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Rajput, M.
Department of Botany Banaras Hindu University

Agrawal, M.
Department of Botany Banaras Hindu University

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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

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RAJPUT M. and AGRAWAL M. *Responses of soybean plants to sulphur dioxide at varying 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 SO₂ for 4 hrs day⁻¹ for 5 days week⁻¹ for 6 weeks. The interaction of SO₂ 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 SO₂ treated plants grown at different 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 SO₂ treated plants were always lower compared to respective controls. *RSR* increased in SO₂ treated plants without fertilizer treatment. *SLA* was always higher for SO₂ treated plants. SO₂ fumigation resulted in significant reduction of seed yield. However, fertilizer amendment reduced the loss of seed yield due to SO₂ treatment. Fertilizer amendment has modified the SO₂ 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 (SO₂), have been identified as a cause of great concern for agricultural productivity. SO₂ 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, SO₂ 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 SO₂ 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 SO₂ often decreased the yield of plant without visible symptoms of injury (6). Recent reports have suggested that low levels of SO₂ 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 SO₂ at the concentrations that occur near a point source. Although accurate figures for economic losses in crop yields due to SO₂ 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 SO₂ 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 O₃ 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 SO₂ concentrations (12, 18). No reports are, however, available about responses of soybean plants to SO₂ in tropical environment.

Keeping the above facts in view, the present study was aimed to assess the effects of SO₂ 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 DS m⁻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 (F₁), NPK double recommended dose (F₂) and without NPK application (F₀). 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 $390 \pm 10 \mu\text{g m}^{-3}$ (0.15 ppm) SO₂ 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 × 1.5 m² transparent polythene chamber (0.25 mm) supported on a 1.5 × 1.5 × 1.5 m iron frame. Sulphur dioxide gas was provided with SO₂ 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 SO₂ analyzer (Model 319, KIMOTO, Japan) based on conductivity changes in hydrogen peroxide solution due to sulphuric acid formation. For convenience, plants were designated as F₀C, F₁C and F₂C for those without NPK, those at recommended dose of NPK and those at double recommended dose of NPK, respectively and F₀T, F₁T and F₂T, respectively for their SO₂ 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°C 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 SO₂ 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 F₁T and F₂T treatments had less symptoms of SO₂ injury than

the F₀T plants.

The values for shoot and root lengths, numbers of leaves, nodules and pods and leaf area were lower for SO₂ treated plants compared to their respective untreated controls (Figs. 1 and 2). All these characters were reduced maximally in F₀T 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 F₀T, F₁T and F₂T 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 F₀T, F₁T and F₂T plants, respectively at 75 days age (Fig. 1).

Analysis of variance test showed significant variations in plant biomass due to plant age, fertility levels, SO₂ treatment and their interactions (Table 1). With the increase in age and dose of SO₂, 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 F₀T, F₁T and F₂T plants, respectively (Fig. 3).

The effect of SO₂ fumigation at different fertility levels on assimilate partitioning was further assessed by growth analyses. Leaf area ratio values of SO₂ 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 SO₂ treatment as that of *LAR* except in case of F₀T 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 SO₂ treated plants as compared to their respective controls, the increase being 10.5, 1.4 and 1.2 in F₀T, F₁T and F₂T 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 F₀T plants up to 45 days age and thereafter increased

Table. 1 Results of analysis of variance of the effects of SO₂ treatment, fertility levels and plant age on the total biomass and growth indices of soybean plants.

Plant parameter	F A C T O R						
	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.

