as a response to SO_2 fumigation (Table 52). SO_2 had reduced the amount of Chl 'b' under LN in cvs CO 43 and TKM 9 and under HN in cvs CO 43 and GR 3. NH_3 fumigation brought about an inhibition in the cv CO 43 by 12 % under NN. The cv GR 3 had a marginal

Table : 51 Individual and combined effects of SO_2, NH_3 and NO_2 on the chlorophyll 'a' content (μ moles/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	1.71 (0.06)	1.87 (0.12)	1.81 (0.12)	1.67 (0.13)	1.58 (0.06)	1.96 (0.06)	1.84 (0.11)	1.96 (0.08)	2.08 (0.18)
SO_2	1.78 (0.08)	1.64 (0.10)	2.20 (0.17)	1.33 (0.09)	1.40 (0.08)	1.73 (0.16)	1.65 (0.10)	1.88 (0.10)	1.85 (0.11)
NH_3	1.50 (0.09)	2.41 (0.16)	1.74 (0.13)	1.60 (0.08)	1.74 (0.06)	1.90 (0.13)	1.54 (0.13)	2.03 (0.08)	2.00 (0.17)
NO_2	1.55 (0.13)	1.55 (0.11)	1.85 (0.14)	1.70 (0.11)	1.45 (0.12)	2.10 (0.15)	1.91 (0.09)	1.86 (0.09)	2.02 (0.16)
Mixed fumigations									
Control	1.68 (0.14)	1.79 (0.14)	1.78 (0.13)	1.70 (0.13)	1.61 (0.08)	2.02 (0.11)	1.72 (0.06)	2.01 (0.08)	1.93 (0.08)
$SO_2 + NH_3$	1.73 (0.13)	2.09 (0.07)	1.71 (0.18)	1.47 (0.11)	1.85 (0.09)	2.06 (0.18)	1.64 (0.14)	2.13 (0.09)	2.07 (0.08)
$SO_2 + NO_2$	1.36 (0.10)	1.48 (0.13)	1.48 (0.13)	1.65 (0.12)	1.55 (0.14)	1.82 (0.08)	1.61 (0.08)	1.89 (0.14)	2.11 (0.10)
$SO_2 + NH_3 + NO_2$	1.52 (0.13)	2.13 (0.14)	1.72 (0.12)	1.21 (0.11)	1.50 (0.09)	2.04 (0.15)	1.70 (0.13)	2.13 (0.16)	1.86 (0.15)

Values in parentheses represent SE of three replicates.

Table : 52 Individual and combined effects of SO_2, NH_3 and NO_2 on the chlorophyll 'b' content (μ moles/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	0.90 (0.04)	1.14 (0.07)	1.22 (0.08)	0.85 (0.08)	0.98 (0.04)	1.17 (0.09)	1.07 (0.09)	1.34 (0.11)	1.40 (0.04)
SO_2	0.84 (0.03)	1.18 (0.11)	0.74 (0.07)	0.69 (0.05)	0.98 (0.05)	0.95 (0.06)	0.76 (0.07)	1.17 (0.05)	1.36 (0.11)
NH_3	0.79 (0.05)	1.19 (0.08)	1.16 (0.04)	0.89 (0.07)	0.99 (0.04)	1.15 (0.13)	0.97 (0.08)	1.57 (0.08)	1.35 (0.12)
NO_2	0.92 (0.07)	1.05 (0.04)	1.35 (0.13)	0.67 (0.10)	0.87 (0.06)	1.14 (0.11)	1.05 (0.09)	1.29 (0.04)	1.56 (0.10)
Mixed fumigations									
Control	0.95 (0.05)	1.16 (0.05)	1.32 (0.11)	0.88 (0.04)	0.96 (0.06)	1.18 (0.09)	1.08 (0.04)	1.28 (0.08)	1.50 (0.13)
$SO_2 + NH_3$	0.95 (0.08)	1.27 (0.08)	1.02 (0.08)	0.85 (0.05)	0.98 (0.05)	1.09 (0.04)	1.10 (0.08)	1.43 (0.05)	1.21 (0.08)
$SO_2 + NO_2$	0.78 (0.07)	0.94 (0.09)	1.39 (0.09)	0.82 (0.07)	0.90 (0.08)	1.10 (0.09)	0.94 (0.05)	1.22 (0.08)	1.58 (0.14)
$SO_2 + NH_3 + NO_2$	0.56 (0.08)	1.46 (0.13)	1.43 (0.13)	0.70 (0.05)	0.94 (0.07)	1.23 (0.12)	0.89 (0.09)	1.32 (0.06)	1.46 (0.14)

Values in parentheses represent SE of three replicates.

enhancement in the Chl 'b' content to NH_3 fumigation under HN and there was no marked effect in others. To NO_2 fumigation cv TKM 9 showed an increase in the Chl 'b' content under NN while cv GR 3 experienced a 8 % reduction over the control. The cv CO 43 under LN regime showed a reduction by 21 % but a 11 % increase was evident under HN to NO_2 fumigation in the same cultivar.

