RESPONSES OF SOYBEAN PLANTS TO SULPHUR DIOXIDE AT VARYING SOIL FERTILITY REGIMES

Rajput, M.
Department of Botany Banaras Hindu University

Agrawal, M.
Department of Botany Banaras Hindu University

http://hdl.handle.net/2324/8198

出版情報：BIOTRONICS. 23, pp.81-92, 1994-12. Biotron Institute, Kyushu University
バージョン：
権利関係：

BIOTRONICS **23**, 81–92, 1994

RESPONSES OF SOYBEAN PLANTS TO SULPHUR DIOXIDE AT VARYING SOIL FERTILITY REGIMES

M. RAJPUT and M. AGRAWAL

Department of Botany Banaras, Hindu University, Varanasi—221 005 INDIA

(Received April 14, 1994; accepted September 7, 1994)

RAJPUT M. and AGRAWAL M. *Responses of soybean plants to sulphur dioxide at uarying soil fertility regimes.* BIOTRONICS **23**, 81–92. 1994. Soybean (*Glycine max* L. cv. JS–72–44) plants were grown at three fertility levels i. e. NPK recommended dose, NPK double recommended dose and without NPK application. Thirty day old plants were exposed to 0.15 ppm SO_2 for 4 hrs day^{-1} for 5 days week^{-1} for 6 weeks. The interaction of SO_2 and fertility regimes were studied singly and in combination on growth, biomass accumulation, resource allocation and yield at different stages of plant growth. Yield components were determined at maturity. Morphological characteristics such as shoot and root lengths, number of leaves, nodules and pods, leaf area and biomass accumulation in shoot and root and net primary productivity decreased significantly in SO_2 treated plants grown at diferent fertility regimes. Growth indices such as *LAR, LWR, SLA, RSR, NAR* and *RGR* were computed for assessing the change in resource allocation. *NAR and RGR* of SO_2 treated plants were always lower compared to respective controls. *RSR* increased in SO_2 treated plants without fertilizer treatment. *SLA* was always higher for SO_2 treated plants. SO_2 fumigation resulted in significant reduction of seed yield. However, fertilizer amendment reduced the loss of seed yield due to SO_2 treatment. Fertilizer amendment has modified the SO_2 induced changes in growth and resource partitioning. The study suggests that fertilizer at recommended dose may be used to alleviate the injurious effects of sulphur dioxide on soybean.

Key words: *Glycine max* L.; sulphur dioxide; fertility regime; soybean; growth; biomass.

INTRODUCTION

Adverse effects of gaseous pollutants, particularly sulphur dioxide (SO_2), have been identified as a cause of great concern for agricultural productivity. SO_2 a by-product of fossil fuel combustion is one of the most phytotoxic and widespread air pollutant. In India with increasing dependence on coal as an energy source, SO_2 concentration is increasing at high rate (*20*). Concentrations

---

LAR (Leaf area ratio), *LWR* (Leaf weight ratio), *SLA* (Specific leaf area), *RSR* (Root shoot ratio), *RGR* (Relative growth rate), *NAR* (Net assimilation rate).

of SO_2 around thermal power plant were reported in the range of 65.1–156.5 μg m^{-3} (annual average) with the peak reaching 300 μg m^{-3} (4 hr average) (*21*).

Long term, low concentrations of SO_2 often decreased the yield of plant without visible symptoms of injury (*6*). Recent reports have suggested that low levels of SO_2 have significantly reduced several components of growth like dry matter production, tillering, relative growth rate, leaf area, number of spikelets or pods and percentage of grains or seeds in many agricultural crops (*10, 12*). Sprugel *et al.* (*23*) found significant yield reductions in soybean exposed to SO_2 at the concentrations that occur near a point source. Although accurate figures for economic losses in crop yields due to SO_2 are not available for India, but significant reductions in crop yield have been reported around point sources of pollution (*21*).

The extent of crop damage due to SO_2 pollution is influenced by many environmental factors including both climatic and edaphic (*6*). Heck *et al.* (*7*) reported that the plants growing in soil of low fertility regimes are more sensitive to pollutants than the plants growing in well fertilized soils. However, Ormrod *et al.* (*16*) and Pell *et al.* (*17*) demonstrated that O_3 exposure has reduced the dry matter accumulation less in plants grown under a low nitrogen regime compared to those grown under high nitrogen.

Soybean (*Glycine max*) is a nutritious and versatile crop. In India, its cultivation has increased from 32,400 hectares in 1970–71 to over 2 million hectares in 1989–90. It has become a cash crop for farmers. There are many constraints in raising the production of soybean crop. With the advancement of industrialization and urbanization, air pollution is becoming a problem in cultivation of this crop. Studies conducted in temperate environment showed that *Glycine max* (soybean) is sensitive to elevated SO_2 concentrations (*12, 18*). No reports are, however, available about responses of soybean plants to SO_2 in tropical environment.

Keeping the above facts in view, the present study was aimed to assess the effects of SO_2 on the morphology, assimilate partitioning and yield of soybean grown at different fertility levels under dry tropical environment.

