Effect of reduced PAR on growth and photosynthetic efficiency of soybean genotypes

Article *in* Journal of agrometeorology · March 2017

8 authors, including:

Kiran Bhagat
ICAR- Central Citrus Research Institute, Nagpur
20 PUBLICATIONS **8** CITATIONS

Yogeshwar Singh
National Institute of Abiotic Stress Management
47 PUBLICATIONS **230** CITATIONS

Ratna Kumar Pasala
Indian Council of Agricultural Research
70 PUBLICATIONS **524** CITATIONS

G C Wakchaure
Indian Council of Agricultural Research
45 PUBLICATIONS **96** CITATIONS

Journal of Agrometeorology 19 (1) : 1-9 (March 2017)

Effect of reduced PAR on growth and photosynthetic efficiency of soybean genotypes

KIRAN P. BHAGAT*, S.K. BAL, YOGESHWAR SINGH, S. POTEKAR, SUNAYAN SAHA, P. RATNAKUMAR, G.C. WAKCHAURE and P.S. MINHAS

ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati, Pune, India

*E-mail: kiranbhagat.iari@gmail.com

ABSTRACT

Soybean is an important crop, and physiologically, it is photosensitive in nature and therefore, is likely to be highly affected by the atmospheric brown clouds (ABCs) which reduce PAR (Photosynthetically Active Radiation) availability, and moisture stress conditions those may prevail as a consequence of climate change scenario. Therefore, the impact of reduced natural PAR was evaluated on its determinate (DT; cv. JS-93-05), semi-determinate (SDT; cv. JS-335) and indeterminate (IDT; cv. Kalitur) genotypes. For simulating the reduced PAR condition, three different shapes of structures, *viz*., rectangular-cuboid, octagonal-dome and hemispherical-dome with shade-net covering were initially tested to check the uniformity of PAR availability inside the structure and the last one was found better. The light saturation point (LSP) was found to be 800, 1200 and 1000 PAR µmol $m^{-2}s^{-1}$ in case of DT, SDT and IDT genotypes, respectively. Under reduced PAR and restricted irrigation condition, the photosynthetic rate was 20.8, 21.9 and 28.9 µmol $m^{-2}s^{-1}$ in case of DT, SDT and IDT cultivars, respectively, while their seed yields were 151.3, 238.7 and 264.2 kg ha^{-1} indicating better source-sink relations of the IDT cultivar. Therefore, it is projected that IDT cultivars are likely to be popular under futuristic scenarios of low PAR availability and water scarcities.

Keywords: Light saturation point, PAR, Photosynthesis, Shade-net structure, Source-sink relationship, Soybean.

Atmospheric particles generally termed aerosols, significantly perturb the atmospheric absorption of solar radiation by scattering/absorbing solar radiation and emitting/absorbing long wave (IR) radiation. However, aerosol concentration changes with altitude, regulate the radiation fluxes at the surface as well as at the top of the atmosphere and affects ambient temperature also. In addition, they reflect some of the incoming solar radiation back to space, cooling the earth's surface, and at the same time absorbs some of the energy coming from sun, heating the atmosphere around them. But the magnitude of aerosol energy absorption on the global scale and its contribution to global warming are uncertain (Seinfeld, 2008). ABCs (Atmospheric Brown Clouds) induced atmospheric heating and surface dimming are large over Asia in general and over India and China, in particular (Ramanathan *et al*., 2007). For India, the observed surface dimming trend was 4.2 Wm^{-2} per decade (about 2 per cent per decade) during 1960 -2000, while it accelerated to 8 Wm^{-2} per during the period between 1980–2004. Cumulatively, these decadal trends suggest a reduction of about 20 Wm^{-2} from 1970s-2002 and are projected to increase as per future projections (Ramanathan *et al*., 2007).

Another potential environmental effect of ABCs is their large effect in reducing the total (direct + diffuse) PAR. The brown clouds over the Arabian Sea decreased direct PAR by 40 - 70 per cent, but enhanced the diffuse PAR substantially, with a net reduction in total PAR by 10 - 30 percent (Meywerk and Ramanathan, 2002). The potential impact of large reductions in direct PAR and corresponding enhancements in diffuse PAR accompanied by net reduction in total PAR on marine and terrestrial photosynthesis and on agricultural productivity (Bal *et al.,* 2004; Chameides *et al*., 2002; Stanhill and Cohen, 2001) have not been adequately reported. Very few studies have examined the impacts of ABCs on agriculture (Chameides *et al*., 1999; UNEP, 2002), but it needs to be mainly focused on the impact of solar radiation on yield and productivity. The estimations are that the dimming effect of ABCs has reduced rice yield by 6–17 per cent (Auffhammer *et al*., 2006). For wheat and rice, yield reductions up to 8 per cent were predicted in India when single effect of aerosols on radiation was considered by crop simulation models (UNEP, 2008). However, when cooling effect was also incorporated in the model, it nullified the yield reductions due to enhanced crop duration effect (UNEP, 2008). The reduction in PAR may or may not reduce the yield of photo-insensitive crops, but certainly, it will hamper the yield potential of photo-sensitive crops like soybean (Ramanathan *et al.*, 2007).