The mixed fumigation of SO_2 and NH_3 reduced the amount of Chl 'b' in the cv TKM 9. The cv CO 43 showed not much difference under all the N regimes, while in cv GR 3 HN resulted in a 12 % increase. Inhibition of 18 and 19 % were evident in NN regime of cv CO 43 and GR 3 to the mixture of SO_2 and NO_2. The fumigation of all the three gases depicted a decrease in CO 43 and an increase in GR 3 and TKM 9 cultivars under NN regimes. The inhibition was minimised under LN and HN of CO 43 and there were no significant effects in cvs GR 3 and TKM 9.

(c) Total Chlorophyll

Under NN regime the cv CO 43 showed no disparity between the control and the individual fumigation of SO_2 and NO_2 under NN but showed a marginal reduction in the total Chl content to NH_3 fumigation (Table 53). The cv GR 3 showed an interesting increase of 20 % to NH_3 treatment but there was a marginal inhibition to SO_2 and NO_2. On the other hand, cv TKM 9 showed no significant effect to SO_2, NH_3 and NO_2 individually. Under LN there was a marginal reduction in cvs CO 43 and TKM 9 to SO_2 fumigation and under HN regime the reduction in the total Chl was noted only in cv CO 43.

Table : 53 Individual and combined effects of SO_2, NH_3 and NO_2 on the total chlorophyll content (μ moles/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	2.61 (0.13)	3.00 (0.19)	3.03 (0.21)	2.52 (0.21)	2.56 (0.23)	3.13 (0.15)	2.90 (0.20)	3.30 (0.19)	3.49 (0.27)
SO_2	2.61 (0.11)	2.82 (0.24)	2.94 (0.24)	2.03 (0.14)	2.38 (0.13)	2.68 (0.22)	2.41 (0.17)	3.05 (0.15)	3.22 (0.22)
NH_3	2.30 (0.14)	3.60 (0.24)	2.90 (0.17)	2.49 (0.15)	2.74 (0.10)	3.05 (0.27)	2.51 (0.21)	3.61 (0.16)	3.35 (0.29)
NO_2	2.47 (0.18)	2.60 (0.15)	3.20 (0.27)	2.37 (0.21)	2.32 (0.18)	3.24 (0.26)	2.96 (0.16)	3.15 (0.13)	3.58 (0.26)
Mixed fumigations									
Control	2.63 (0.19)	2.95 (0.19)	3.10 (0.24)	2.58 (0.17)	2.57 (0.14)	3.20 (0.20)	2.80 (0.10)	3.29 (0.16)	3.44 (0.21)
$SO_2 + NH_3$	2.66 (0.21)	3.36 (0.15)	2.72 (0.26)	2.31 (0.16)	2.83 (0.14)	3.15 (0.22)	2.74 (0.22)	3.57 (0.14)	3.28 (0.16)
$SO_2 + NO_2$	2.14 (0.17)	2.42 (0.23)	2.86 (0.23)	2.47 (0.19)	2.45 (0.22)	2.93 (0.17)	2.55 (0.12)	3.11 (0.22)	3.68 (0.24)
$SO_2 + NH_3 + NO_2$	2.09 (0.21)	3.59 (0.27)	3.15 (0.25)	1.90 (0.16)	2.44 (0.14)	3.27 (0.27)	2.59 (0.23)	3.45 (0.22)	3.31 (0.29)

Values in parentheses represent SE of three replicates.

The cv CO 43 showed not much effect in its total Chl fumigated with the mixture of SO_2 and NH_3 but was reduced by 19 and 20 % to SO_2 + NO_2 and SO_2 + NH_3 + NO_2 mixtures. On the other hand cv GR 3 showed a marginal increase in total Chl to the fumigation of SO_2 + NH_3 and SO_2 + NH_3 + NO_2 mixtures, but was reduced to SO_2 + NO_2. The cv TKM 9 depicted no significant effect to the mixed fumigations under NN. Though the mixture of SO_2 and NH_3 under LN brought about a reduction in the total Chl of cv CO 43 and an increase in cv GR 3, they were insignificant. To the mixture of SO_2 and NO_2 under HN regime, cv CO 43 responded with a reduction in the total Chl. To the fumigation of SO_2, NH_3 and NO_2 mixture the cv CO 43 showed a 26 % reduction under LN regime and the cvs GR 3 and TKM 9 indicated no significant effect under LN and HN regimes.

(d) Chlorophyll Temperature Stability Index (CTSI)

The individual fumigation of SO_2 and NO_2 produced a lesser chlorophyll stability indices in cv CO 43 and TKM 9 under NN than the controls (Table 54). The cv GR 3 experienced a higher value to NO_2. The NH_3 fumigation decreased the CTSI in cv GR 3 and increased in cv TKM 9. Under LN the CTSI was found to be less in cvs CO 43 and TKM 9 to SO_2 and high in cv GR 3. To NH_3 fumigation cv TKM 9 showed reduced value under LN. To NO_2 cv GR 3 dramatically increased the index while cv CO 43 responded with a decrease under LN. Under high N cv CO 43 increased the CTSI to NH_3 and decreased to NO_2. A lesser values were evident in cv GR 3 to NH_3 and TKM 9 to SO_2 fumigation under HN than the controls.