MATERIALS AND METHODS

The present experiment was conducted at the Agricultural Research Farm, Banaras Hindu University, Varanasi Located at 25.20°N latitude and 83.03°E longitude at an altitude of 128.93 meters. Soybean (*Glycine max L.* cv. JS–72–44) seeds were sown in the Kharif season. During the experiment the average maximum and minimum temperature ranged from 34.1° to 17.4°C. The seasonal mean precipitation was approximately 100 cm. The average maximum and minimum relative humidity ranged from 91 to 35%.

The soil of agricultural farm is alluvial type. It was almost neutral in reaction having pH 7.70 and electrical conductance (EC) 0.18 DSm^{-1}. The contents of organic carbon in soil were 0.49%, available nitrogen 250 kg ha^{-1}, available phosphorus 18 kg ha^{-1} and available potassium 170 kg ha^{-1}.

Experimental design was split plot type and plot size was 1.5 m ×1.5 m. Soybean seeds were inoculated with *Bradyrhizobium japonicum* strains just before sowing. Inoculated seeds were sown 20 cm apart from each other in eighteen plots of three different fertility levels of nitrogen, phosphorus and potassium (6 plots each) i.e. NPK recommended dose (F_1), NPK double recommended dose (F_2) and without NPK application (F_0). Recommended NPK ratio was 20: 80: 40. N, P and K were given as urea, single superphosphate and muriate of potash as basal dressing before sowing.

Fumigation of plants with $390 \pm 10 \mu g\ m^{-3}$ (0.15 ppm) SO_2 was started when the plants were 30 days old. It was performed for 4 hrs daily (between 800 and 1200 h) for 5 days $week^{-1}$ for 6 weeks in a $1.5 \times 1.5\ m^2$ transparent polythene chamber (0.25 mm) supported on a $1.5 \times 1.5 \times 1.5$ m iron frame. Sulphur dioxide gas was provided with SO_2 cylinders and the desired concentrations within the chambers were achieved by dilution with carrier air (56 LS^{-1}). Control plants were placed in the identical chambers, but flushed with activated charcoal filtered air. Sulphur dioxide concentration within the chamber was continuously monitored by SO_2 analyzer (Model 319, KIMOTO, Japan) based on conductivity changes in hydrogen peroxide solution due to sulphuric acid formation. For convenience, plants were designated as F_0C, F_1C and F_2C for those without NPK, those at recommended dose of NPK and those at double recommended dose of NPK, respectively and F_0T, F_1T and F_2T, respectively for their SO_2 treated ones.

Random samplings of plants were done at 30 days prior to fumigation and then after 15 days intervals up to 75 days of plant age. For morphological characters, the fresh plant samples were analysed with respect to root and shoot lengths and numbers of leaves, nodules and pods. An average of five replicates were taken for each of these parameters. Leaf area was measured by LI-COR leaf area meter (LI-3000, USA). For dry weight determinations, different plant parts were oven dried at 80℃ till the constant weight was obtained and values were expressed as g $plant^{-1}$. Net primary productivity (*NPP*) was calculated as g $plant^{-1}$ day^{-1}. Different growth indices were calculated from the formulae modified by Hunt (*9*).

Yield was calculated as numbers of pods and seeds $plant^{-1}$ and weight of seeds $plant^{-1}$ after final harvest at 110 days age. Weight of 1000 seeds was also measured. Yield was calculated g m^{-2}.

Data were analysed through Analysis of variance (ANOVA) and Students 't' test for assessing the significance of quantitative changes in different parameters due to treatments.

RESULTS

Soybean plants exposed to SO_2 irrespective of soil fertility regimes showed foliar injury in the form of interveinal chlorotic lesions after receiving fumigation for 3 weeks. These chlorotic spots later changed into necrotic lesions. Plants of F_1T and F_2T treatments had less symptoms of SO_2 injury than the F_0T plants.

The values for shoot and root lengths, numbers of leaves, nodules and pods and leaf area were lower for SO_2 treated plants compared to their respective untreated controls (Figs. 1 and 2). All these characters were reduced maximally in F_0T plants. At the age of 75 days, the shoot length decreased by 16.36, 5.88 and 7.52% and the root length by 9.09, 7.14 and 6.67% in F_0T, F_1T and F_2T treatments, respectively as compared to their respective controls (Fig. 1). Among all the morphological characters maximum reductions were observed in leaf area which decreased by 50.9, 32.2 and 31.1% in F_0T, F_1T and F_2T plants, respectively at 75 days age (Fig. 1).

Analysis of variance test showed significant variations in plant biomass due to plant age, fertility levels, SO_2 treatment and their interactions (Table 1). With the increase in age and dose of SO_2, reduction in biomass increased and the maximum reduction was observed at 75 days age, the reductions in total plant biomass being 48.0, 28.9 and 27.8% and in *NPP* being 55.3, 32.0 and 34.1% in F_0T, F_1T and F_2T plants, respectively (Fig. 3).