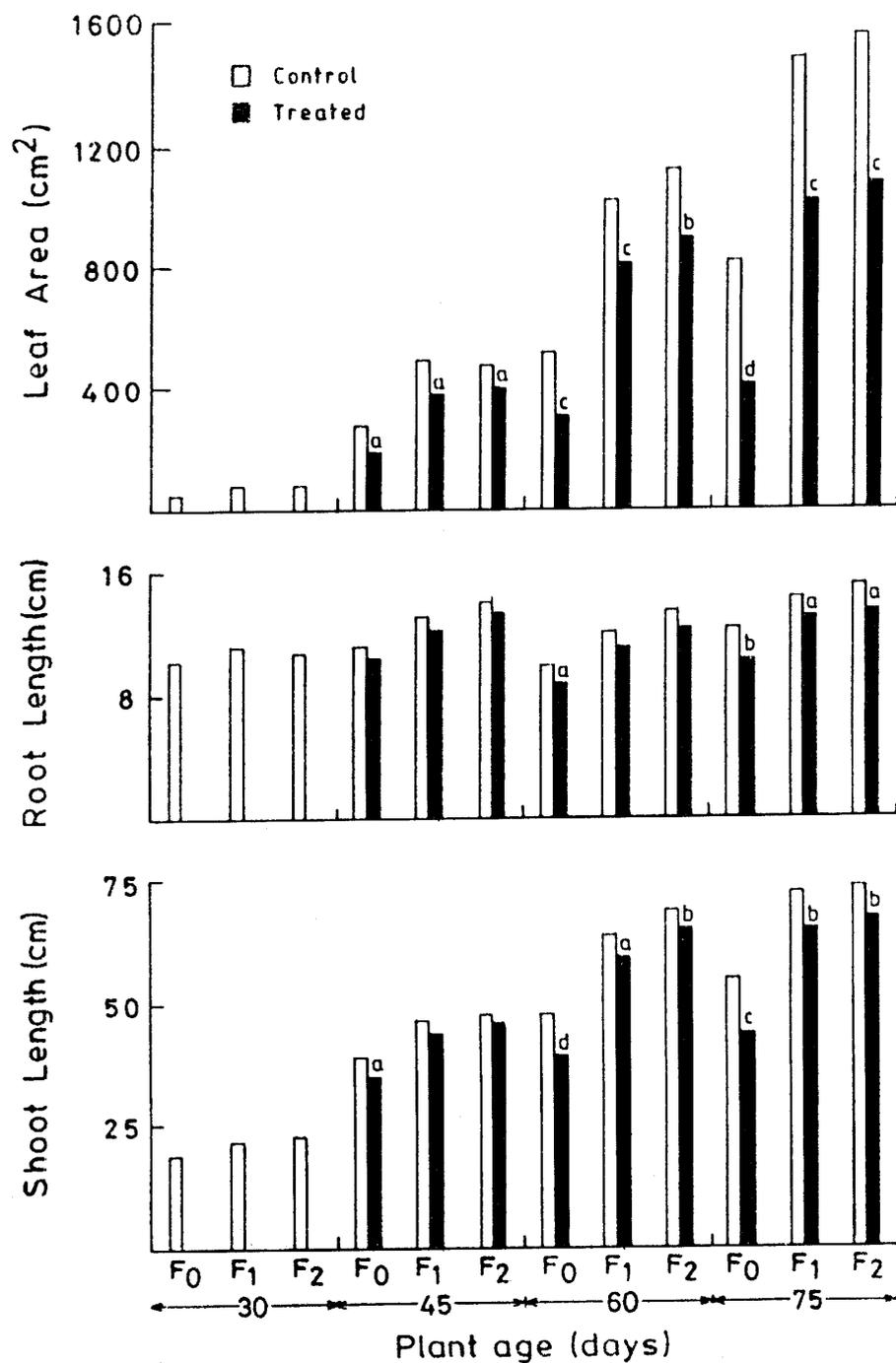


Fig. 1. Shoot length, root length and leaf area of control (C) and SO₂ treated (T) soybean plants grown at different fertility levels. F₀, without NPK application; F₁, NPK recommended dose; F₂T, NPK double recommended dose. Level of significance: a, p<0.05; b, p<0.01; c, p<0.005; d, p<0.001.

