Significance of plant canopy in crop yield: A review

Or

SIGNIFICANCE OF PLANT CANOPY MAINATAINACE IN CROP YIELD

ABSTRACT

The yield of any crop depends on the capacity of a plant canopy to intercept and efficiently use the sunlight, which is dependent on canopy architecture of a plant *viz.*, leaf size, shape and angle, number of leaves and branches, and a crop geometry *viz.,* row orientation, row spacing, plant geometry, plant density, *etc*. The amount and the extent of the leaf area distribution and the leaf area index ~~of leaf area~~ in a crop canopy determine the way, by which, the photosynthetic active radiation is intercepted and consequently it influences the canopy photosynthesis and yield. The balance between the source and sink significantly contributes towards the higher accumulation of photosybthates Cropping g~~G~~eometry of a plant/crop affects the radiation use efficiency, intercepted photosynthetic active radiation (IPAR) and thereby the biological and economical yield of a crop. Optimum plant population stand and its density and a planting pattern with adequate spatial arrangement are important cultural factors that increase radiation interception and yield production.

KEYWORDS: Plant canopy, row spacing, row orientation, plant density, plant architecture, radiation use, light interception, source to sink ratio

1. Introduction

Canopy, which is the structure of aerial vegetative part with special reference to size, orientation, density and arrangement of leaves, influences the penetration and interception of radiant energy. Light absorption being one of the driving forces behind plant photosynthesis is an important factor for determining crop yield, and at the same time, it is highly dependent on single plant architecture and overall canopy structure (Niinemets, 2007), which can be administered by managing agronomical practices such as row orientation, planting geometry, row spacing, plant density, leaf area and leaf area index (LAI), pruning, training,total number of yielding branches and nodes *etc*. Therefore, the solar radiation interception can be increased by enhancing ground cover depending upon leaf area index, which is defined as the total leaf area per unit ground area, resulting in higher dry matter production. The optimum LAI is prerequisite for higher dry matter production since LAI above optimum causes mutual shedding of leaves, resulting in negative net assimilation. Optimum LAI varies with crop and its leaf orientation, as the crops with horizontal leaf orientation have the LAI value 3 to 4 and the crops with upright leaf orientation have the LAI value 6 to 9. Increasing solar radiation above compensation point- light intensity at which the photosynthesis and respiration rates are equal, increases the rate of photosynthesis. The light intercepting factors influencing the growth and development of crop and weeds in the field are discussed as under:

2. Row orientation

The crop row orientation affects the photosynthetic efficiency and canopy temperature since it impinges on solar radiation interception by the crop canopy. A uniform distribution and proper orientation of plants over a cropped area are needed for greater light interception throughout the crop profile and maximum photosynthetic efficiency by all plant leaves. Diepenbrock *et al.* (2001) concluded that sunflower planted in east-west direction yielded 12% higher seed yield ~~oil~~ than the crop planted in north-south direction rows due to greater number of branches m^{-2}, aboveground biomass and harvest index. Mahto (2001) experimented with 45 genotypes of *Brassica juncea* at Ranchi and observed that the genotypic coefficient of variation of plants sown with east-west row orientation was greater as compared to the plants sown with north-south orientation for number of seeds per siliqua, number of siliquae per plant, number of secondary branches per plant, test weight and seed yield per plant. While working with two phenotypically different mustard varieties (erect and spreading type), Jha *et al.* (2012) obtained significantly higher yield from the crop sown east-west direction (1325 kg ha^{-1}) as compared to broadcast (1291 kg ha^{-1}) and north-south (1267 kg ha^{-1}) sown crops, thus, the farmers should opt east-west direction sowing when they are going to select erect plant type and short duration mustard varieties in respect of more oil seed productivity, RUE and yield, otherwise, they may safely go for longer duration spreading type varieties, which are less affected by sowing direction in respect of oil productivity. Pandey *et al*. (2013) observed that the grain yield of wheat was significantly higher (11%) when the crop was sown in north-south direction as compared to the crop sown in east-west direction since the crop sown in north-south direction intercepted more solar radiation and had significantly lower canopy temperature especially at reproductive stage, resulting in higher net assimilation rate and thus contributed to higher grain yield. Among the row orientation, the east-west sown rapeseed mustard recorded significantly higher yield and yield attributes (Roy, 2003), harvest index (Jha *et al*., 2015) and radiation interception efficiency than north-south sown crop (Singh *et al*., 2018a). However Lunagaria and Shekh (2005) did not found any significant influence of different row orientation on leaf orientation and direct beam radiation interception in wheat.