The effect of SO_2 fumigation at different fertility levels on assimilate partitioning was further assessed by growth analyses. Leaf area ratio values of SO_2 treated plants were lower than their respective controls except at the age of 60 days (Fig. 4). Leaf weight ratio (*LWR*) showed a similar pattern of change due to SO_2 treatment as that of *LAR* except in case of F_0T plants where it did not change at 45 days age. Variations in *LWR* were significant due to plant age, fertility levels and their interactions (Table 1).

Specific leaf area (*SLA*) was always higher in SO_2 treated plants as compared to their respective controls, the increase being 10.5, 1.4 and 1.2 in F_0T, F_1T and F_2T plants, respectively at 75 days age. Increase in *SLA* was significant due to plant age treatment and plant age and fertility levels. Root: shoot ratio (*RSR*) was lower in F_0T plants up to 45 days age and thereafter increased

Table. 1 Results of analysis of variance of the effects of SO_2 treatment, fertility levels and plant age on the total biomass and growth indices of soybean plants.

Plant parameter	FACTOR						
	Plant age (A)	Fertility levels (F)	SO_2 treatment (T)	A×F	F×T	A×T	A×F×T
Total biomass	**	**	**	**	**	**	**
Leaf area ratio	**	NS	NS	*	NS	NS	NS
Leaf weight ratio	**	**	NS	*	NS	NS	NS
Specific leaf area	**	NS	**	**	NS	NS	NS
Root shoot ratio	**	NS	NS	**	NS	NS	NS
Net assimilation rate	**	**	**	**	**	**	**
Relative growth rate	**	**	**	**	**	**	NS

*$p<0.025$, **$p<0.005$, NS: Not significant.