As soybean is a photo-sensitive crop and the yield gets negatively affected by surface dimming Brazil has started adopting indeterminate soybean varieties (Anonymous, 2012). In Brazil, the 50 per cent of cultivated area of determinate soybean genotypes were replaced and occupied by indeterminate genotypes and it is expected to eventually reach 100 per cent (Anonymous, 2012). The huge advantage of indeterminate varieties over determinate varieties was that they could recuperate after periods of dry weather. Under hot and dry weather the indeterminate varieties which are at flowering stage, may abort their flowers and pods to escape the conditions, they recovers with new flush of flowers once rainfall occurs. In India, about 70 per cent soybean area is cultivated with semi-determinate genotypes, around 20 per cent with determinate and only 10 per cent with indeterminate genotypes. Therefore, experiments were conducted to i) develop suitable shade-net structures for simulating reduced PAR condition, ii) determine the light saturation point (LSP) for maximizing photosynthesis among the soybean genotypes iii) identify the better performing cultivars under reduced PAR and moisture stress conditions.

MATERIALS AND METHODS

The experiments were conducted at ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati (latitude: 18°09'N, longitude: 74°30'E, elevation: 550 MSL), Pune, Maharashtra, India during two *Kharif* seasons in 2013 and 2014.

Crop raising conditions

The experiment was carried out in black 60-70 cm deep silty clay soil (around 40 % clay) developed over native basaltic terrain. Baramati is prone to drought and characterized by low and erratic rainfall. The long term annual rainfall is 588 mm of which about 71 per cent is received during the four months of southwest were monsoon season (June-September). Prevailing weather conditions during the two experimental *kharif* seasons of 2013 and 2014 monitored at automatic weather station (AWS).

Seed materials and experimental design

Soybean genotypes of determinate (JS-93-05), semi-determinate (JS-335) and indeterminate (Kalitur) used for the conduct of experiment was obtained from Agharkar Research Institute (ARI), Regional Station, Wadgaon-Nimbadkar, Pune, India. The field was initially prepared to pulverize the soil and thereafter, ridges and furrows were created using a mini tractor. Sowing was done on 21st July in 2013 and 14th July in 2014. The experiment was conducted under split plot design with three replications having two irrigation levels i.e. normal irrigation (NI) and restricted irrigation (RI) (withheld irrigation at 60 DAS, i.e., *anthesis period*); and three genotypes of contrasting growth characteristics, namely, Determinate (JS-93-05), Semi-determinate (JS-335) and Indeterminate (Kalitur), in sub-plots having size of 8.0 x 4.5m^2. Total water applied in normal and restricted irrigations were 18 and 12 cm during 2013; 24 and 18 cm during 2014, respectively. Three irrigations in 2013 and four in 2014 were applied under normal irrigation while in restricted irrigation it was two and three, respectively. The irrigation frequencies between two years were differed due to variation in time and amount of rainfall. Recommended practices were followed for fertilizer application, and weed and insect-pests control.

Selection of shade-net and design of shade-net structure

Three shade-net structures of different shapes which are generally used for experimental purpose namely; rectangular-cuboid (6 m length x 4 m width x 3 m height), octagonal-dome (6 m diagonal length, 3 m height) and hemispherical-dome (6 m diameter, 3 m height) were fabricated to evaluate and standardize the uniformity of PAR availability within the structures (Fig. 1). The corrosion resistant iron pipe (25-50 mm diameter and 14-16 gauge thickness) was used for fabrication; which could withstand and protect the structure during entire growth stages from the extreme wind and rain. About 0.25 m distance was maintained between bottom side and ground surface for all shade-net structures using iron stand to avoid temperature rise and uniform air flow within the structure. The shade-net structures were covered with the research grade white shade-net (25% reducing factor of sunlight). During construction and selection of shade-net, intensive care was taken to test the PAR availability without affecting the other parameters *viz.*, temperature and relative humidity. The PAR observations were recorded randomly from 20 different fixed points in each shade-net structure at three different heights of 0.5m, 1.0m and 1.5m from the ground level.