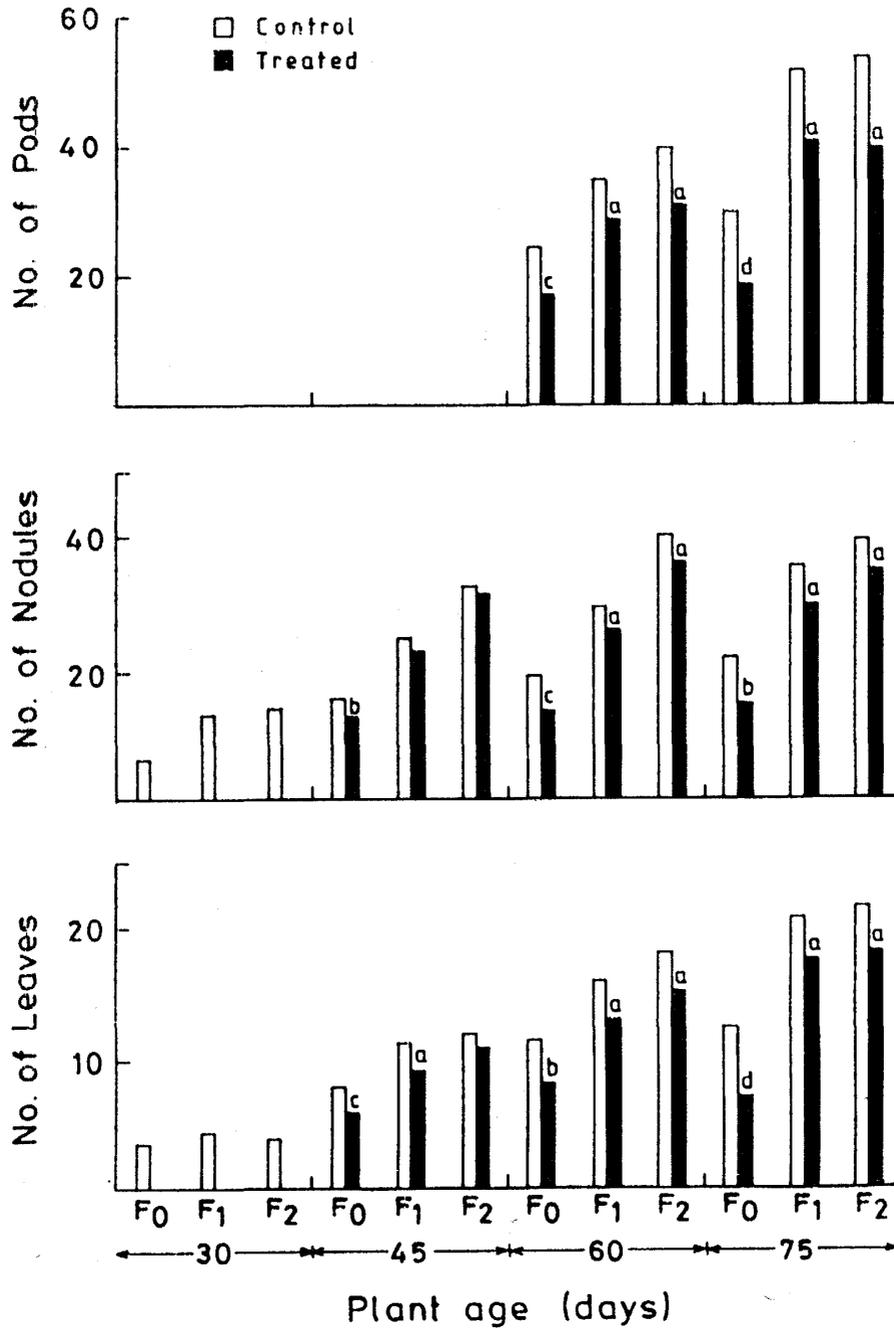


Fig. 2. Number of leaves, nodules and pods of control (C) and SO₂ treated (T) soybean plants grown at different fertility levels. F₀, without NPK application; F₁, NPK recommended dose; F₂, NPK double recommended dose. Level of significance: a, $p < 0.05$; b, $p < 0.01$; c, $p < 0.005$; d, $p < 0.001$.