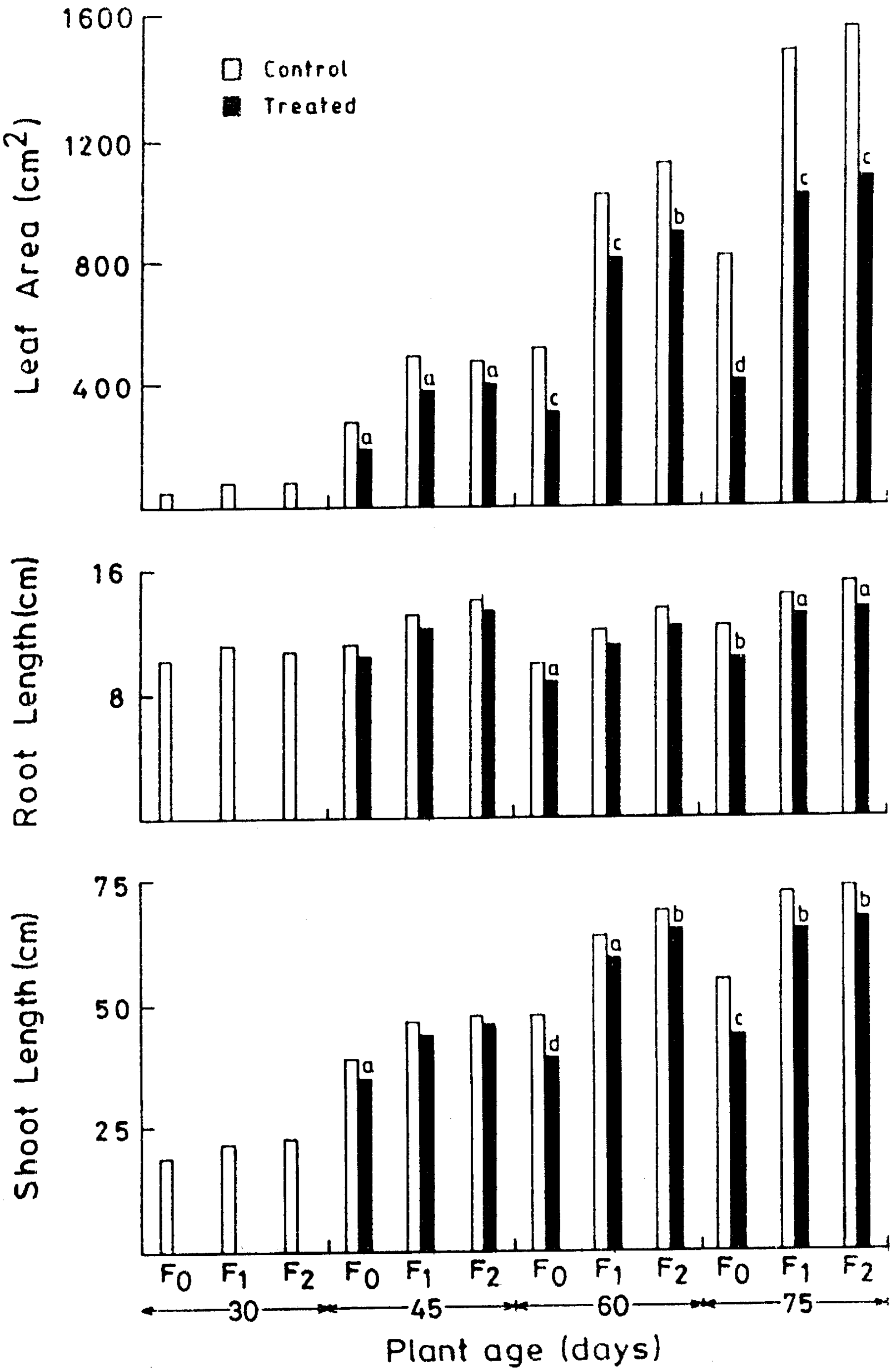

Fig. 1. Shoot length, root length and leaf area of control (C) and SO_2 treated (T) soybean plants grown at different fertility levels. F_0, without NPK application; F_1, NPK recommended dose; F_2T, NPK double recommended dose. Level of significance: a, $p<0.05$; b, $p<0.01$; c, $p<0.005$; d, $p<0.001$.

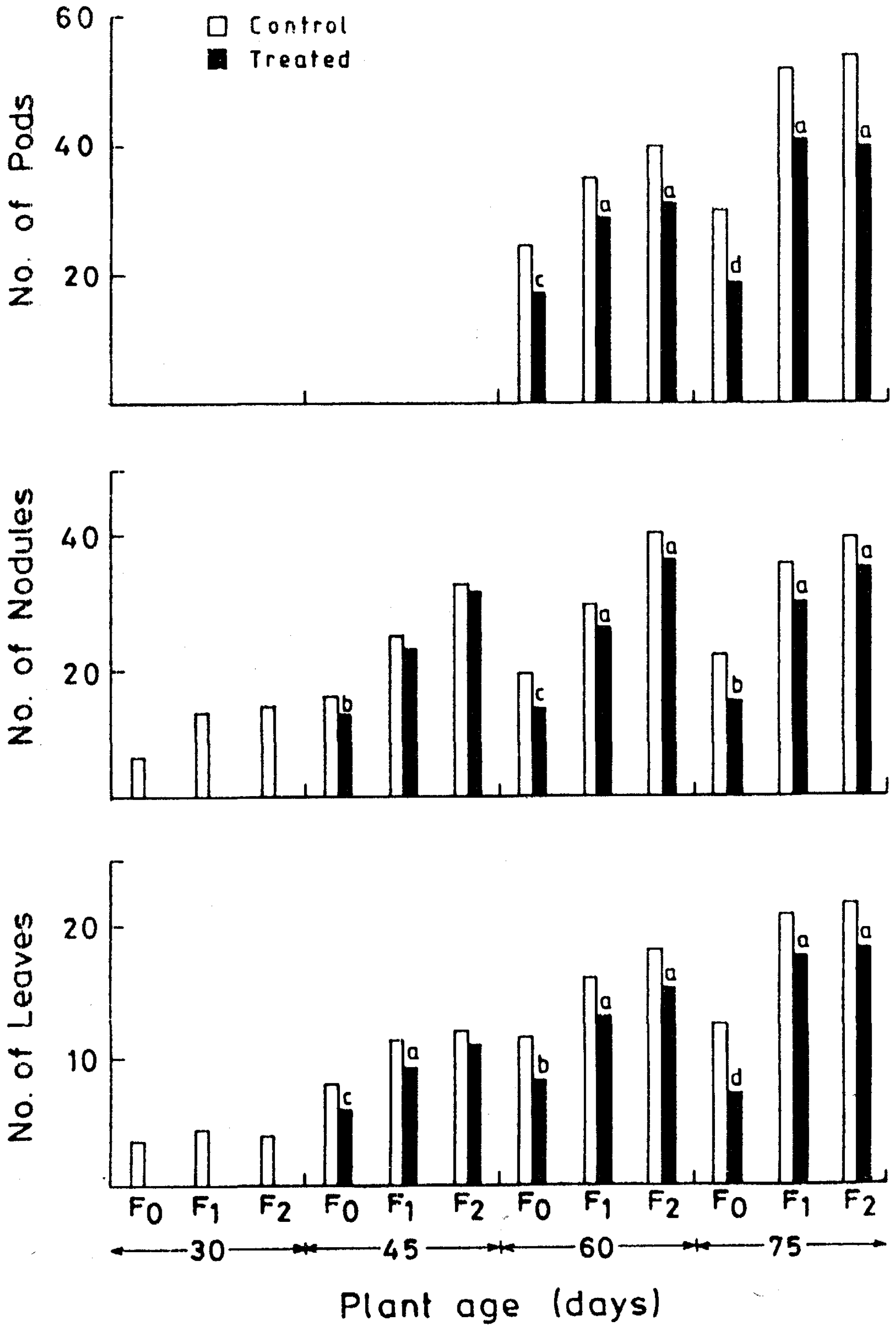

Fig. 2. Number of leaves, nodules and pods of control (C) and SO_2 treated (T) soybean plants grown at different fertility levels. F_0, without NPK application; F_1, NPK recommended dose; F_2, NPK double recommended dose.
Level of significance: a, $p<0.05$; b, $p<0.01$; c, $p<0.005$; d, $p<0.001$.