Photosynthetically active radiation

The PAR availability was measured using Line quantum sensor (LI-191S, LICOR). Twenty sample points were marked inside shade-net structures of the three shapes, at three heights, viz. 0.5m, 1.0m and 1.5m on a grid pattern and observations were recorded at one hour interval from 09:30 am to 04:30 pm with shade-net of 25% reduced factor. PAR reduction was calculated by using the following formula:

Reduction in PAR (%)

$$= 100 - \frac{\text{PAR availability inside the structure}}{\text{PAR availability outside the structure}} \; x \; 100$$

Photosynthetic assimilation rate (A)

The photosynthetic assimilation rate of soybean genotypes was measured by Advance Photosynthetic System *GFS-3000* (WALZ, Germany). Gas exchange measurements were made between 10.30 am and 11.30 am IST on generally cloud free days. For measuring photosynthetic assimilation rate (A), stomatal conductance (g_s) and transpiration rate (E) in light, photosynthetic leaf chamber (*model*: GFS-3010-S) was clipped onto the attached leaf, which had been exposed to sunlight. The chamber was held in such an angle that the enclosed leaf surface faced the sun, to avoid shading inside the curette. The irradiance at the upper surface of the leaf chamber was measured by calibrated sensor (filtered silicon photocell, *model*: 3055-FL) mounted on the same surface of the leaf chamber. It was 1300 ± 50 PAR µmol m^{-2} s^{-1} outside during the most photosynthesis measurements; and the temperature, relative humidity and CO_2 concentration were 26.1 ± 2°C, 68 ± 2% and 390 ± 15 µmol CO_2 mol^{-1}, respectively. The photosynthesis and stomatal conductance become stable within 2 minutes after clipping the selected attached leaf experiencing saturated solar irradiance and values on photosynthesis gas exchange were then recorded. Measurements were made on six different plants on the third leaf from the stem apex. The photosynthetic assimilation rate (A) was calculated as given by Caemmerer and Farquhar (1981)

$$A = \frac{u_e \; x \; (c_e - c_o)}{LA} - \; (E \; x \; c_o)$$

Where,

A = Photosynthetic assimilation rate [µmol m^{-2} s^{-1}],

u_e = Molar flow rate at the inlet of the cuvette [µmol s^{-1}],

c_o = CO_2 mole fraction at the outlet of the cuvette [ppm],

c_e = CO_2 mole fraction at the inlet of the cuvette [ppm].

LA = Leaf area [cm^2],

E = Transpiration rate [mmol m^{-2} s^{-1}]

Growth and yield parameters

The plants were harvested after physiological maturity, and separated into leaf, stem, pods and fractions. Plant height of each plant was measured in each subplot of irrigation treatments and control (well-irrigated) plots. Dry weights of plant parts and seeds were measured after drying at 80°C in a hot air oven for 72 hours.

Statistical analysis

The data obtained from the above experiment were analysed in split plot design as given by Panse and Sukhatme (1967). The significance of difference was evaluated by 'F' test at 5% level of significance. Accordingly, the critical differences were calculated.

RESULTS AND DISCUSSION

Development of equal PAR distribution shade-nets

Surface dimming is an atmospheric stress from photosynthetic efficiency view point and it will increase in future (Ramanathan *et al*. 2007). Hence, it was necessitated to establish a methodology to simulate surface dimming in closed environments for experiment purpose. Before the conduct of the experiment and to understand its impact on photosensitive crops like soybean, it was imperative to test the uniformity of PAR availability within the shade-net structures. Therefore, different shapes of structures were tested to select the ideal one. Among the structures, the hemispherical-dome shape structure was most stable in field conditions as compared to octagonal-dome shape and rectangular-cuboid shape structures (Fig. 1). Furthermore, by recording the PAR values at 0.5m, 1.0m and 1.5m height above the ground level, it was observed that the hemispherical-dome shape structure provided more uniform availability of PAR inside the structure followed by octagonal-dome shape and rectangular-cuboid shape structures (Fig. 2). Distribution of PAR was also found uneven in both rectangular-cuboid and octagonal-dome structures during morning and late afternoon hours. Dey and Deka (2012) reported that the shape of the dome encloses maximum amount of space with least surface area for which dome's surface area requires lesser quantity of expensive building materials, which reduces cost and improves efficiency too.

Perusal of height of observation clearly reveals that, amongst three structures tested (Table 1), hemispherical-dome shape had resulted uniform PAR distribution as it had not shown any significant difference from centre to corners

Table 1: Mean value of PAR reduction in rectangular-cuboid shape (R), octagonal-dome shape (O) and hemispherical-dome shape (H) structures.

