Abstract/Synopsis

1. Terrestrial life evolved only after the formation of stratospheric ozone layer that absorbed most of the damaging UV-B radiation. Chlorofluorocarbons have been mainly implicated for the depletion of ozone shield. Consequently, terrestrial levels of UV-B radiation are increasing with potentially deleterious effects on living being including plants. UV-B at enhanced level can result in a wide variety of morphological, physiological and biochemical alterations in plants, leading to yield losses. Sensitivity to enhanced UV-B, however, varies with crop species, cultivar, UV-B dose, developmental stage, PAR level and other environmental conditions including nutrient levels in the soil.
2. In view of the deleterious effects of UV-B on plants and possible modification of response under varying nutrient levels in soil, the present study was conducted to assess the impact of supplemental UV-B (sUV-B) radiation on selected vegetable crops, namely amaranthus (*Amaranthus tricolor* L. cv Badi Chaulai), potato (*Solanum tuberosum* L. cv Kufri Badshah), radish (*Raphanus sativus* L. cv Pusa Himani), spinach (*Spinacia oleracea* L. cv All Green) and tomato (*Lycopersicum esculentum* L. cv Pusa Ruby) at varying nutrient levels under natural levels of photosynthetic active radiation (PAR) at the Botanical Garden of Banaras Hindu University, Varanasi, India from March, 2006 to April, 2008.
3. Field plots were prepared using specified agronomic practices for different test vegetables at their respective growing season. N, P and K in form of urea, superphosphate and muriate of potash were given in different combinations. The nutrient combinations for amaranthus, radish and potato were, recommended NPK, 1.5 times recommended NPK, 1.5 times recommended N and 1.5 times recommended K whereas for spinach and tomato, the nutrient combinations were, recommended NPK, 1.5 times recommended NPK, 1.25 times recommended N plus recommended PK and 1.25 times recommended NPK. Since the nutrient combinations were different among the test vegetables, therefore the results are summarized below on the basis of two nutrient levels (recommended NPK and 1.5

times recommended NPK), common for all the vegetables.

4. Supplemental UV-B was provided artificially by Q panel UV-B 313 fluorescent lamps. Banks of 3 lamps fitted 30 cm apart on a steel frame were suspended above and perpendicular to the planted rows. Forty five cm distance between the top of the canopy and UV-B lamps were kept constant by adjusting the steel frame. Plants were irradiated after germination for 3 h day^{-1} in the middle of the photoperiod till the maturity of respective vegetable. Control plants under polyster filter lamps received only ambient and that beneath cellulose diacetate film received ambient+ supplemental UV-B (7.1 kJ m^{-2}). The sUV-B_{BE} dose mimicked 20 % stratospheric ozone layer depletion.
5. Plant samplings were done at periodical intervals to measure various physiological (photosynthesis rate, stomatal conductance, transpiration, water use efficiency (WUE), initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv) and Fv/Fm ratio), biochemical (MDA content, superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR) and phenylalanine ammonia lyase (PAL) activities and contents of photosynthetic and non-photosynthetic pigments, ascorbic acid, total phenolics, proline and protein), and growth characteristics (root and shoot lengths, number of leaves, leaf area, biomass accumulation and allocation, specific leaf weight (SLW), relative growth rate (RGR). At maturity, plants were harvested and yield and other characteristics such as number and weight of tubers for potato and number of fruits for tomato and root diameter for radish were quantified. Quality of edible portion was also evaluated with respect to the contents of mineral nutrients for all the test vegetables and starch and reducing sugar for potato.
6. Photosynthesis rate (Ps) declined in radish and amaranthus plants under sUV-B treatment at 1.5 times recommended NPK. At recommended NPK, Ps increased in radish whereas reduction was observed in amaranthus, while at 1.5 times NPK more reduction in radish was observed (Table 7.1). Stomatal conductance and WUE reduced under sUV-B treatment in both the test vegetables compared to control.

Amaranthus showed reduction in transpiration rate at both the nutrient levels whereas radish showed an increment at recommended NPK and reduction at 1.5 times NPK (Table 7.1).

7. Fo increased in all test vegetables under sUV-B radiation at recommended NPK, while radish, spinach and tomato showed a similar response, but a reduction in Fo was observed in amaranthus and potato at 1.5 times NPK. Fv reduced in all test vegetables under sUV-B treatment at both nutrient levels except radish and tomato, where an increment was observed at recommended NPK. Fv/Fm ratio decreased in all test vegetables under sUV-B at varying nutrient levels. Fv/Fm ratio showed more decline at recommended NPK compared to 1.5 times NPK except in potato.
8. Degree of lipid peroxidation measured as malondialdehyde (MDA) content was higher in plants grown under sUV-B at varying nutrient levels compared to their controls. Magnitude of increase in MDA content was highest in spinach at recommended NPK and in potato at 1.5 times NPK, but lowest for radish at both nutrient levels. Increments in MDA content were found to be higher in all test vegetables at recommended NPK except in radish, where increment was more at 1.5 times NPK.
9. Total chlorophyll content declined under sUV-B in all test vegetables with highest reduction in spinach at recommended NPK and in potato at 1.5 times NPK. Reduction in total chlorophyll content was more at recommended NPK than 1.5 times NPK except in radish. Carotenoid content increased under sUV-B in all test vegetables except in potato, where a reduction was observed at recommended NPK. At 1.5 times NPK, carotenoid content increased maximally in spinach. Flavonoid and anthocyanin contents increased in all test vegetables at both the nutrient levels under sUV-B treatment. Both flavonoid and anthocyanin contents increased more at recommended NPK than 1.5 times NPK except in tomato.
10. Activities of antioxidative enzymes such as POX and SOD were higher in plants grown under sUV-B at varying nutrient levels except POX, which reduced in spinach at both the nutrient levels. Higher increment in SOD activity was observed