Fumigation of SO_2 + NH_3 decreased the stability index in cvs GR 3 and TKM 9 while SO_2 + NO_2 increased it in all the cultivars. Mixture of three pollutants

Table : 54 Individual and combined effects of SO_2, NH_3 and NO_2 on the chlorophyll temperature stability index (mg/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	0.55 (0.05)	0.30 (0.03)	0.31 (0.04)	0.52 (0.06)	0.30 (0.04)	0.27 (0.03)	0.35 (0.04)	0.29 (0.06)	0.19 (0.04)
SO_2	0.44 (0.04)	0.37 (0.03)	0.24 (0.03)	0.33 (0.05)	0.42 (0.06)	0.15 (0.04)	0.28 (0.04)	0.27 (0.04)	0.10 (0.02)
NH_3	0.63 (0.07)	0.17 (0.03)	0.41 (0.04)	0.62 (0.04)	0.27 (0.03)	0.46 (0.08)	0.52 (0.08)	0.16 (0.03)	0.28 (0.07)
NO_2	0.40 (0.06)	0.45 (0.07)	0.16 (0.04)	0.39 (0.04)	0.56 (0.07)	0.28 (0.04)	0.16 (0.02)	0.36 (0.04)	0.25 (0.03)
Mixed fumigations									
Control	0.62 (0.05)	0.37 (0.05)	0.29 (0.02)	0.58 (0.05)	0.38 (0.04)	0.28 (0.04)	0.43 (0.06)	0.31 (0.03)	0.21 (0.03)
$SO_2 + NH_3$	0.66 (0.04)	0.25 (0.03)	0.23 (0.03)	0.76 (0.09)	0.41 (0.04)	0.37 (0.05)	0.86 (0.10)	0.21 (0.04)	0.39 (0.04)
$SO_2 + NO_2$	0.76 (0.06)	0.49 (0.04)	0.34 (0.03)	0.58 (0.04)	0.51 (0.06)	0.28 (0.04)	0.36 (0.04)	0.66 (0.08)	0.45 (0.08)
$SO_2 + NH_3 + NO_2$	0.52 (0.04)	0.34 (0.03)	0.27 (0.02)	0.45 (0.03)	0.31 (0.04)	0.28 (0.05)	0.75 (0.09)	0.35 (0.04)	0.47 (0.05)

Values in parentheses represent SE of three replicates.

showed a marginal decrease in cv CO 43. LN regimed plants showed significant increase in the CTSI of cv CO 43 to SO_2 + NH_3 and of cv GR 3 to SO_2 + NO_2 mixture. The mixture of three pollutants reduced the index in cv CO 43 and no effect in cv TKM 9. To the mixture of SO_2 and NH_3, HN regimed plants tremendously increased the stability index while it was decreased in cv GR 3. However, to the mixture of SO_2 and NO_2 cvs GR 3 and TKM 9 showed increased indices under HN and to the mixture of all, the cvs CO 43 and TKM 9 exhibited increased values dramatically. The increase was 1.2 fold in cv TKM 9.

(e) Carotenoids

The individual fumigation of SO_2 brought about a 13 % increase in the carotenoids content in cvs GR 3 and TKM 9 under NN (Table 55). The cvs CO 43 and TKM 9 under HN experienced a 13 % decrease in their carotenoids content to SO_2. The cv TKM 9 seemed to be sensitive to NH_3 fumigation by showing 21 % reduction under NN. However, the level of carotenoids was marginally increased in all the regimes of cv GR 3. HN regimed plants reduced the carotenoids content to NH_3 fumigation by 25 % in cv TKM 9. NO_2 fumigation brought about a marginal decrease in GR 3 and an increase in TKM 9 cultivars under NN regime. The cvs CO 43 and GR 3 experienced only inhibition under LN and HN, whereas cv TKM 9 depicted no significant effect to NO_2 fumigation.

The mixture of SO_2 and NH_3 rendered a modest increase in the cvs CO 43 and GR 3 and a decrease in TKM 9 under NN. HN regimed plants showed a marginal increase in the carotenoids content in cv GR 3 to SO_2 + NH_3 mixture, while there was not much effect in other cultivars. The cultivars CO 43

Table : 55 Individual and combined effects of SO_2, NH_3 and NO_2 on the carotenoids content (mg/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	0.785 (0.050)	0.918 (0.011)	0.920 0.013)	0.804 (0.020)	0.855 (0.004)	0.897 (0.016)	0.876 (0.026)	0.941 (0.019)	0.951 (0.060)
SO_2	0.761 (0.022)	1.037 (0.044)	1.040 (0.041)	0.836 (0.029)	0.881 (0.028)	0.915 (0.011)	0.762 (0.022)	0.979 (0.042)	0.827 (0.013)
NH_3	0.754 (0.024)	0.936 (0.023)	0.727 (0.090)	0.868 (0.014)	0.915 (0.026)	0.897 (0.026)	0.823 (0.014)	0.997 (0.011)	0.713 (0.023)
NO_2	0.793 (0.038)	0.845 (0.002)	0.975 (0.012)	0.740 (0.016)	0.828 (0.005)	0.924 (0.021)	0.774 (0.013)	0.894 (0.058)	1.000 (0.013)
Mixed fumigations									
Control	0.801 (0.020)	0.920 (0.014)	0.923 (0.013)	0.807 (0.013)	0.862 (0.023)	0.900 (0.014)	0.890 (0.034)	0.945 (0.017)	0.965 (0.054)
$SO_2 + NH_3$	0.849 (0.013)	0.975 (0.022)	0.877 (0.026)	0.823 (0.011)	0.845 (0.026)	0.870 (0.021)	0.917 (0.006)	1.011 (0.059)	0.994 (0.021)
$SO_2 + NO_2$	0.737 (0.021)	0.846 (0.025)	0.941 (0.011)	0.718 (0.021)	0.802 (0.028)	0.924 (0.035)	0.846 (0.022)	0.828 (0.026)	1.023 (0.015)
$SO_2 + NH_3 + NO_2$	0.745 (0.014)	0.994 (0.040)	0.941 (0.011)	0.775 (0.016)	0.819 (0.013)	0.906 (0.016)	0.837 (0.030)	0.903 (0.016)	0.859 (0.013)

Values in parentheses represent SE of three replicates.