Height of observation	0.5 m R	0.5 m O	0.5 m H	1.0 m R	1.0 m O	1.0 m H	1.5 m R	1.5 m O	1.5 m H
Factor A									
A1	28.1	24.7	25.2	28.1	24.7	25.3	29.2	25.7	25.3
A2	25.7	24.3	25.3	25.7	24.4	25.6	26.8	25.4	25.6
A3	25.6	24.0	25.3	26.7	24.1	25.1	25.9	25.2	25.3
A4	26.7	24.5	25.3	28.0	24.5	25.8	27.4	25.6	25.2
C.D. (P=0.05)	0.6	NS	NS	0.9	NS	NS	0.5	NS	NS
Factor B									
B1	24.2	24.5	25.2	24.7	24.6	25.2	26.1	25.4	25.6
B2	26.8	24.6	25.4	27.2	24.7	25.4	27.1	25.5	25.2
B3	26.4	25.6	25.3	26.9	25.6	25.3	26.7	26.7	25.1
B4	25.2	24.6	25.2	25.9	24.6	25.3	27.0	26.1	25.1
B5	27.8	24.2	24.8	28.4	24.2	24.6	29.0	25.0	25.5
B6	28.8	23.9	25.7	29.4	23.9	25.7	28.1	24.7	25.5
B7	25.4	24.2	25.9	26.0	24.2	25.9	27.5	25.1	25.8
B8	27.8	23.6	26.0	28.4	23.6	26.0	27.2	25.2	25.5
C.D. (P=0.05)	0.8	0.6	NS	1.00	0.9	NS	0.8	0.7	NS
Interaction	S	S	NS	S	S	NS	S	S	NS

Where, A1 = Right outer border within the structure; A2 = Right inner border within the structure; A3 = Left outer border within the structure; A4 = Left inner border within the structure; B1, B2, B3, B4, B5, B6, B7 and B8 are time of observations at 09:00 am, 10:00 am, 11:00 am, 12:00 pm, 01:00 pm, 02:00 pm, 03:00 pm and 04:00 pm, respectively.

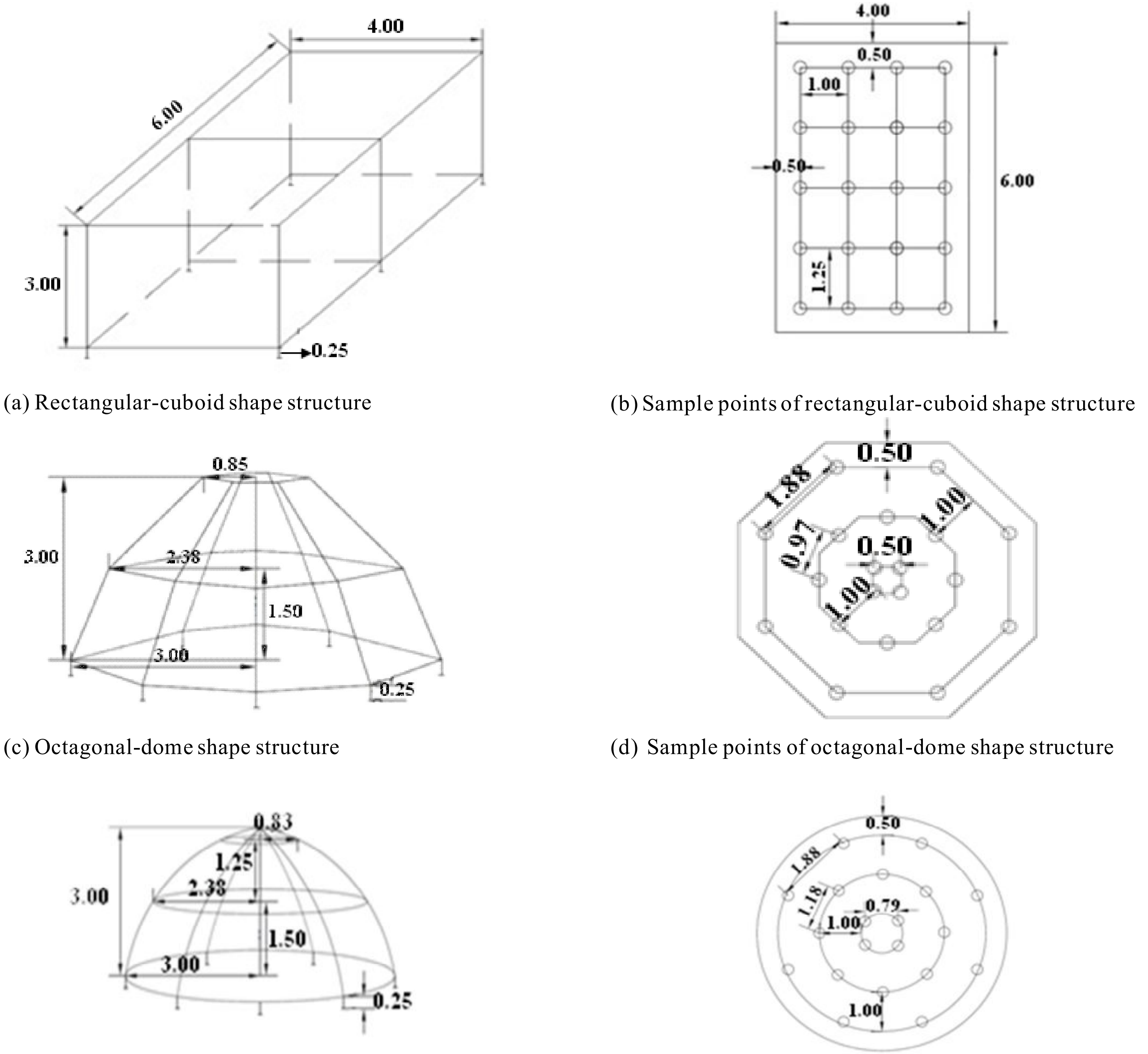
as well as time of observation. Octagonal-dome and rectangular-cuboid structures exerted significant variation in terms of time of observation and from centre to corners. Therefore, due to homogeneity in terms of PAR availability within the structure in hemisphere-dome shape structure as compared to rectangular-cuboid and octagonal-dome shape structures, the hemisphere-dome shape structure was identified as the most appropriate for conducting such type of research work.