at 1.5 times NPK under sUV-B treatment except in radish. APX activity increased in sUV-B treated plants compared to control except in spinach and tomato, where it reduced at recommended NPK. CAT activity reduced under sUV-B treatment in spinach and tomato at recommended NPK, while increased in spinach at 1.25 times NPK and in tomato at 1.5 times NPK. Increment in GR activity was observed at all nutrient levels under sUV-B treatment of spinach and tomato compared to control.

11. Proline content increased in all test vegetables under sUV-B except in spinach, where reduction was observed at recommended NPK. Proline content increased more at 1.5 times NPK except in radish where more increment was observed at recommended NPK. Increments in total phenolic content were more at 1.5 times recommended NPK compared to recommended NPK except in spinach. Protein content was lower in all test vegetables under sUV-B radiation at varying nutrient levels. Reduction in protein content was more at recommended NPK except in radish and tomato where more reduction was observed at 1.5 times NPK. Ascorbic acid content under sUV-B treatment increased in amaranthus and potato at recommended NPK and in amaranthus at 1.5 times NPK.
12. Root length reduced in all test vegetables under sUV-B except in spinach where increment in root length was observed at both nutrient levels. The observed reduction in root length was more at recommended NPK compared to 1.5 times NPK except in radish. Shoot length also declined in all test vegetables under sUV-B at varying nutrient levels except in tomato where an increment was observed under recommended NPK. Shoot length reduced more at 1.5 times NPK than recommended NPK under sUV-B treatment except in amaranthus.
13. Leaf area decreased in all test vegetables under sUV-B treatment at both nutrient levels except in potato where an increment was observed at recommended NPK. Reductions in leaf area were less at 1.5 times recommended NPK than recommended NPK under sUV-B treatment. Number of leaves increased in amaranthus and spinach under sUV-B treatment at both nutrient levels, whereas it increased in potato and tomato only at 1.5 times recommended NPK.

14. Total biomass was significantly lower in all test vegetables under sUV-B treatment, however, NPK at different levels modified the response of biomass accumulation. Potato and radish showed more reductions in total biomass under sUV-B treatment at 1.5 times NPK, whereas amaranthus, spinach and tomato showed more reductions at recommended NPK.
15. Yield of all test vegetables was lower under sUV-B treatment at varying nutrient levels. Yield loss was more at recommended NPK compared to 1.5 times NPK level except in radish.
16. Mineral nutrients showed varying levels of changes in response to sUV-B and nutrients levels. Concentrations of mineral nutrients decreased under sUV-B treatment. Potato tubers showed reduction in starch content, whereas increment in reducing sugar was observed under sUV-B treatment at all nutrient levels.
17. Amaranthus, radish and potato plants also grown at 1.5 times recommended N and 1.5 times recommended 1.5 k showed reductions in Fv/Fm ratio, chlorophyll and protein contents and growth characteristics at sUV-B treatment. The above parameters showed lower magnitude of reductions at 1.5 times N compared to 1.5 times K, but higher magnitude of reductions than recommended and 1.5 times recommended NPK. Yield showed a different trend of response under sUV-B among all nutrient levels as maximum yield loss was observed at 1.5 times N in potato and radish compared to other three nutrient combinations. However, amaranthus showed maximum yield loss at 1.5 times K.
18. Spinach and tomato plants also grown at 1.25 times N plus recommended PK at 1.25 times NPK, showed maximum reduction in yield under sUV-B treatment at recommended NPK. Among the various nutrient levels, maximum ameliorating effect was observed for 1.5 times recommended NPK followed by 1.25 times NPK, 1.25 times N + recommended PK and minimum for recommended NPK.
19. Supplemental UV-B (sUV-B: Ambient+7.2 kJ m^{-2} d^{-1}) mimicking 20 % stratospheric ozone depletion led to significant negative effects on growth, physiological and biochemical characteristics and yield of all test vegetables. The

magnitude of negative effects, however, varied with test vegetables, age and availability of different nutrients, their combination and concentrations. Yield response did not directly correlate with physiological and biochemical responses assessed at different ages.

20. Quality of edible parts of vegetable also deteriorated under sUV-B treatment. The application of 1.5 times NPK provided yield improvement under sUV-B for potato, but the quality of tubers deteriorated. Application of either N or K at concentration higher than recommended showed no protective role against sUV-B.