Table : 56 Individual and combined effects of SO_2, NH_3 and NO_2 on the ascorbic acid content (mg/g fr. wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	0.76 (0.04)	1.03 (0.08)	1.08 (0.07)	1.03 (0.09)	1.07 (0.03)	1.12 (0.06)	1.02 (0.10)	1.20 (0.09)	1.16 (0.09)
SO_2	0.69 (0.03)	1.07 (0.10)	0.93 (0.06)	0.78 (0.08)	0.94 (0.08)	0.86 (0.09)	1.00 (0.08)	0.92 (0.06)	1.18 (0.12)
NH_3	0.64 (0.03)	0.56 (0.07)	0.43 (0.04)	0.72 (0.04)	0.52 (0.09)	0.67 (0.03)	0.58 (0.06)	0.91 (0.07)	0.51 (0.08)
NO_2	1.13 (0.11)	0.66 (0.08)	0.99 (0.08)	1.26 (0.14)	1.06 (0.19)	0.96 (0.05)	1.14 (0.08)	1.08 (0.08)	0.99 (0.06)
Mixed fumigations									
Control	0.76 (0.05)	1.02 (0.06)	1.09 (0.09)	1.04 (0.10)	1.08 (0.08)	1.11 (0.09)	1.01 (0.07)	1.22 (0.05)	1.17 (0.09)
SO_2 + NH_3	0.37 (0.12)	1.15 (0.09)	0.95 (0.06)	0.97 (0.08)	0.98 (0.08)	1.12 (0.10)	0.69 (0.05)	1.34 (0.08)	1.22 (0.10)
SO_2 + NO_2	0.58 (0.04)	0.79 (0.08)	1.06 (0.11)	0.83 (0.06)	0.72 (0.06)	0.89 (0.05)	0.74 (0.04)	1.25 (0.09)	1.03 (0.08)
SO_2 + NH_3 + NO_2	0.82 (0.07)	0.81 (0.07)	0.73 (0.07)	0.98 (0.09)	1.24 (0.11)	0.76 (0.07)	1.24 (0.12)	0.91 (0.04)	1.06 (0.09)

Values in parentheses represent SE of three replicates.

in its endogenous ascorbic acid content. The cv GR 3 also showed a marginal reduction under NN. To the mixture of SO_2, NH_3 and NO_2 fumigation a decreased level of ascorbic acid content was noted in cvs GR 3 and TKM 9 under NN. However, LN seemed to induce the level of ascorbic acid in the cv GR 3 and HN induced in cv CO 43 while in cv TKM 9 a reduction was evident under LN.

3.3.2.3 Free Proline

The individual fumigation of SO_2, NH_3 and NO_2 always induced an accumulation of a high amount of free proline content in the leaves of cvs GR 3 and TKM 9 under HN (Table 57). A lesser accumulation of proline than the control under NO_2 stress was evident under NN in all the cultivars. In response to air pollution mixtures, proline content was enhanced in cvs GR 3 and TKM 9. On the contrary, cv CO 43 generally showed a reduction in the proline content even under high N regime towards fumigations.

3.3.2.4 Total Nitrogen

The changes in the total nitrogen content in the shoot of rice cultivars as affected by the fumigation of air pollutants are presented in Table 58. The cv GR 3 showed a reduction by 9 % to SO_2 fumigation under NN, but increased under LN. However, under HN only cvs CO 43 and TKM 9 could accumulate a marginally high amount of total N. On the other hand, to NH_3 fumigation only cv GR 3 could show a modest increase under LN and HN, while cv CO 43 experienced a marginal reduction under LN. The fumigation of NO_2 rendered the cv TKM 9 to increase the total nitrogen by 21 % under LN, and the cv CO 43 decrease marginally under HN.