Determination of light saturation points for maximum photosynthesis among soybean genotypes

Photosensitivity plays an essential role in the response of plants to their changing environments throughout their life cycle. Being a photosensitive crop, soybean needs specific PAR range for photosynthesis beyond which its production is affected drastically. Light saturation point was measured by giving different levels of PAR from 200 to 1600 µmol m^{-2} s^{-1} at canopy level of all the three genotypes. The determinate genotype (JS-93-05) showed its light saturation point near to 800 PAR µmol m^{-2} s^{-1} with photosynthetic rate of 20.77 µmol m^{-2} s^{-1} (Fig. 3), whereas semi-determinate soybean genotype JS-335 shown its light saturation point near to 1200 PAR µmol m^{-2} s^{-1} with photosynthetic rate of 21.95 µmol m^{-2} s^{-1}, while indeterminate soybean genotype Kalitur shown its light saturation point near to 1000 PAR µmol m^{-2} s^{-1} with photosynthetic rate of 28.88 µmol m^{-2} s^{-1}. Therefore it can be interpreted that indeterminate soybean genotype Kalitur will perform better in terms of photosynthetic rate which is directly proportional to the yield as compared to the determinate and semi-determinate types under future PAR scenario due to more aerosol and increase in cloudy days.

Yield variation among soybean genotypes under reduced PAR and restricted irrigation

To understand the response of different soybean genotypes under restricted irrigation condition during



(a) Rectangular-cuboid shape structure

(b) Sample points of rectangular-cuboid shape structure

(c) Octagonal-dome shape structure

(d) Sample points of octagonal-dome shape structure

(e) Hemispherical-dome shape structure

(f) Sample points of hemispherical-dome shape structure

Fig. 1: Schematic diagrams of rectangular-cuboid shape structure (a) and layout of sample point used (b); octagonal-dome shape structure (c) and layout of sample point used (d); hemispherical-dome shape structure (e) and layout of sample point used (f) to test the uniformity of PAR availability within the structure (all dimensions in meter).

reproductive stage, irrigation was withheld at 60 DAS (i.e. anthesis period). Due to this restricted irrigation, per cent reduction in terms of number of pods per plant (Table 2) was recorded minimum in indeterminate Kalitur (7.48%), followed by JS-93-05 determinate (25.26%) and semi-determinate JS-335 (33.33 %). Under restricted irrigation condition, indeterminate genotype Kalitur (66.8) performed better in number of pods per plant as compared to semi-determinate JS-335 (37.6) and determinate JS-93-05 (35.5). Similarly per cent reduction in terms of grain yield (q ha^{-1}) was recorded minimum in indeterminate Kalitur (7.43%), followed by semi-determinate JS-335 (17.80%) and determinate JS-93-05 (37.09 %). Under restricted irrigation condition, indeterminate genotype Kalitur (264.2 kg ha^{-1}) performed better in terms of grain yield (q ha^{-1}) as compared to semi-determinate JS-335 (238.7 kg ha^{-1}) and determinate JS-93-