3. Row spacing

Row spacing requirement of a crop depends on architecture and growth pattern of the varieties. If a crop is sown at too wider row spacing, the solar radiation that falls between crop rows remains underutilized. On the other hand, the crop sown at too narrow spacing suffers from mutual shading. Moreover, the yield of crop spaced too narrow is reduced due to increased competition among the plants for nutrients, moisture, space and light. Gunri *et al.* (2004) found in rice that closer plant spacing (15×15 cm) resulted in significantly higher panicle length, number of panicle m^{-2}, number of fertile grains $panicle^{-1}$ and grain yield over wider spacing (20×15 cm). Shinde *et al*. (2005) reported that wider row spacing of 30 cm resulted in significantly higher grain (9.53 t ha^{-1}) and straw (12.79 t ha^{-1}) yield of 'Sahayadri' hybrid rice because of significantly higher number of panicles m^{-2} (292), panicle length (25.78 cm) and test weight (26.94 g) over the plant attributes at closer row spacing of 25 cm. Pol *et al*. (2005) also reported significantly higher number of panicles $hill^{-1}$ (12.25) and panicle weight $hill^{-1}$ (34.13 g) and grain yield of 'Sahayadri' hybrid rice at Dapoli with wider plant spacing (20×20 cm) as compared to narrow (15×10, 20×15 and 20×10 cm) plant spacing. Rautaray (2007) observed that skipping one row after every three rows at 15×15 cm spacing and providing optimum fertilizer dose resulted in highest grain yield in rice-rice cropping system at Assam during wet (4.51 t ha^{-1}) and dry (5.27 t ha^{-1}) season. Jalil (2008) affirmed that the rice cv. BRRI Dhan 29 gave highest grain yield (5.87 t ha^{-1}) at 25 cm row spacing as against the grain yield (4.3 t ha^{-1}) at 20 cm row spacing under aerobic conditions. Avasthe (2009) observed highest water use efficiency (2.879 kg ha^{-1}mm), grain yield (6.73 t ha^{-1}), nitrogen (84.3 kg ha^{-1}) and potassium (84.3 kg ha^{-1}) uptake, net return (Rs. 72,750) and benefit to cost ratio (2.09) at a spacing of 20×20 cm in rice at Tandong, Sikkim. Kandil *et al*. (2010) that planting of rice at 20×15 cm spacing resulted in highest panicle length, test weight, grain yield, harvest index as well as milling, head rice percentage and protein content. Jena *et al.* (2010) recorded significantly maximum plant height (70.9), effective tillers $hill^{-1}$ (8.13), LAI (5.13), leaf area duration (252.9 days), dry matter production $hill^{-1}$ (34.41 g), root volume $hill^{-1}$ (26.1 cc), root weight $hill^{-1}$ (3.83 g), crop growth rate (26.07 g m^{-2}), relative growth rate (64.79 mg g^{-1} day^{-1}), net assimilation rate (7.37 g m^{-2} leaf area day^{-1}), panicle length (26.1 cm), fertile spikelet $panicle^{-1}$ (106.7), test weight (23.07 g) and grain yield (5.87 t ha^{-1}) at plant spacing of 15×15 cm at CRRI, Cuttack Orissa. According to Uddin *et al*. (2010), the rice plant height, total tillers $hill^{-1}$ and effective tillers $hill^{-1}$ were significantly higher at plant spacing of 15×15 cm than at other spacing. The panicle length (22.0 cm), number of grains $panicle^{-1}$ (195.8) and grain yield of aerobic rice (57.3 q ha^{-1}) were significantly higher at 45 cm plant spacing at UAS, Bangalore (Basavaraja *et al*., 2010). The plant height (90.9 cm), number of tillers $hill^{-1}$ (26.5), panicle length (19.6 cm), number of seeds $panicle^{-1}$ (200.4) and seed index (2.2 g) were significantly higher at a spacing of 30×40 cm as compared to the crop planted at other spacing, however, the grain yield (47.2 q ha^{-1}) was significantly higher at 30×15 cm spacing under aerobic rice conditions at ZARS, V.C. Farm, Mandya, Karnataka (Murthy, 2011). Among the three plant spacing (5×15, 20×20 and 25×25 cm), Bozorgi *et al*. (2011) obtained the maximum rice grain yield (3415 kg ha^{-1}) at 15×15 cm plant spacing. Banerjee and Pal (2011) concluded that plant spacing had an outstanding influence on more or less all the yield-attributing traits and crop yield and recorded increased panicle length, filled grains $panicle^{-1}$ and test weight significantly with wider spacing at West Bengal. In Bangladesh, Sultana *et al*. (2012) obtained higher grain yield of Boro rice cv. BRRI Dhan 45 planted at a spacing of 25×15 cm under aerobic system of cultivation (5.69 t ha^{-1}) as compared to the grain yield (2.11 t ha^{-1}) obtained at 20×25 cm spacing due to improved number of effective tillers $hill^{-1}$(13.11). According to Rasool (2012), plant spacing caused variation in yield parameters of rice, the number of effective tillers m^{-2} being maximum under 15x15 cm spacing and lowest under 20x20 cm spacing, which might be due to the more number of plants at closer spacing than the plants at wider spacing, thus, 15x15 cm spaced crop gave significantly more grain and straw yield than at 15x20 and 20x20 cm spacing.