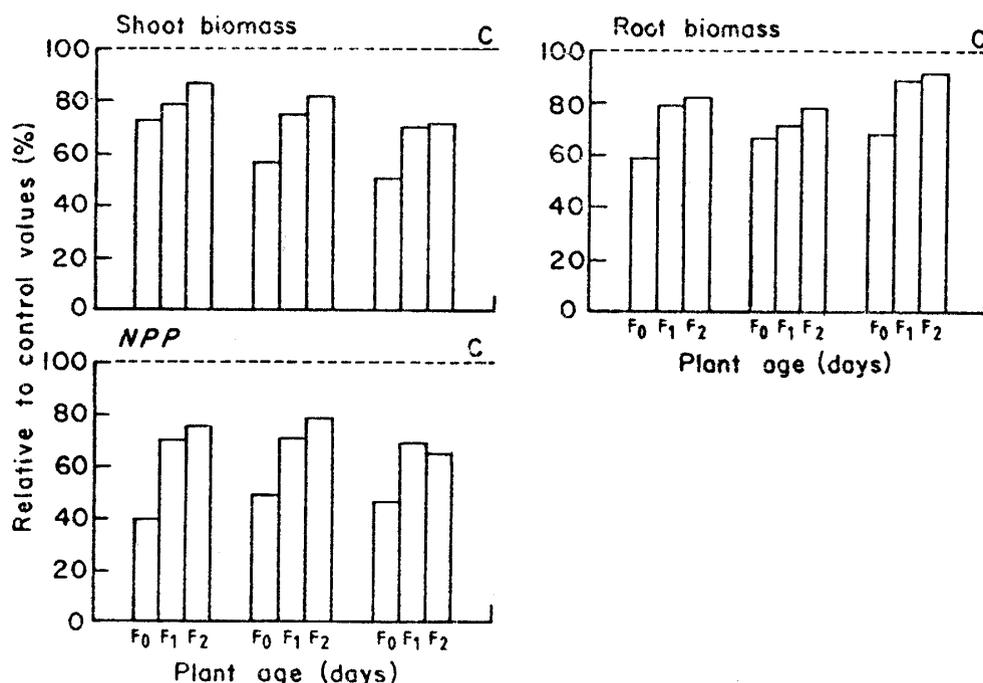


Fig. 3. Relative to the control values for root and shoot biomass and net primary productivity of SO₂ treated soybean plants grown at different fertility levels. C, control (100%); F₀, without NPK application; F₁, NPK recommended dose; F₂, NPK double recommended dose.

compared to F₀C (Fig. 4). In F₁T, 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 SO₂ fumigated plants throughout the plant life (Fig. 5). Maximum reduction was observed for F₀T plants. NAR was reduced by 20.6, 11 and 13.3% and RGR by 24.1, 13 and 15.1% in F₀T, F₁T and F₂T 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, SO₂ 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 SO₂ treated plants as compared to their respective controls (Table 2). Maximum reductions were observed in F₀T plants. F₁T and F₂T plants showed more or less same trend of changes due to SO₂ treatment. Reductions in yield were 54.2, 28 and 27.3% for F₀T, F₁T, and F₂T 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)