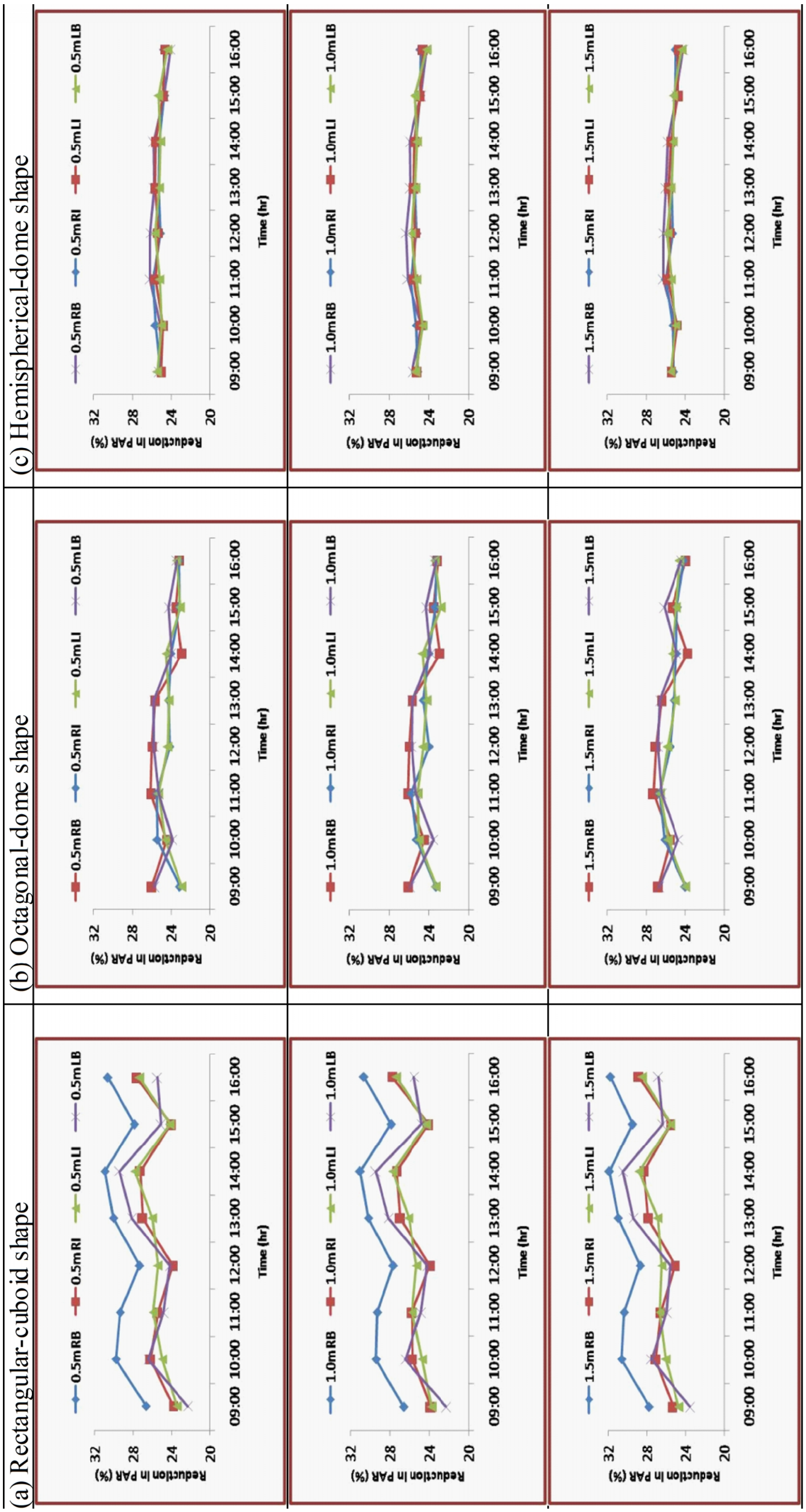


Fig. 2: Reduction in PAR availability (in %) under rectangular-cuboid (a), octagonal-dome (b) and hemispherical-dome (c) shape structures at the height of 0.5 m, 1.0 m and 1.5 m from ground surface of right border (RB), right internal (RI), left internal (LI) and left border (LB).

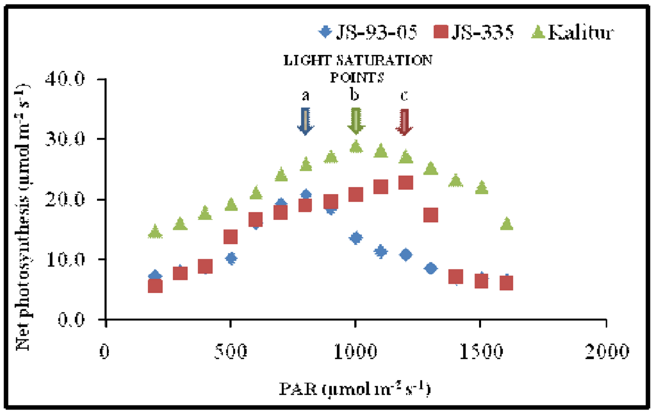


Fig. 3: Light saturation point of determinate (arrow 'a'), semi-determinate (arrow 'b') and indeterminate (arrow 'c') soybean genotypes.