Table : 58 Individual and combined effects of SO_2, NH_3 and NO_2 on the total nitrogen (mg/g dry wt.) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	16.89 (0.81)	18.11 (0.69)	15.93 (0.64)	13.44 (0.61)	15.50 (0.42)	15.81 (0.90)	18.20 (0.75)	18.80 (0.81)	19.11 (0.90)
SO_2	16.89 (0.90)	16.48 (0.48)	16.09 (0.92)	13.70 (0.98)	16.90 (0.51)	16.44 (0.82)	20.57 (1.27)	19.74 (0.84)	21.82 (1.21)
NH_3	16.22 (0.78)	18.83 (0.51)	15.45 (1.1)	11.15 (0.62)	17.36 (1.21)	14.86 (0.96)	17.47 (0.98)	21.43 (1.50)	19.49 (0.42)
NO_2	16.39 (0.72)	17.39 (0.48)	16.72 (0.90)	13.03 (0.80)	14.95 (0.86)	19.13 (0.70)	17.10 (0.38)	17.04 (1.10)	18.53 (0.67)
Mixed fumigations									
Control	17.48 (0.87)	18.13 (0.90)	16.13 (0.58)	13.88 (0.65)	15.79 (0.87)	15.96 (0.74)	18.83 (0.79)	19.15 (1.12)	19.31 (0.74)
SO_2 + NH_3	15.21 (0.48)	18.13 (0.81)	15.48 (0.69)	13.04 (0.98)	19.27 (1.19)	15.63 (0.93)	18.78 (0.77)	22.21 (0.81)	20.66 (0.90)
SO_2 + NO_2	13.98 (0.69)	13.05 (0.63)	17.58 (0.72)	17.20 (1.17)	18.63 (0.80)	16.44 (0.77)	18.62 (0.97)	14.93 (1.61)	20.67 (0.98)
SO_2 + NH_3 + NO_2	17.43 (0.90)	18.67 (0.82)	17.09 (1.00)	13.04 (0.70)	15.95 (0.90)	17.39 (0.40)	19.95 (0.93)	20.87 (1.11)	21.44 (1.53)

Values in parentheses represent SE of three replicates.

To the mixed fumigation of SO_2 and NH_3 there was a reduction by 13 % in cv CO 43 whereas with no change in others. The mixture of SO_2 and NO_2 brought about a 9 % increase in cv TKM 9 and in cvs CO 43 and GR 3 a decrease of 20 and 28 % respectively. However, to the mixture of SO_2, NH_3 and NO_2 there was no significant effect in all the cultivars under NN. Under LN there was a marked increase of 22 % in cv GR 3 to SO_2 + NH_3. The mixture of SO_2 and NO_2 produced an increase in the total N content of cvs CO 43 and GR 3 by 24 and 18 % respectively. To the mixture of SO_2, NH_3 and NO_2 a 9 % increase in cv TKM 9 was evident. Under HN cv GR 3 showed a 16 % increase to SO_2 + NH_3, however, it showed a reduction to SO_2 + NO_2. To the mixture of SO_2, NH_3 and NO_2 a slight increase in the total N was observed in cvs GR 3 and TKM 9, when compared to their controls.

3.3.2.5 Nitrate reductase (NR)

The fumigation of gaseous pollutants to rice cultivars affected the activity of nitrate reductase to varying extent (Table 59). Under NN levels, the cvs CO 43, GR 3 and TKM 9 experienced a reduction in their NR activity by 24, 14 and 11 % to SO_2 fumigation, when compared to their respective control. The magnitude of inhibition was of same to NH_3 and NO_2 fumigations. Under LN the cvs GR 3 and TKM 9 showed only a marginal reduction to SO_2 and NH_3 fumigation however, it was modestly reduced in cv CO 43. NO_2 fumigation resulted in 20 % inhibition in the NR activity in the leaves of all the cultivars. Under HN there was an increase by 8 % in cv TKM 9 to SO_2, whereas the activity got reduced in cvs GR 3 and CO 43. As a result of NH_3 exposure there was an inhibition in the enzyme activity in GR 3 and TKM 9 and it was high in cv CO 43. However, NO_2 fumigated plants showed a high reduction in all the cultivars.

Table : 59 Individual and combined effects of SO_2, NH_3 and NO_2 on the nitrate reductase activity of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	534	609	586	487	539	435	566	609	406
SO_2	406	522	522	364	480	440	477	524	438
NH_3	397	536	402	362	478	382	343	554	365
NO_2	462	548	390	406	432	348	416	419	304
Mixed fumigations									
Control	498	588	540	463	560	465	510	604	475
SO_2 + NH_3	411	529	475	467	436	487	463	568	487
SO_2 + NO_2	409	491	509	422	435	478	348	478	496
SO_2 + NH_3 + NO_2	477	477	464	493	477	435	493	544	464

Unity : n moles of NO_2^- released/g fresh weight/ hour

All the mixtures of pollutants inhibited the NR activity in the leaves of all the cultivars, when compared to their respective control. But LN and HN treatments in the cv TKM 9 resulted in slight increase in NR activity over its control, to the fumigation with SO_2 + NH_3 and SO_2 + NO_2 mixtures. The mixture of SO_2, NH_3 and NO_2 pollutants brought about a slight increase in the cv CO 43 under LN, whereas it was inhibited in cvs GR 3 and TKM 9. HN regimed plants recorded an inhibition of low magnitude in all the cultivars.

3.3.2.6 Glutamine synthetase (GS)

The activity of the enzyme glutamine synthetase as affected by the fumigation of gaseous air pollutants is given in Table 60. The activity was found to be inhibited by the individual fumigation of SO_2, NH_3 and NO_2 in all the cultivars. The inhibition was 31, 22 and 28 % to SO_2 under NN, in CO 43, GR 3 and TKM 9 cultivars respectively. The inhibition was marginal to NH_3 in cvs CO 43 and GR 3 and it was high by 48 % in cv TKM 9 under NN. The cv GR 3 showed a maximum reduction of 32 % to NO_2 fumigation, as compared to the control. Under LN regime the reduction was minimum by 9 to 13 % in cvs GR 3 and CO 43 and under HN 4 to 11 % in cvs TKM 9 and GR 3 to NH_3 fumigation. Other treatments exhibited a highly reduced activity of GS towards the individual fumigation of SO_2, NH_3 and NO_2.