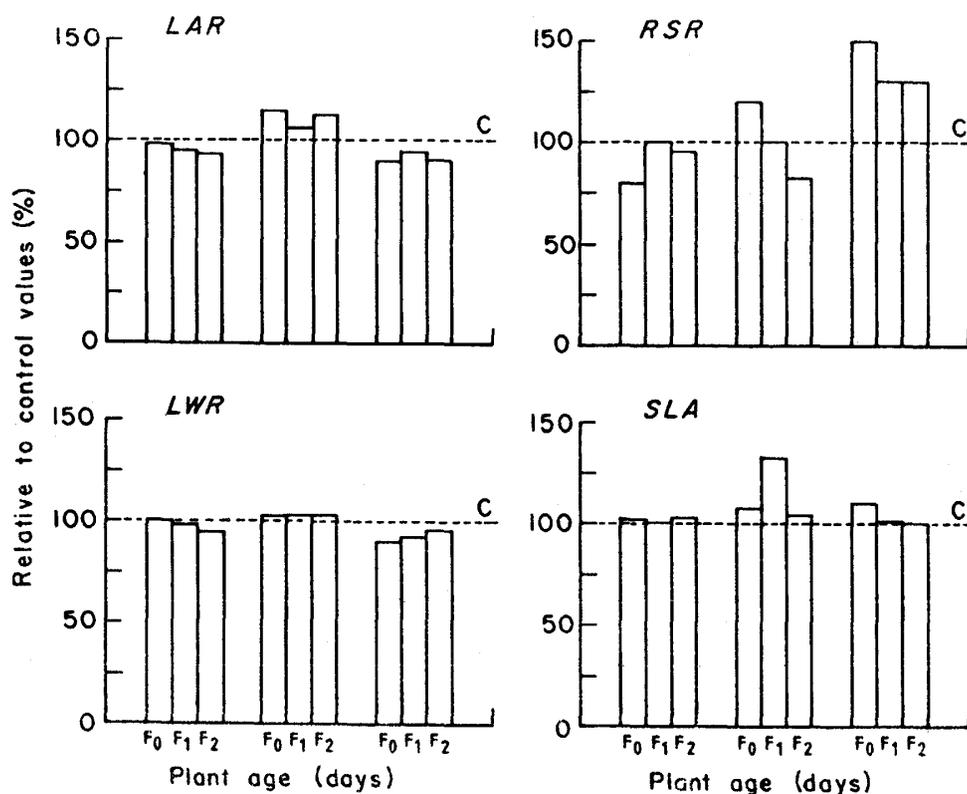


Fig. 4. Relative to the control values for *LWR*, *LAR*, *SLA* and *RSR* of SO₂ treated soybean plants grown at different fertility levels. C, control (100%); F₀, without NPK application; F₁, NPK recommended dose; F₂, NPK double recommended dose.

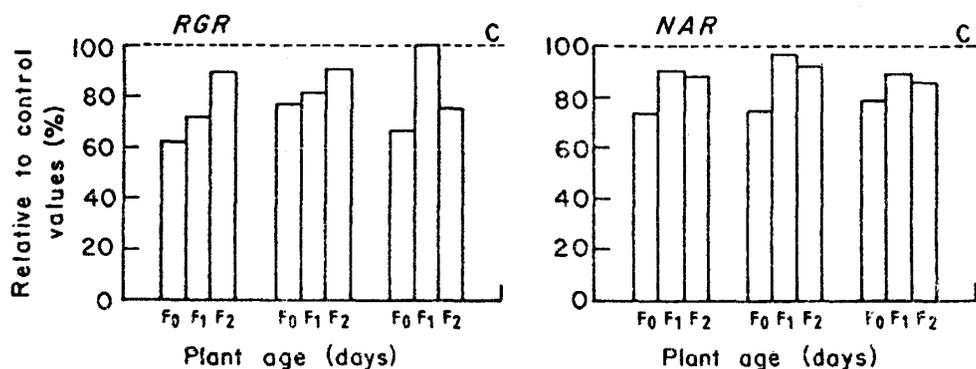


Fig. 5. Relative to the control values for *RGR* and *NAR* of SO₂ treated soybean plants grown at different fertility levels. C, control (100%); F₀, without NPK application; F₁, NPK recommended dose; F₂, NPK double recommended dose.

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

F₀: Without NPK application; F₁: NPK recommended dose; F₂: 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 SO₂ exposed soybean plants. Nitrogen limitation has also been shown to reduce dry matter production in plants (15). The effect of SO₂ 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 SO₂ exposed plants. Ormrod *et al.* (16) and Pell *et al.* (17) have, however, reported greater sensitivity to O₃ of plants grown with higher nitrogen supply. Foliar injury assessment also showed that plants grown without NPK amendment elicited maximum injury due to SO₂ 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 F₀T plants, inadequate mineral nutrients reduced plant growth primarily by restricting leaf area development and further exposure of SO₂ 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 SO₂ 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 metabolic activities in plants (1, 23, 24), its significant reduction further confirms that SO₂ may directly interfere with these functional processes resulting in biomass reductions as well as growth retardation. Initially SO₂ 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 SO₂ 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 SO₂ with respect to *RSR*. *RSR* was significantly low in F₀T plants within 15 days of treatment whereas this did not change much in F₁T and F₂T plants compared to their controls. But at 30 day of treatment *RSR* was higher for F₀T 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 SO₂ exposed plants due to reduced nutrient availability.

RGR and *NAR* of the SO₂ 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 SO₂ treated plants. Although *LAR* was higher for SO₂ 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 SO₂ exposed plants. Coleman *et al.* (4) also found sharp decrease in *RGR* of SO₂ 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 SO₂ 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 SO₂ gas may have been used as a source of S and is being incorporated into organic S compounds and thus provided higher resistance against SO₂ in F₁T and F₂T plants compared to F₀T plants.

The results of the present study clearly indicate that an atmosphere polluted with 0.15 ppm SO₂ 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 SO₂. Plants grown on low fertile soil are more sensitive to SO₂ 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 SO₂ grown at recommended and double recommended doses of NPK. Fertilizer amendment has reduced the adverse effects of SO₂ 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 SO₂. NPK nutrients at recommended dose may be used to alleviate the injurious effects of SO₂ on soybean.

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