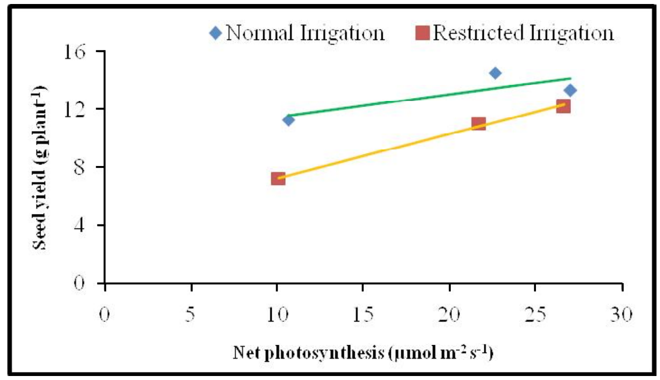


Fig. 4: Representation of variation in source (net photosynthesis) and sink (seed yield) relationship among the genotypes under normal irrigation and restricted irrigation conditions.

05 (151.3 kg ha^{-1}). The only problem with the indeterminate soybean genotype (Kalitur) was more shattering of the pods, if kept for longer time in the field after harvest maturity. Therefore, it is suggested that it should be harvested immediately after physiological maturity. From the above results, we brought to a close that the semi-determinate and indeterminate genotypes performed better under normal irrigated conditions (Table 2) in terms of grain yield as compared to determinate types, whereas, under restricted irrigation condition (60 DAS), indeterminate soybean genotype (Kalitur) performed better as compared to semi-determinate (JS-335) and determinate (JS-93-05) genotypes. Therefore, indeterminate soybean genotype (Kalitur) may be a better option to replace semi-determinate and determinate soybean genotypes for higher/sustainable production under reduced PAR scenario as Auffhammer *et al*. (2006) estimated that the reduction in PAR availability reduces rice yield.

Source and sink relation among soybean genotypes under reduced PAR and restricted irrigation

The varied relationship between source and sink was assessed among different genotypes (Fig. 4). The relationship was positive in both normal and restricted irrigation conditions and it was significant under restricted irrigation condition. Under restricted irrigation conditions, the source in terms of net photosynthesis was minimum in determinate (JS-93-05) genotype even under maximum PAR availability required. It clearly indicates that restricted irrigation hampered the partitioning of photosynthates in JS-93-05. The reduction in source and sink relation was almost two folds in case of JS-93-05 while the ratio was less in JS-335 and Kalitur between two irrigation treatments. It was also observed that difference in source and sinks relationship was not significant in Kalitur under both normal and restricted irrigations. These results indicate that the source and sink relationship at reproductive phase of determinate genotype JS-93-05 was affected due to restriction of irrigation and reduced PAR availability, whereas the JS-335 and Kalitur adapted better to restricted irrigation by skipping its reproductive phase.

Genotypic variations under reduced PAR and restricted irrigation conditions

As a convention, the surface dimming will affect more to photo-sensitive crops. In this study indeterminate soybean genotype performed better under reduced PAR compared to the determinate and semi-determinate soybean genotypes. At the same time, it also performed better under restricted irrigation condition, and hence, it may be taken as future option to replace semi-determinate and determinate soybean genotypes with indeterminate one for higher/sustainable production particularly under reduced PAR as well as limited availability of irrigation water. Restricted irrigation had marked deleterious effect on number of pods/plant, seed yield and biomass production as compared to normal irrigation. Indeterminate Genotype (Kalitur) had recorded significantly higher number of pods per plant and biomass production as compared to determinate and semi-determinate genotypes, while in terms of seed yield it was at par with semi-determinate genotype. Interaction effect was found significant for number of pods per plant, seed yield and biomass production. Indeterminate genotype Kalitur under normal irrigation generated significantly highest no. of pods/plant and biomass production and was followed by semi-determinate genotype (JS-335) grown under restricted

Table 2: Yield and yield attributes in determinate, semi-determinate and indeterminate soybean genotypes

Yield Parameters	Determinate (JS-93-05)			Semi-determinate (JS-335)			Indeterminate (Kalitur)		
	NI	RI	Reduction (%)	NI	RI	Reduction (%)	NI	RI	Reduction (%)
No. of pods plant^{-1}	47.5	35.5	25.3	56.4	37.6	33.3	72.2	66.8	7.5
Biomass (g plant^{-1})	41.3	32.4	21.6	48.8	39.4	19.1	55.1	51.0	7.4
Seed yield (g plant^{-1})	11.3	7.2	36.0	14.5	11.1	23.9	13.4	12.2	8.6
Seed yield (q ha^{-1})	24.1	15.1	37.1	29.0	23.9	17.8	28.5	26.4	7.4

Yield Parameters	No. of pods plant^{-1}			Seed yield (kg ha^{-1})			Biomass (g plant^{-1})		
	NI	RI	Mean	NI	RI	Mean	NI	RI	Mean
Determinate (JS-93-05)	47.5	35.5	41.5	240.5	151.3	195.9	41.3	32.4	36.8
Semi-determinate (JS-335)	56.4	37.6	47.0	290.4	238.7	264.6	48.8	39.4	44.1
Indeterminate (Kalitur)	72.2	66.8	69.5	285.4	264.2	274.8	55.1	51.0	53.1
Mean	58.7	46.6	52.7	272.1	218.1	245.1	48.4	40.9	44.7
CD (P=0.05)									
Irrigation (I)	8.7	3.2	5.7						
Genotype (G)	3.6	2.2	2.8						
I x G	5.0	3.2	4.0						