In wheat, Chhokar *et al.* (2012) noticed that closer row spacing of 15 cm with 50% higher seed rate and cross sowing showed distinct advantage in reducing the weed population, dry weight and herbicide requirement and they also found the cross sowing at spacing of 22.5x22.5 cm to have favourable effect on crop yield by providing better plant orientation. Dahiya et al. (2019) observed in two rowed malt barley cv BH885 that row spacing of 18 cm gave significantly higher grain and malt yield as compared to 22 cm but was at par with 20 cm spacing. Mondal *et al.* (2013) showed that wider spacing (20×20 cm) had stupendous performance in all morpho-physiological and yield attributing characters, resulting in highest grain yield (8.53 t ha^{-1}). Kaur *et al.* (2014) found that the bidirectional (22.5x22.5 cm) and closer spacing (15 cm) sown wheat produced higher grain (12.66 and 10.9%) and straw (12.61 and 10.89%) yield than the wheat sown at 20 cm row spacing. They also observed that wheat sown by following the same pattern smothered the weeds and reduced the weed population by 41.0 and 36.9% in comparison of 20 cm spacing. Biswas *et al.* (2014) obtained significantly highest grain yield from maize sown at a spacing of 60x20 cm as compared to a crop sown at plant geometry of 75x20 and 60x20 cm. In cotton, Singh *et al.* (2018b) found that plant spacing of 67.5x45 cm intercepted more radiation followed by 67.5x60 and 67.5x75 cm, while the radiation use efficiency was also recorded maximum under wider plant spacing 67.5x75 cm followed by 67.5x60 and 67.5x45 cm. Diepenbrock *et al.* (2001) obtained maximum yield of sunflower when sown in east-west direction keeping four to eight plants m^{-2} at 75 to 100 cm row spacing. Dhillon *et al.* (2017) observed that widely sown spring sunflower required slightly more AGDD (accumulated growing degree days) than closely sown for attaining physiological maturity while, closely sown crop have marginally higher heat use efficiency for stalk but differences were very meager in case of seed.