To the fumigation of SO_2 and NH_3 mixture, the cv GR 3 showed a maximum reduction in the activity of GS as compared to the other cultivars under NN. The inhibition was 23 to 48 % to SO_2 and NO_2 mixture in all the cultivars. Nevertheless, it was increased marginally in cvs CO 43 and GR 3 and reduced in

Table : 60 Individual and combined effects of SO_2, NH_3 and NO_2 on the glutamine synthetase activity of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	30.4	31.8	38.7	35.8	37.7	40.1	44.4	41.9	34.15
SO_2	20.9	24.8	27.9	23.9	29.9	29.1	38.9	30.7	26.3
NH_3	29.2	28.9	20.0	31.0	34.3	26.3	30.6	37.4	32.8
NO_2	24.6	20.3	30.3	26.8	27.2	29.7	29.2	34.5	27.8
Mixed fumigations									
Control	28.4	33.0	36.8	34.8	35.1	37.3	45.3	44.2	36.0
$SO_2 + NH_3$	21.2	28.5	21.6	22.0	29.8	26.6	29.2	33.7	33.3
$SO_2 + NO_2$	14.8	25.5	25.8	18.3	21.5	26.4	20.3	27.1	23.2
$SO_2 + NH_3 + NO_2$	31.7	35.5	31.6	21.3	25.6	35.8	29.4	31.6	32.8

Unit : n moles of glutamate released / mg protein/ 15 minutes.

the cv TKM 9 to the mixture of SO_2, NH_3 and NO_2. There was lesser reduction in the activity of GS to SO_2 + NH_3 in the cv GR 3 under LN and in cv TKM 9 under HN than the other variables. The inhibition was high by 30 to 55 % to the mixture of SO_2 and NO_2 in all the cultivars. To the mixture of all the three pollutants the cv TKM 9 showed a much lesser inhibition under LN and HN than the other cultivars.

3.3.2.7 Total Water Extractable SH Compounds

The fumigation of gaseous pollutants affected the total water extractable SH compounds to varying extent (Table 61). SO_2 effected into a reduction of 31 % in cv CO 43 while it was increased by 17 % in cv GR 3 under NN, when compared to the control. There was a marginal increase in the SH contents of cv GR 3 to SO_2 under HN while other cultivars showed no significant effect under LN as well as HN regimes. NH_3 fumigation reduced the SH content in cv GR 3 and increased in cvs CO 43 and TKM 9 under NN. The content was reduced in cvs CO 43 and TKM 9 under LN and the reduction was evident only in cv TKM 9 under HN regimed plants. The NO_2 fumigation rendered an increase in the SH compounds of cv CO 43 under all the regimes and cv GR 3 under NN.

To the mixture of SO_2 and NH_3 an increase in the SH compounds was evident by 16 % in cv CO 43 under NN but got reduced marginally under LN and HN regimes. The cvs GR 3 and TKM 9 showed no significant effect to SO_2 and NH_3 mixture. To SO_2 and NO_2 mixture there was an increase in the amount of SH compounds under NN in cvs CO 43 and TKM 9. The HN plants of cv CO 43 also experienced modest increase. To the mixture of SO_2, NH_3 and NO_2 there

Table : 61 Individual and combined effects of SO_2, NH_3 and NO_2 on the total water extractable SH compounds (m moles/g fresh weight) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations									
Control	87	100	98	96	92	94	91	93	99
	(3)	(4)	(4)	(5)	(4)	(4)	(4)	(3)	(4)
SO_2	60	117	94	90	95	87	104	102	111
	(4)	(8)	(3)	(7)	(7)	(8)	(10)	(4)	(8)
NH_3	96	85	121	78	85	74	84	96	86
	(50	(7)	(9)	(5)	(4)	(7)	(7)	(6)	(4)
NO_2	108	111	92	127	110	100	106	102	108
	(7)	(6)	(4)	(14)	(4)	(6)	(8)	(12)	(14)
Mixed fumigations									
Control	85	102	101	97	93	96	89	96	102
	(4)	(4)	(8)	(3)	(4)	(4)	(5)	(9)	(6)
$SO_2 + NH_3$	99	92	105	90	85	92	77	106	96
	(2)	(6)	(9)	(2)	(4)	(9)	(6)	(8)	(8)
$SO_2 + NO_2$	105	106	101	82	101	116	113	93	113
	(5)	(7)	(7)	(4)	(8)	(9)	(4)	(7)	(15)
$SO_2 + NH_3 + NO_2$	105	124	158	114	109	108	86	124	119
	(4)	(9)	(8)	(3)	(9)	(7)	(8)	(11)	(9)

Values in parentheses represent SE of three replicates.

appeared to be an increase by 24, 22 and 56 % in cvs CO 43, GR 3 and TKM 9 under NN, while the increase was only 19, 17 and 13 % under LN respectively. The HN regimed cvs GR 3 and TKM 9 also had a moderate increase in the levels of SH compounds in their leaves.