Where, NI = Normal irrigation; RI = Restricted irrigation

irrigation condition. Significant interaction effect was also observed in terms of seed yield and was recorded maximum in semi-determinate (JS-335) genotype grown under normal irrigation condition which was significantly superior to determinate genotype (JS-93-05) while remain statistically at par with indeterminate genotype (Kalitur) grown under normal and restricted irrigation conditions. The present study was undertaken to understand the effect of surface dimming and PAR reduction on few soybean genotypes and its mitigation options under projected climate change scenario whereas more genotypes need to be tested to abridge the research gap on this aspect.

CONCLUSIONS

Hemispherical-dome shaped shade-net structure was evaluated as an ideal option for conducting field experiments on assessing the impact of surface dimming (due to ABCs) which causes reduction in PAR availability to crops. The indeterminate soybean cultivar showed lesser impact on photosynthesis under dimmed PAR scenario and was also better suited under moisture stress conditions as compared to determinate and semi-determinate soybean cultivars. Therefore, a shift towards cultivation of indeterminate soybean genotypes is reasonably accepted in view of future projected climatic scenario as compared to popular determinate and semi-determinate cultivars in future. This study will pave the way in preparing ourselves for taking soybean crop in future. However, more research efforts are required to test large number of genotypes among different types, i.e., determinate, semi-determinate and indeterminate to validate this conclusion and assess it as a mitigation option.

ACKNOWLEDGEMENT

The authors sincerely acknowledge ICAR-National Institute of Abiotic Stress Management, Baramati for the financial support, and Agharkar Research Institute, Regional Station, Wadgaon-Nimbalkar, Pune, India for providing breeders seed material.

REFERENCES

Anonymous. (2012). Indeterminate Soybeans Replacing Determinate Varieties in Brazil, *In:* Soybean and Corn Advisor, Brazil. http://cornandsoybean.com/news/Feb24_2012.

Auffhammer, M., Ramanathan, V. and Vincent, J.R. (2006). Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India. *PNAS*, 103 (52): 19668–19672.

Bal, S.K., Mukherjee, J., Mallick K. and Hundal S.S. (2004)

Wheat yield forecasting models for Ludhiana district of Punjab. *J Agrometeorol.*, (6): 161-165.

Caemmerer, S.V. and Farwuhar, G.D. (1981). Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. *Planta*, 153: 376-387.

Chameides, W.L., Yu, H., Liu, S.C., Bergin, M., Zhou, X., Mearns, L., Wang, G., Kiang, C.S., Saylor, R.D., Luo, C., Huang, Y., Steine, A. and Georgi, F. (1999). Case study of the effects of atmospheric and regional haze on agriculture: An opportunity to enhance crop yields in China through emission controls? *Proc Natl Acad Sci USA* 96:13626–13633.

Dey, A.K. and Deka, C. (2012). Effectiveness of Dome Structures in Reduction of Stresses under Transverse Loadings. *Proc. Int. Conf. Advances in Civil Eng.*, pp. 136-140.

Kumar, K.K., Kumar, K.R., Ashrit, R.G., Deshpande, N.R. and Hansen, J.W. (2004). Climate Impacts on Indian Agriculture. *Int J Climatol.,* 24:1375–1393.

Meywerk, J., and V. Ramanathan (2002). Influence of Anthropogenic Aerosols on the Total and Spectral Irradiance on the Sea Surface During INDOEX, *J. Geophys. Res. Atmospheres*, 107, D19, 8018, 17-1 to 17-14. Doi: 10.1029/2000JD000022.

Panse, V.G. and Sukhatme, P. V. (1967). Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi.

Ramanathan, V., Ramana, M.V., Roberts, G., Kim, D., Corrigan, C., Chung, C. and Winker, D. (2007). Warming trends in Asia amplified by brown cloud solar absorption, *Nature*, 7153 (448): 575-578.

Seinfeld, J. (2008). Atmospheric science: Black carbon and brown clouds. *Nature Geosci.*, 1 (1): 15-16.

Stanhill, G. and Cohen, S. (2001). Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences, *Agric. For. Meteorol.*, 107:255-278.

UNEP. (2002). The Asian Brown Cloud: Climate and Other Environmental Impacts. *In*: United Nations Environment Programme, Nairobi, Kenya, pp. 38-41.

UNEP. (2008). Atmospheric brown clouds: Regional assessment report with focus on Asia, *In*: United Nations Environment Programme, Nairobi, Kenya, pp. 30-31.

Received : July 2016 ; Accepted : December 2016