Inter-row spacing in orchard of olive is more determinants of incident irradiance on canopy and consequently on fruit characteristics than intra-row spacing (Trentacoste *et al*., 2015a). In olive, fruit mass and oil content increase with increasing irradiance (Connor *et al*., 2009; Caruso *et al*., 2017). The reduction of row spacing reduced position effects and resulted in more uniform radiation distribution across rows of maize as the sun light interception anagle ~~elevation~~ changed (Timlin *et al*., 2014). Singh *et al*. (2005) observed that the guava tree planted at 6x6 m spacing captured significantly more solar radiation than those spaced at 6x5 m and 6x4 m on per unit basis.

4. Planting densities

Appropriate plant population for each crop varies greatly from region to region. Since many crops exhibit great plasticity in their response to varying plant densities due to tillering or branching habit, there is no optimum plant population for any crop, except optimum range of plant population within which there will not be any significant variation in yield. Tillering or branching can compensate the low plant population for yield within a reasonable initial stand establishment. Generally, bigger the plant size lesser will be the plant population for optimum yield. Crop such as maize requires relatively low plant density compared with sorghum, pearl millet, rice and wheat. Zeng (2003) recorded higher number of panicles hill^{-1} and grain yield in rice with denser planting of 330000 holes as against 250000 holes hectare^{-1} in China. Zhang *et al*. (2004) found that transplanting density of hybrid rice at China did not influenced plant height significantly. Zarea *et al.* (2005) reported that different planting patterns sometimes produced higher yield, but not always. Furthermore, equidistant plant distribution at equal plant densities produced higher radiation interception and extinction coefficient. Moreover, when row spacing was reduced, grain yield increased. The greatest increase in radiation interception and in the extinction coefficient due to the response of planting patterns and plant densities was observed in twin zigzag rows of eight plants per square meter. Twin zigzag rows of eight plants per square meter and conventional rows of eight plants per square meter produced the highest yield of sunflower.

In maize, narrow row spacing has been proposed as a strategy to increase plant spacing within the row, thereby promoting less inter-plants competition and greater yield, though the inconsistent responses to narrow row spacing as well as the large capital investment in narrow row planting and harvesting equipment have led some maize producers to adopt a twin row planting arrangement, however, elevated plant density might not be a successful strategy for increasing grain yield if the hybrids grown are not tolerant to greater competition (Thelen, 2006). The increased plant density beyond optimum leads to high dilution effect, resulting in lower yield, however, on the other hand, lower yield at less than optimal density is probably due to the inability to intercept maximum available radiation due to poor stand establishment (Mahajan *et al*., 2010). At Texas, the grain sorghum planted at 76 cm row spacing with 170000 to 200000 plants per hectare produced the highest ~~greatest weight of~~ thousand grains weight as compared to the crop planted at 38 cm row spacing (Fernandez *et al*., 2012). In chickpea, maintaining 33 plants m^{-2} was optimum plant population for the future climate scenario at all the study sites in Andhra Pradesh (Kadiyala *et al*., 2016). Row-orientation in olive orchard is more determinants of incident irradiance on canopy and consequently on fruit characteristics than intra-row spacing (Trentacoste *et al*., 2015b). Singh *et al*. (2014) at Anantpur found that changing plant population had insignificant effect on the yield of groundnut with delayed sowing under climate change, indicating that plant population of 25 plants m^{-2} is good for the future climate at this site.

5. Plant architecture

Light absorption- an important factor for determining the crop yield, is highly dependent on single plant architecture. Plant architectural characteristics such as the number and geometry of organs, *i.e*., their shape and position within the plant and the canopy, are genotype specific, while at the same time, it is highly dependent on climatic conditions at the time of their initiation and development (Godin, 2000).