3.3.2.8 Total Sulphur

The fumigation of SO_2, individually and in mixture with other pollutants had altered the amount of sulphur accumulation in shoot of plants when compared to the control (Table 62). Under NN conditions cv TKM 9 experienced an 18 % reduction to the fumigation of SO_2. Under LN cvs CO 43 and TKM 9 accumulated increased amount of S by 31 and 19 % over the control. However, under HN all the cultivars showed a modest increase in the sulphur content. To the mixture of SO_2 and NH_3 the cv CO 43 brought about 32 % increase, while cv TKM 9 showed 13 % reduction under NN. SO_2 + NO_2 mixture had resulted in tremendous increase of 66, 47 and 37 in cvs CO 43, GR 3 and TKM 9 respectively. To the mixture of SO_2, NH_3 and NO_2 increase of 56 and 46 in the sulphur content were observed in cvs CO 43 and GR 3, while the content was reduced by 13 % in cv TKM 9. The mixture of SO_2 and NO_2 increased the S content by 11 % in GR 3 under LN. To the mixture of the 3 pollutants cvs CO 43 and GR 3 showed an 18 and 23 % reduction under LN. To the mixture of SO_2, NH_3 and NO_2 cvs GR 3 and TKM 9 showed 12 % increase and 16 % decrease in the total sulphur content in their shoots of the plants grown under high N regime.

Table : 62 Individual and combined effects of SO_2, NH_3 and NO_2 on the total sulphur content (mg/g dry weight) of three rice cultivars grown under three N levles.

	Normal N			Low N			High N		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigation :									
Control	1.54 (0.15)	1.87 (0.04)	1.99 (0.10)	1.72 (0.05)	1.96 (0.12)	1.62 (0.05)	1.67 (0.07)	1.84 (0.07)	1.75 (0.04)
SO_2	1.76 (0.12)	1.95 (0.08)	1.64 (0.11)	2.05 (0.13)	1.82 (0.12)	1.93 (0.11)	1.98 (0.14)	2.01 (0.09)	1.97 (0.05)
Mixed fumigations									
Control	1.70 (0.10)	1.95 (0.08)	2.05 (0.09)	1.64 (0.06)	1.90 (0.05)	1.75 (0.08)	1.81 (0.06)	1.78 (0.08)	1.88 (0.06)
$SO_2 + NH_3$	2.24 (0.09)	1.85 (0.04)	1.79 (0.11)	1.68 (0.05)	1.97 (0.02)	1.79 (0.06)	1.86 (0.04)	1.84 (0.06)	1.80 (0.04)
$SO_2 + NO_2$	2.82 (0.19)	2.87 (0.29)	2.85 (0.24)	1.52 (0.06)	2.10 (0.10)	1.86 (0.06)	2.05 (0.12)	1.85 (0.05)	1.82 (0.08)
$SO_2 + NH_3 + NO_2$	2.66 (0.31)	2.85 (0.26)	1.78 (0.11)	1.35 (0.12)	1.47 (0.12)	1.89 (0.09)	1.82 (0.10)	2.00 (0.13)	1.57 (0.10)

Values in parentheses represent SE of three replicates.

Table : 63 Individual and combined effects of SO_2, NH_3 and NO_2 on the tissue buffering capacity of three rice cultivars grown under three N levles.

	Buffering capacity H ions			Buffering capacity OH ions		
	CO 43	GR 3	TKM 9	CO 43	GR 3	TKM 9
Individual fumigations						
Control	17.0 (0.6)	13.7 (0.5)	12.0 (0.4)	10.8 (0.9)	10.7 (1.1)	11.5 (0.6)
SO_2	87.0 (7.0)	73.0 (7.0)	103.0 (3.0)	88.0 (6.0)	104.0 (3.0)	96.0 (2.0)
NH_3	94.0 (4.0)	106.0 (4.0)	93.0 (5.0)	82.0 (7.0)	102.0 (4.0)	68.0 (12.0)
NO_2	85.0 (6.0)	75.0 (7.0)	100.0 (3.0)	105.0 (5.0)	96.0 (5.0)	104.0 (6.0)
Mixed fumigations						
Control	18.2 (0.7)	14.4 (0.6)	11.8 (1.1)	11.1 (1.0)	10.9 (0.6)	11.7 (0.9)
$SO_2 + NH_3$	111.0 (7.0)	104.0 (4.0)	108.0 (6.0)	100.0 (3.0)	102.0 (5.0)	99.0 (4.0)
$SO_2 + NO_2$	90.0 (4.0)	90.0 (4.0)	103.0 (7.0)	81.0 (6.0)	100.0 (2.0)	104.0 (5.0)
$SO_2 + NH_3 + NO_2$	71.0 (6.0)	106.0 (3.0)	105.0 (4.0)	94.0 (4.0)	98.0 (3.0)	102.0 (4.0)

Values in parentheses represent SE of three replicates.

3.3.2.9 Buffering Capacity (β)

The buffering capacity of SO_2 fumigated plants of cvs CO 43 and GR 3 was greatly reduced for H ions (Table 63). With relation to OH ions it was equally reduced in cv CO 43 but with marginal change in the other two cultivars. The fumigation of NH_3 brought about a marginally increased 'β' in the cv GR 3 for H ions and OH ions, while they were decreased for OH ions in cvs CO 43 and TKM 9. The effect of NO_2 on 'β' was found to be the same as that of SO_2 for H ions. To the mixed fumigation of SO_2 and NH_3 the 'β' appeared to be either increased or not affected for both the type of ions in all the cultivars, but it modestly reduced in cvs CO 43 and GR 3 for H ions, to the mixture of SO_2 and NO_2. However, only in cv CO 43 the 'β' appeared to be reduced for OH ions. To the mixture of SO_2, NH_3 and NO_2 the 'β' of the cv CO 43 was severely reduced while cv GR 3 and TKM 9 were marginally increased for H ions in the leaves. In relation to OH ions cv CO 43 appeared to reduce the 'β' marignally.