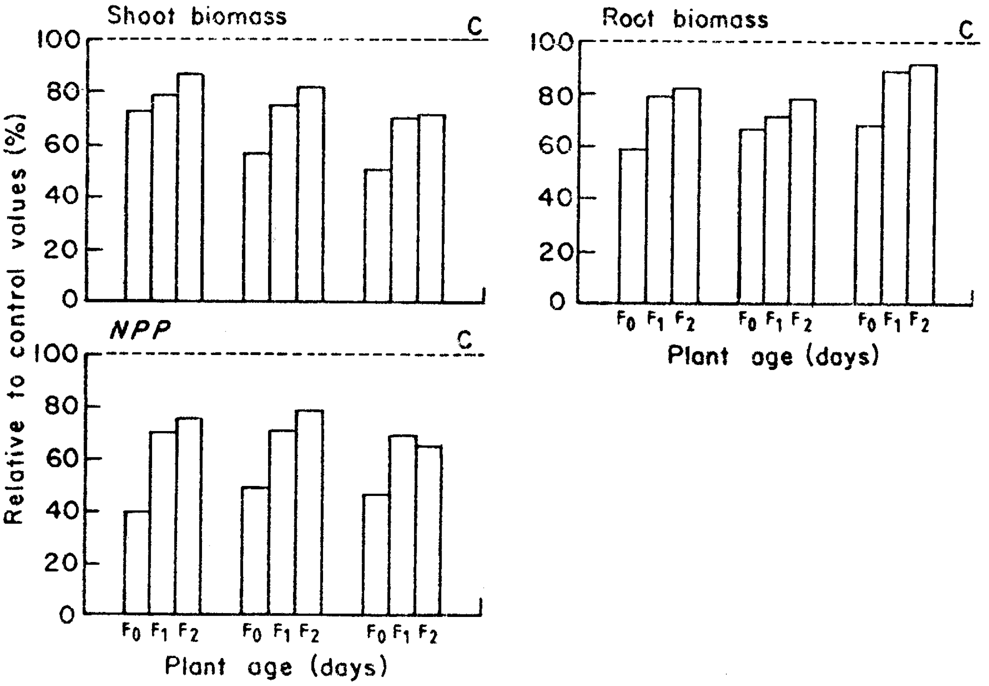

Fig. 3. Relative to the control values for root and shoot biomass and net primary productivity of SO_2 treated soybean plants grown at different fertility levels. C, control (100%); F_0, without NPK application; F_1, NPK recommended dose; F_2, NPK double recommended dose.

compared to F_0C (Fig. 4). In F_1T, *RSR* did not change up to 60 days age, thereafter it increased compared to the control at 75 days age.

Net assimilation rate (*NAR*) as well as relative growth rate (*RGR*) were lower in SO_2 fumigated plants throughout the plant life (Fig. 5). Maximum reduction was observed for F_0T plants. *NAR* was reduced by 20.6, 11 and 13.3% and *RGR* by 24.1, 13 and 15.1% in F_0T, F_1T and F_2T plants, respectively at the age of 75 days. Analysis of variance test also showed significant variations in *NAR* and *RGR* due to plant age, fertility levels, SO_2 treatment and their interactions (Table 1).

At the time of harvest, number of pods $plant^{-1}$, number of seeds $plant^{-1}$ and weight of seeds $plant^{-1}$ decreased significantly in SO_2 treated plants as compared to their respective controls (Table 2). Maximum reductions were observed in F_0T plants. F_1T and F_2T plants showed more or less same trend of changes due to SO_2 treatment. Reductions in yield were 54.2, 28 and 27.3% for F_0T, F_1T, and F_2T plants, respectively compared to their respective controls.

DISCUSSION

Sulphur dioxide and limiting mineral nutrients both reduced the plant height, dry matter accumulation and yield of soybean plants. Klarer *et al.* (*10*)