Both leaf shape and size are important aspects of leaf morphology affecting mutual shading of leaves and light absorption of the canopy (Falster and Westoby, 2003).

In tomato, Sarlikioti *et al*. (2011) achieved the optimal results when leaf elevation-angle distribution ranged between 15° (top) and 23° (bottom), indicating that the plant orientates its leaves during the cultivation period in such a way so as to maximize light absorption, however, deviations from that range failed to increase distinctly both light absorption and photosynthesis. They concluded that a new plant ideotype with more spacious canopy architecture due to long internodes and long and narrow leaves led to an increase in crop photosynthesis up to 10%. A high leaf length and width ratio has been reported to have a positive effect on light capture and crop photosynthesis in many species (Falster and Westoby, 2003). Zotz *et al.* (2002) observed that an alteration of leaf phyllotaxis to a golden angle of 137.5° significantly enhanced the light capture efficiency of an epiphytic plant.

Alterations in the leaf size and arrangement can affect light availability, particularly in the lower plant canopy and improves leaf photosynthetic activity by adjusting light-harvesting efficiency (Werner *et a*l., 2001). However, the significance of leaf elevation angle for better light-absorption condition at whole plant level has been observed in various studies (Sinoquet *et al*., 2005) results about the significance of leaf phyllotaxis are contradictory as some studies did and some did not found its influence on the light absorption capacity of the canopy (Brites and Valladares, 2005).

6. Pruning and training

Gill *et al*. (2011) observed that among the pruning treatments, the pear tree kept at 1.0 m height received highest solar radiation in all parts of canopy and recorded maximum soil temperature round the year as compared to the trees having height more than 1 m or not headed back. They also recorded maximum yield efficiency in 2.5 m pruned trees of Patharnakh pear. Harwadikar *et al.* (2013) found the wine grapes with 30 canes per vine significantly superior over all the treatment in respect of leaf area (101.04 dm^2), leaf area index (2.18), number of bunches per vine (21.85), weight of bunch (138.52 g), yield per vine (2.59 kg $vine^{-1}$ and 11.99 t ha^{-1}) and TSS (0.93%). They also found that the increased number of canes per vine decreased the canopy temperature and increased the relative humidity. In peach, Singh *et al*. (2004) observed that the Y shaped (YS) trees intercepted significantly higher (75.1%) mean total radiation as compared to modified leader system (MLS) trees (67.2%) and fruits harvested from YS trees were superior in quality than those from MLS trees. They also found that the fruits of YS trees matured earlier than that of MLS trees.

7. conclusion

Plant canopy with special reference to size, orientation, density and arrangement of leaves total leaf area and its index, accumulated photosyntheticaly active radiation ,the penetration and interception of radiant energy,and net assimilation in the form of photosynthates and the establishment of balanced and optimum source to sink ratio in the crop influences ~~the penetration and interception of radiant energy,~~ which ultimately increase in the ~~photosynthesis, resulting in~~ higher yield of the crop.

REFERENCES

Avasthe, R.K. 2009. Nitrogen management in transplanted rice (*Oryza sativa*) in mid hill acidic soils of Sikkim Himalayas. *Indian Journal of Agronomy* **54**: 47-51.

Banerjee, H. and Pal, S. 2011. Effect of planting geometry and different levels of nitrogen on hybrid rice. *Oryza*, **48**(3): 274-275.

Basavaraja, M.K., Siddaram, K., Ramesha, Y.M., Yogeeshappa, H. and Prakash, H. 2010. Effect of spacing and genotypes on yield and genotypes on growth and yield of aerobic rice. *International Journal of agricultural Sciences* **6**(2): 485-487.

Biswas, M., Rahman, A. and Ahmed, F. 2014. Effect of variety and planting geometry on the growth and yield of hybrid maize. *Journal of Agriculture and Environmental Sciences* **3**(2) 27-32.

Bozorgi, H.R., Faraji, A., Danesh, R.K., Keshavarz, A., Azarpour, E. and Tarighi, F. 2011. Effect of planting density on yield and yield components of rice. *World Applied Sciences Journal* **12**(11): 2053-2057.