3.3.2.10 Leaf Absorption Spectra

Variations were observed in the absorption spectra of leaf of rice cultivars exposed to the mixture of SO_2, NH_3 and NO_2, as compared to that of control in the visible region (Fig. 25). It has been observed that there was no qualitative shift in the peak of absorption spectrum in any exposed plant. However, in quantitative terms, the absorption was found to be different at all wavelengths. The absorption peak at 667 nm has been chosen for evaluating the effects of the air pollution treatments. The leaf absorption was increased in cv GR 3 by 16.67 % under NN, 18.25 % under LN and 20.63 % under HN. The cv CO 43 showed increased absorption under NN by 26.67 % and 52.40 % under LN, however, it reduced the peak by 53.33 % under HN. On the other

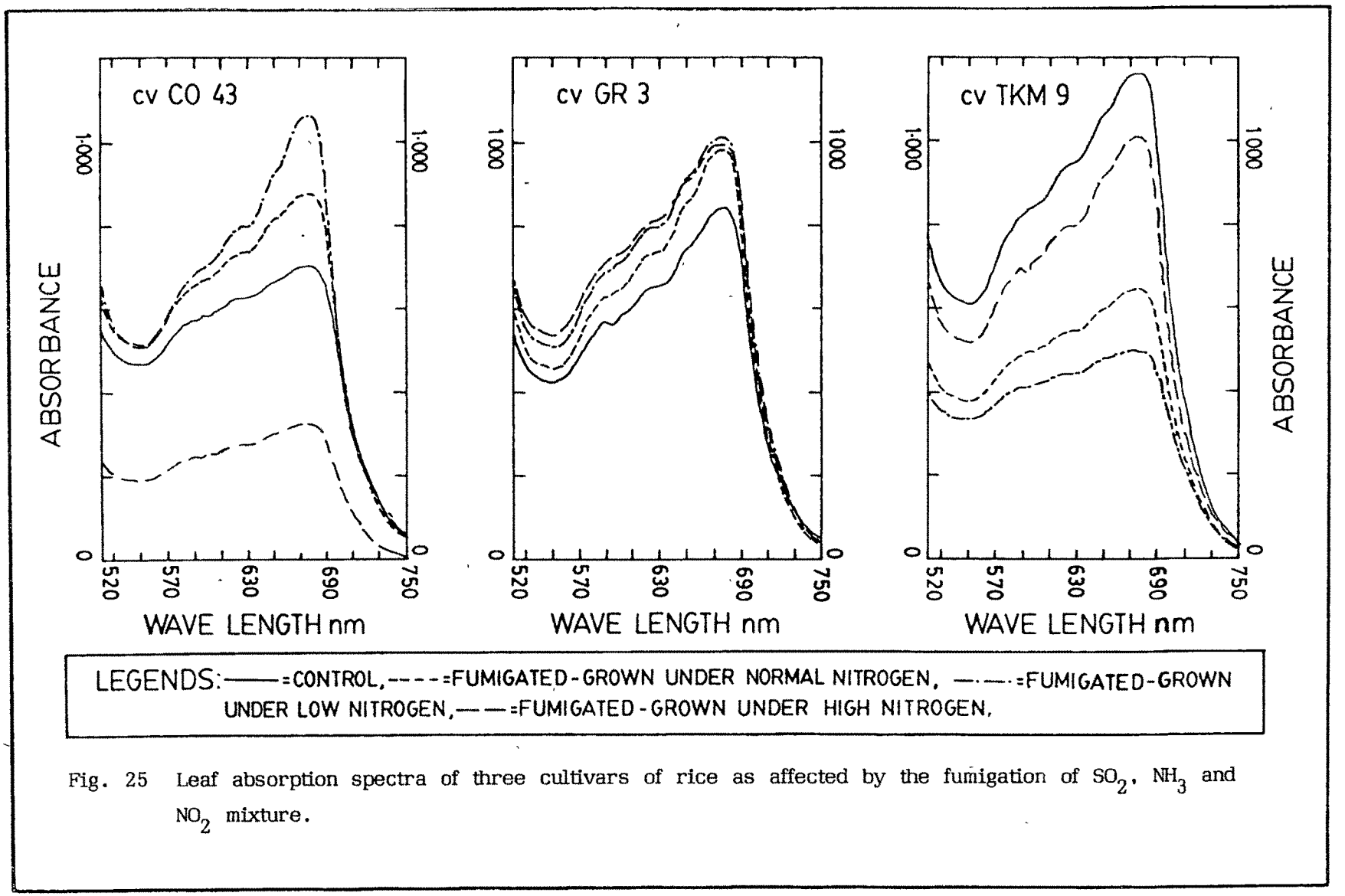


Fig. 25 Leaf absorption spectra of three cultivars of rice as affected by the fumigation of SO_2, NH_3 and NO_2 mixture.

hand, cv TKM 9 which showed higher peak than the other cultivars under control was reduced by the fumigation. The reduction was 41.16 % under NN, 54.27 % under LN and 7.93 % under HN.