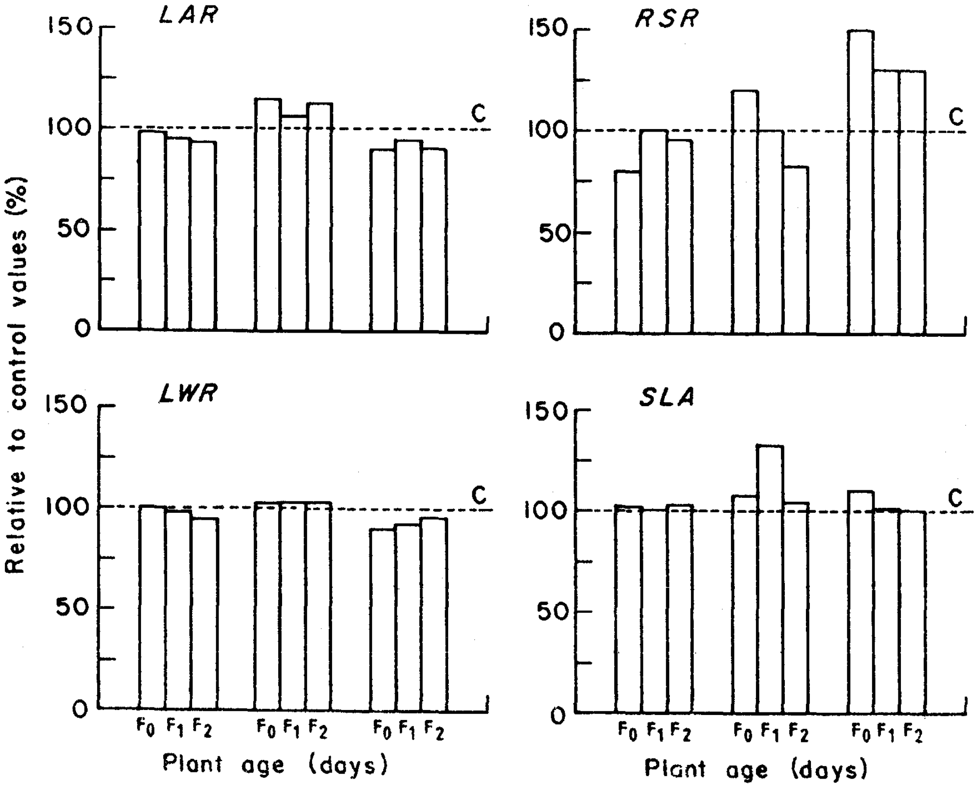

Fig. 4. Relative to the control values for *LWR*, *LAR*, *SLA* and *RSR* of SO_2 treated soybean plants grown at different fertility levels. C, control (100%); F_0, without NPK application; F_1, NPK recommended dese; F_2, NPK double recommended dose.

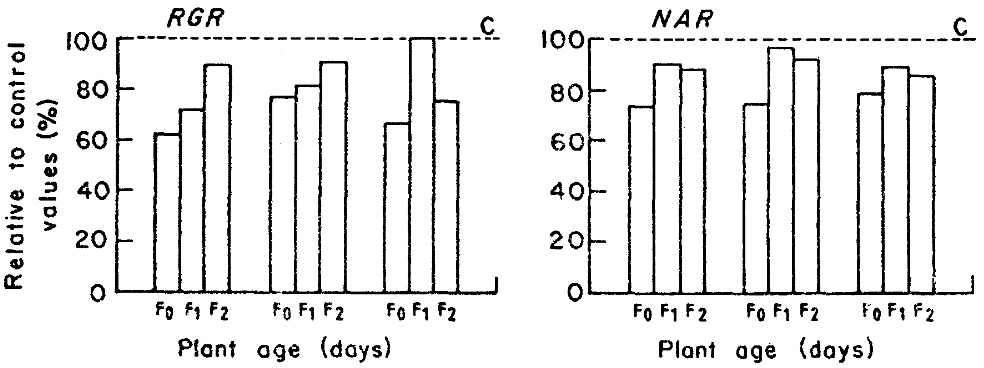

Fig. 5. Relative to the control values for *RGR* and *NAR* of SO_2 treated soybean plants grown at different fertility levels. C, control (100%); F_0, without NPK application; F_1, NPK recommended dose; F_2, NPK double recommended dose.

Table 2 Number of pods and seeds, weight of seeds, weight of 1000 seeds and yield of soybean in control (C) and treated (T) plants grown at different fertility levels.

Fertility	No. of pods (plant^{-1})		No. of seeds (plant^{-1})		Weight of seeds (g plant^{-1})		Weight of 1,000 seeds (g)		yield (g m^{-2})	
	C	T	C	T	C	T	C	T	C	T
F_0	32.67	19.67^d	65.33	39.00^d	6.32	3.05^d	96.87	78.33^d	126.57	61.09^d
F_1	49.67	37.67^b	99.33	73.33^c	10.42	7.49^b	104.90	102.23^{NS}	208.45	149.90^b
F_2	51.00	40.00^b	102.00	79.67^c	10.98	7.91^b	107.73	99.36^{NS}	219.77	158.32^b

F_0: Without NPK application; F_1: NPK recommended dose; F_2; NPK double recommended dose.
Level of significance: NS: Not significant; b, $p<0.01$; c, $p<0.005$; d, $p<0.001$.

have also shown reductions in biomass of SO_2 exposed soybean plants. Nitrogen limitation has also been shown to reduce dry matter production in plants (*15*). The effect of SO_2 on growth and development was maximum in plants grown without NPK amendment. Silvius *et al.* (*22*) have also reported that N supply has increased the productivity of SO_2 exposed plants. Ormrod *et al.* (16) and Pell *et al.* (*17*) have, however, reported greater sensitivity to O_3 of plants grown with higher nitrogen supply. Foliar injury assessment also showed that plants grown without NPK amendment elicited maximum injury due to SO_2 exposure. This is in contrary of the findings of Ormrod *et al.* (*16*) that high N availability leads to high conductance *vis a vis* more injury.