Brites, D. and Valladares, F. 2005. Implications of opposite phyllotaxis for light interception efficiency of Mediterranean woody plants. Trees **19**: 671–679.

Caruso, G., Gucci, R., Sifola, M.I., Selvaggini, R., Urbani, S. and Esposto, S. 2017. Irrigation and fruit canopy position modify oil quality of olive trees (cv. Frantoio). *Journal of the Science of Food and Agriculture* **97**: 3530-3539.

Chhokar, R.S., Sharma, R.K. and Sharma, I. 2012. Weed management strategies in wheat- A review. *Journal of Wheat Research* **4**(2): 1-21.

Connor, D.J., Centeno, A. and Gómez-del-Campo, M. 2009. Yield determination in olive hedgerow orchards II. Analysis of radiation and fruiting profiles. *Crop and Pasture Science* **60**: 443-452.

Dahiya, S., Singh, J., Singh, B. and Khedwal, R.S. 2019).Yield and quality of malt barley (Hordium distichum L.) as influenced by seed rate, row spacing and nitrogen levels. *Applied Biological Research* **21**(1): 35-40.

Dhillon, B.S., Sharma, P.K. and Kingra, P.K. 2017. Agronomic measures to improve thermal energy utilization by spring sunflower (*Helianthus annuus* L.). *Journal of Agrometeorology* **19**(1): 34-38.

Diepenbrock, W., Lang, M. and Feil, B. 2001. Yield and quality of sunflower as affected by row orientation, row spacing and plant density. *Die Bodenkultur* **52**(I): 29-36.

Falster, D.S. and Westoby M. 2003. Leaf size and angle vary widely across species: what consequences for light absorption? *New Phytologist* **158**: 509-525.

Fernandez, C.J., Fromme, D.D. and Grichar, W.J. 2012. Grain sorghum response to row spacing and plant populations in the texas coastal bend region. *International Journal of Agronomy* **10**: 1-6.

Gill, P.P.S., Dhillon, W.S., Singh, N.P and Singh, S. 2011. The influence of canopy architecture on light penetration, soil temperature and fruiting in sub-tropical pear. *Journal of Agrometeorology* **13**(2): 157-159.

Godin, C. 2000. Representing and encoding plant architecture: A review. *Annals of Forest Science* **57**: 413-438.

Gunri, S.K., Pal, S.K. and Chaudhury, A. 2004. Effect of integrated nitrogen application on yield of rice in foothill soil of West Bengal. *Indian Journal of Agronomy* **49**(4): 248-250.

Harwadikar, N.S., Jaybhaye, P.R. and Tambe, T.B. 2013. Influence of cane density on microclimate of canopy, growth, yield and quality of wine grapes. *Journal of Agrometeorology* **15**(1): 79-81.

Jalil, M.A. 2008. Effect of spacing and seed rate of fertilizer application on yield performance of Boro rice cv. BRRI Dhan 29 under aerobic system of cultivation. M.Sc. Thesis, Department of Agronomy, Bangladesh Agricultural University, Mymemsingh, pp. 48-49.

Jena, S., Annie, P. and Nayak, B.C. 2010. Response of hybrid rice to time of planting and planting density. *Oryza*, **47**(1): 48-52.

Jha, S., Sehgal, V.K. and Subbarao, Y.V. 2012. Effect of direction of sowing and crop phenotype on radiation interception, use efficiency, growth and productivity of mustard (*Brassica juncea* L.). *Journal of agricultural Physics* **12**(1): 37-43.

Jha, S., Sehgal, V.K. and Subbarao, Y.V. 2015. Effect of sowing direction and crop geometry on water use efficiency and productivity of Indian mustard (*Brassica juncea*. L.) in semi-arid region of India. *Journal of Oilseed Brassica* **6**: 257-264.