Shoot length was affected more than root length. Sulphur dioxide affects shoot growth directly by affecting the physiological and biochemical functions of leaves (*1, 24*). Leaf area increased in plants grown at higher levels of mineral nutrients. Lemcoff *et al.* (*13*) have shown significant increases in leaf size with increase in N supply. In F_0T plants, inadequate mineral nutrients reduced plant growth primarily by restricting leaf area development and further exposure of SO_2 has reduced the leaf area by causing symptoms of injury. Reduced leaf area has been found to reduce photosynthetic capacity and dry matter accumulation of plants (*2*). Leaf area is influenced by NPK supply and SO_2 exposure more than leaf number suggesting that leaf expansion is more susceptible than leaf emergence. Low N has been shown to reduce water transport to the shoot resulting in reduced leaf water content and turgor for cell enlargement (*19*). Cell elongation is reported to be more sensitive to different stresses than cell division and photosynthesis (*8*).

Since biomass accumulation is an integrated result of all biochemical, physiological and metabolical activities in plants (*1, 23, 24*), its significant reduction further confirms that SO_2 may directly interfere with these functional processes resulting in biomass reductions as well as growth retardation. Initially SO_2 induced reductions were higher in below ground biomass but later above ground biomass was more severely affected. As the growth of underground plant parts is dependent on photosynthate translocated to them from the above ground parts, direct effects of SO_2 on the photosynthetic leaves are reflected in poor development of the root system and number of nodules.

Plants without NPK amendment exhibited some what different response to SO_2 with respect to *RSR*. *RSR* was significantly low in F_0T plants within 15 days of treatment whereas this did not change much in F_1T and F_2T plants compared to their controls. But at 30 day of treatment *RSR* was higher for F_0T plants and it remained significantly higher till the last sampling. Koch *et al.* (*11*) reported that nutrient depletion in root environment leads to increase in partitioning of resources to roots for more uptake of nutrients. The changes in *LWR* were found to be correlated with RSR. This suggests that initially the resource allocation favoured the leaf production but later root partitioning increased in SO_2 exposed plants due to reduced nutrient availability.

RGR and *NAR* of the SO_2 treated plants remained lower throughout the experiment compared to their controls. Reduction in *RGR* reflects resource limitation or resource imbalance in plants (*3*). Reductions in size and efficiency of assimilatory surface are responsible for a decline in *RGR* and *NAR* in SO_2 treated plants. Although *LAR* was higher for SO_2 treated plants at 60 days age, yet this increase in assimilatory area was not enough to compensate the decrease in photosynthetic efficiency (*NAR*). NPK amendment had a beneficial effect on maintaining a higher *RGR* and *NAR* in SO_2 exposed plants. Coleman *et al.* (*4*) also found sharp decrease in *RGR* of SO_2 exposed radish in response to decreasing nitrate concentrations.

Nitrogen, P and K are major nutrients essential for good plant growth and yield. Balanced applications of N, P and K have been shown to increase yield of crop species. The role of N in protein metabolism and photosynthesis has been documented (*14*). Potassium is known to activate enzymes related to ATP production and release and to increase buffering capacity. In NPK amended plants good plant growth has increased the resistance and recovery power of plants and thus reduced the adverse impact of SO_2 on plant functions. Moreover, S is also a major nutrient serving as constituent of proteins and several other important organic compounds. In NPK amended plants with high growth rate a portion of SO_2 gas may have been used as a source of S and is being incorporated into organic S compounds and thus provided higher resistance against SO_2 in F_1T and F_2T plants compared to F_0T plants.

The results of the present study clearly indicate that an atmosphere polluted with 0.15 ppm SO_2 for 4 hrs day^{-1}, 5 day $week^{-1}$ for six weeks has significantly reduced the growth and yield of soybean plants. NPK application has, however reduced the magnitude of reduction caused by SO_2. Plants grown on low fertile soil are more sensitive to SO_2 because of their stunted growth and less resistance as compared to plants grown on well fertile soil. There is not much difference in responses of plants to SO_2 grown at recommended and double recommended doses of NPK. Fertilizer amendment has reduced the adverse effects of SO_2 due to greater biomass production and less investment in nonproductive tissue. In contrast, nutrient unavailability has caused greater proportion of assimilate to be diverted to root and thus reduced the recovery power of the leaves.

The study concludes that the nutritional amendments can induce different physiological and morphological changes that make the plant tissue less susceptible to SO_2. NPK nutrients at recommended dose may be used to alleviate the injurious effects of SO_2 on soybean.

ACKNOWLEDGEMENTS

Authors wish to express their thanks to Farm Incharge of the Institute of Agricultural Sciences, Banaras Hindu University for providing field facilities for experiments. We are also grateful to Hindustan CIBA–GEIGY Ltd. for providing financial support.

REFERENCES

1. Agrawal M., Nandi P. K. and Rao D. N. (1985) Effects of sulphur dioxide fumigation on soil system and growth behaviour of *Vicia faba* plants. *Plant and Soil* **86**, 69–78.
2. Byers D. P., Dean T. J. and Johnson J. D. (1992) Long term effects of ozone and simulated acid rain on the foliage dynamics of slash pine (*Pinus elliottii* var. *elliotti* Engelm). *New Phytol.* **120**, 61–67.
3. Chapin F. S. III, Bloom A. J., Field C. B. and Waring R. H. (1987) Plant responses to multiple environmental factors. *Bio. Science* **37**, 49–57.
4. Coleman J. S., Mooney H. A. and Gorham J. N. (1989) Effects of multiple stresses on radish growth and resource allocation. I. Responses of wild radish plants to a combination of SO_2 exposure and decreasing nitrate availability. *Oecologia* **81**, 124–131.
5. Crittenden P. D. and Read D. J. (1978) The effects of air pollution on plant growth with special reference to sulphur dioxide. II. Growth studies with *Lolium perenne* L. *New Phytol.* **80**, 49–62.
6. Heck W. W. (1989) Assessment of crop loss from air pollutants in the United State. In J. J. Mackenzie and M. T. El–Ashry (eds.) *Air Pollution Toll on Forest and Crops.* Yale Univ. Press, London, pp. 235–315.
7. Heck W. W., Dunning J. A. and Hindawi I. J. (1965) Interactions of environmental factors on the sensitivity of plants to air pollution. *J. Air Pollut. Contr. Ass.* **15**, 511–515.
8. Horst G. L. and Nelson C. J. (1979) Compensatory growth of toll tissue following drought. *Agron. J.* **71**, 559–563.
9. Hunt R. (1982) *Plant Growth Analysis,* University Park Press, Baltimore.
10. Klarer C. I., Reinert R. A. and Huang J. S. (1984) Effects of sulphur dioxide and nitrogen dioxide on vegetative growth of soybeans. *Phytopathology* **74**, 1104–1106.
11. Koch G. W., Schulze E. D., Percival F. and Mooney H. A. (1989). The nitrogen balance of Raphanus Sativus X raphanistrum. II. Growth, nitrogen redistribution, and photosynthesis under nitrate deprivation. *Plant Cell Environ.* **11**, 755–767.
12. Kress L. W., Miller J. E. and Smith H. J. (1986) Impact of O_3 and SO_2 on soybean yield. *Environ. Pollut.* **41** (**Ser. A**), 105–123.
13. Lemcoff J. H. and Loomis R. S. (1986) Nitrogen influences on yield determination in maize. *Crop Sci.* **26**, 1017–1022.
14. Marek M. and Frank R. (1984) Effect of nitrogen supply on net photosynthetic rate in barley leaves. *Photosynthetica* **18**(**2**), 219–225.
15. Metivier R. R. and Dale J. E. (1977) The effect of grain nitrogen and applied nitrate on growth, photosynthesis and protein content of the first leaf of barley cultivars. *Ann. Bot.* **41**, 1287–1296.
16. Ormrod D. P., Adedipe N. O. and Hofstra G. (1973) Ozone effects on growth of radish plants as influenced by nitrogen and phosphorus nutrition and by temperature. *Plant and Soil* **39**, 437–439.

17. Pell E. J., Winner W. E., Vinten-Johansen C. and Mooney H. A. (1990) Responses of radish to multiple stresses. I. physiological and growth responses to change in ozone and nitrogen. *New Phytol.* **115**, 439–446.

18. Pratt G. C., Kromroy K. W. and Krupa S. (1983) Effects of ozone and sulphur dioxide on injury and foliar concentrations of sulphur and chlorophyll in soybean (*Glycine max*). *Environ. Pollut.* **32**, 91–99.

19. Radin J. W. and Boyer J. S. (1982) Control of leaf expansion by nitrogen nutrition in sunflower plants. Role of hydraulic conductivity and turgor. *Plant Physiol.* **75**, 372–377.

20. Rajgopal S. (1991) Power and Environment. On a Collision Course, pp. 93–98 in *The Hindu: Survey of the Environment*, India.

21. Rao D. N., Agrawal M. and Singh J. (1990). Study of pollution sink efficiency, growth response and productivity pattern of plants with respect to flyash and SO_2. *Final Technical Report submitted to Ministry of Environ. & Forest India,* DOE/141/266/85.

22. Silvius J. E., Bear C. H., Dodrill S. and Patrick H. (1976) Photoreduction of sulphur dioxide by spinach leaves and isolated spinach chloroplasts. *Plant Physiol.* **57**, 799–801.

23. Sprugel D. G., Miller J. E., Muller R. N., Smith H. J. and Xerikos P. B. (1980) Sulfur dioxide effects on yield and seed quality in field-grown soybeans. *Phytopathology* **70**, 1129–1133.

24. Winner W. E., Mooney H. A. and Goldsten R. A. (1985) Sulphur dioxide and vegetation. *Physiology, Ecology and Policy Issues.* Stanford Univ. Press, Stanford Calif. p. 593.