Kadiyala, M.D.M., Charyulu, D.K., Nedumaran, S., Shyam, D.M., Gumma, M.K. and Bantilan, M.C.S. 2016. Agronomic management options for sustaining chickpea yield under climate change scenario. *Journal of Agrometeorology* **18**(1): 41-47.

Kandil, A.A., El-Kalla, S.E., Badawi, A.T. and Omnia, M. 2010. Effect of hill spacing, nitrogen levels and harvest date on rice productivity and grain quality. *Crop & Environment* **1**(1): 22-26.

Kaur, J., Singh, G. and Singh, A. 2014. Competitiveness of wheat (*Triticum aestivum* L.) cultivars under spacing and weed levels. *Indian Journal of Ecology* **41**(2): 357-359.

Lunagaria, M.M. and Shekh, A.M. 2005. Leaf orientation and direct beam radiation interception in wheat (*Triticum aestivum* L.) crop as influenced by row direction. *Journal of Agrometeorology* **7**(2): 225-230.

Mahajan, G., Gill, M.S. and Singh, K. 2010. Optimizing seed rate to suppress weeds and to increase yield in aerobic direct-seeded rice in northwestern Indo-Gangatic plains. *Journal of New Seeds* **11**: 225-238.

Mahto, J.L. 2001. Variability studies of different traits in *Brassica juncea* L. in north-south and east-west sowing direction in acidic soil of high altitude. *Cruciferae Newsletter* **23**: 69-70.

Mondal, M., Monjurul, A., Adam, B., Ismail, M. and Yusop, M.R. 2013. Optimizing plant spacing for modern rice varieties. *International Journal of Agriculture and Boilogy* **15**(1): 175-178.

Murthy, P., Prasad, S.R., Siddaraju, R. and Lakshmi, J. 2011. Influence of varieties and spacing on growth, seed yield and quality of rice under aerobic condition. The *Mysore Journal of agricultural Sciences* **45**(3): 521-527.

Niinemets, U. 2007. Photosynthesis and resource distribution through plant canopies. *Plant Cell and Environment* **30**: 1052-1071.

Pandey, B.S., Basnet, K.B., Bhatta, M.R., Sah, S.K., Thapa, R.B. and Kandel, T.P. 2013. Effect of row spacing and direction of sowing on yield and yield attributing characters of wheat cultivated in Western Chitwan, Nepal. *Agricultural Sciences* **4**(7): 309-316.

Pol, P.P., Dixit, A.J. and Thorat, S.T. 2005. Effect of integrated nutrient management and plant densities on yield attributes and yield of Sahayadri hybrid rice. *Journal of Maharashtra Agricultural University* **30**(3): 357- 359.

Rasool, F., Habib, R. and Bhat, M.I. 2012. Evaluation of plant spacing and seedlings per hill on rice (*Oryza sativa* L.) productivity under temperate conditions. *Pakistan Journal of agricultural Sciences* **49**(2): 169-172.

Rautaray, S.K. 2007. Effect of spacing and fertilizer dose on grain yield of rice (*Oryza sativa* L.) in rice-rice cropping sequence. *Oryza*, **44**(3): 285-287.

Roy, S. 2003. Effect of weather on plant growth, development and aphid infestation in *Brassica*. Ph.D. Thesis. IARI, New Delhi.

Sarlikioti, V., Visser, P.H.B., Buck-Sorlin G.H., and Marcelis, L.F.M. 2011. How plant architecture affects light absorption and photosynthesis in tomato: towards an ideotype for plant architecture using a functional–structural plant model. *Annals of Botany* **108**: 1065-1073.

Shinde, D.R., Dixit, A.J. and Thorat, S.T. 2005. Response of Sahyadri hybrid rice to different spacing, seed rates and fertilizer levels under drilled condition in Konkan Region of Maharashtra. *Journal of Maharashtra Agricultural University* **30**(3): 357-359.

Singh, A., Dhaliwal, G.S. and Hundal, S.S. 2005. Effect of planting distance on radiation interception behavior of guava (*Psidium guajava* L.). *Journal of Agrometeorology* **7**(2): 220-224.

Singh, A., Khichar, M.L., Singh, K. and Niwas, R. 2018b. Study on effect of fertility levels and plant spacing on light interception in Bt cotton. *Journal of Agrometeorology* **20**(special issue): 276-281.

Singh, H., Kanwar, J.S. and Hundal, S.S. 2004. Radiation regime and fruit quality of peach trees under different training system. *Journal of Agrometeorology* **6**(special issue): 5-9.

Singh, J., Singh, S.P. and Kingra, P.K. 2018a. Influence of sowing time and planting geometry on yield and radiation use efficiency of various rapeseed-mustard cultivars. *Journal of Agrometeorology* **20**(3): 246-248.

Singh, P., Singh, N.P., Boote, K.J., Nedumaran, S., Srinivas, K. and Bantilan, M.C. 2014. Management options to increase groundnut productivity under climate change at selected sites in India. *Journal of Agrometeorology* **16**(1): 52-59.

Sinoquet, H., Sonohat, G., Phattaralerphong, J., Godin, C., 2005. Foliage randomness and light absorption in 3-D digitized trees: an analysis from multiscale discretization of the canopy. Plant Cell & Environment **28**: 1158–1170.

Sultana, M.R., Rahman, M.M. and Rahman, M.H. 2012. Effect of row and hill spacing on the yield performance of boro rice (cv. BRRI dhan45) under aerobic system of cultivation. *Journal of Bangladesh agricultural University* **10**(1): 39-42.

Thelen, K.D. 2006. Interaction between row spacing and yield: Why it works. www.plantmanagement network.org/ cm/*Crop Manage*.

Timlin, D.J., Fleisher, D.H., Kemanian, A.R. and Reddy, V.R. 2014. Plant density and leaf area index effects on the distribution of light transmittance to the soil surface in maize. *Agronomy Journal* **106**(5): 1828-1837.

Trentacoste, E.R., Connor, D.J. and Gómez-del-Campo, M. 2015a. Effect of row spacing on vegetative structure, fruit characteristics and oil productivity of N–S and E–W oriented olive hedgerows. *Scientia Horticulturae* **193**: 240-248.

Trentacoste, E.R., Connor, D.J., and Gómez-del-Campo, M. 2015b. Effect of olive hedgerow orientation on vegetative growth, fruit characteristics and productivity. *Scientia Horticulturae* **192**: 60–69.

Uddin, M.J., Ahmad, S. and Hasan, M.M. 2010. Effect of spacing on morphology and yield response of different aman rice cultivars under coastal high land ecosystem. *Indian Journal of agricultural Sciences* **44**(4): 251-258.

Werner, C., Ryel, R.J., Correia, O., Beyschlag, W. 2001. Structural and functional variability within the canopy and its relevance for carbon gain and stress avoidance. *Acta Oecologica* **22**: 129–138.

Zarea, M.J., Ghalavand, A. and Daneshian, J. 2005. Effect of planting patterns of sunower on yield and extinction coefficient. *Agronomy for Sustainable Develepment* **25**(4): 513-518.

Zeng, Y.J., Shi, Q.H., Li, M.Y. and Tan, X.M. 2003. Effect of fertilization and transplanting density on mass quality and yield of rice. *Acta agric*ultural *University Jiangxiensis* **25**(3): 225-330.

Zhang, P.J., Zhan, X.C., Zhang, M., Jiang, F.J. and Li, A. 2004. Effect of transplanting densities and seedling number per hill on yield of medium *Japonica* hybrid rice 'III You 98'. *Hybrid Rice* **19**(1): 43-44.

Zotz, G., Reichling, P., Valladares, F. 2002. A simulation study on the importance of size and related changes in leaf morphology and physiology for carbon gain in an epiphytic bromeliad. *Annals of Botany* **90**: 437–443.