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Effects of Minimum and Maximum Limits of Solar Radiation and Its Temporal and Geographic Interactions

Bruna de Villa[1], Mirta Teresinha Petry[1], Maicon Sérgio Nascimento dos Santos[1], Juliano Dalcin Martins[1], Isabel Lago[2], Murilo Brum de Moura[1], Henrique Schaf Eggers[2], Giane Lavarda Melo[1], Felipe Tonetto[1], Cassio Miguel Ferrazza[3], Julia Antunes de Oliveira[3], Rafaela Werle[3] & Ricardo Pacheco Castro[3]

[1] Rural Engineering Department, Federal University of Santa Maria, Santa Maria, Brazil

[2] Crop Science Department, Federal University of Santa Maria, Santa Maria, Brazil

[3] Graduation in Agronomy, Federal University of Santa Maria, Santa Maria, Brazil

Correspondence: Maicon Sérgio Nascimento dos Santos, Rural Engineering Department, Federal University of Santa Maria, Santa Maria, RS, Brazil. Tel: 55-55-99154-6300. E-mail: maiconsergions@gmail.com

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Abstract

In order to achieve high yields, the use of radiation by agricultural crops must be improved in order to maximize and extend the duration of foliar interception of solar radiation. Appropriately, studies aimed at the understanding and behavior of radiation in plants are extremely relevant. Accordingly, the objective of this study was to approach information about the concepts, radiation availability temporal, geographical, photosynthesis efficiency as a function of leaf arrangement and radiation interception efficiency × leaf area index (LAI). Studies aimed at a significant comprehension of radiation in crops demonstrate that the plant growth and development depend on the intensity and duration of solar radiation. More surveys are required on the subject for a better development of the culture, aiming to guarantee that the plants have better conditions to express their potential.

Keywords: agricultural crops, agronomic performance, radiation intensity, radiation use efficiency, solar radiation management

1. Introduction

A considerable comprehension about the climatic elements allows and efficient planning by the farmers to be conducted with higher levels of precision (Filgueiras et al., 2018). In some locations, an agricultural production indicates large fluctuations and one of the most influential factors is the climate (Duarte & Wollmann, 2021). Accordingly, one of the closest relationships between climatic factors and atmospheric weather conditions is located in the balance between solar radiation and vegetation, where climate elements (temperature, humidity, and pressure) are the result of the balance of radiation received and reflected in the atmosphere (Hendges et al., 2020). Accordingly, direct sunlight to plants is a valuable regulator of plant growth and development (Badmus et al., 2022).

Considering the global solar radiation that falls on the earth surface, a specific part is reflected, and part is absorbed by crops, with the absorbed part denomined shortwave radiation balance (Krieger et al., 2019). Furthermore, the ratio between reflected radiation and global solar radiation is defined as albedo, or shortwave reflection coefficient, which is an important variable of the shortwave balance (Krieger et al., 2019).

Moreover, in the quest to achieve high yields, one must maximize and extend the duration of leaf interception of solar radiation, using the energy absorbed efficiently for photosynthesis in order to obtain optimal proportions of leaves, stems, roots, and reproductive structures (Loomis & Amthor, 1999). The efficiency of radiation use is directly influenced by plant species, soil and climate conditions, and availability of natural resources to plants (Mahakosee et al., 2022). The environment for the crop growth is fundamental, as the adaptation of plants to this environment depends on the adjustment of their photosynthetic apparatus (Almeida et al., 2004). Furthermore, solar radiation provides the energy required for the processes associated with photosynthesis (Monteiro, 2009).

Correspondingly, to comprehend the behavior of solar radiation and its effect on plants, the purpose of this study is to approach the main concepts about the availability of radiation × latitude and/or time of year, the efficiency of photosynthesis as a function of leaf arrangement, and the efficiency of interception of radiation × leaf area index (LAI) in plants.

2. General Contextualization

Consideration should be established to studies focused on global solar radiation, which is the primary source of energy responsible for part of the physical and biochemical processes in the soil-plant-atmosphere system (Bexaira et al., 2018). Accordingly, photosynthetically active radiation (PAR) encompasses electromagnetic wavelengths (380 to 710 nm) capable of being used by plants for the purpose of converting this physical energy into chemical energy (Petter et al., 2016). Moreover, the intercepted solar radiation, or the radiation that reaches the surface of the plant, is the result of genetic and agronomic factors (Lopes et al., 2022).

The efficiency of radiation used by a species is given by the intercepted photosynthetically active radiation that is converted into phytomass (Amthor, 2010). Conceptually, it is the ratio between the absorbed radiation and the amount of dry matter produced by the plant. It can be used for plant growth analysis, growth prediction, and production potential, among others (Caron et al., 2014).

Net photosynthesis is the net amount of CO_2 assimilated per unit of leaf area per unit of time (μmol of CO_2 per second per m²) (Inouer & Ribeiro, 1988).

The light/photic compensation point is the nomenclature given to the moment when the gas exchange between the plant and the environment is null once the O_2 released by photosynthesis is consumed in cellular respiration and the CO_2 released in cellular respiration is consumed in photosynthesis. It is obtained by the point where the curve cuts the abscissa axis, according to Decker's model (1957), and can be used as an estimate of photorespiration (Regina & Carboneau, 1995). Furthermore, the luminous saturation point is when the processing speed is maximum and from there it becomes constant since the sun leaves have higher light saturation points in relation to shade leaves (Kimmins,1987).

3. Radiation Availability × Latitude and or Period of the Year

The solar radiation available to plants is largely influenced by the characteristics of the vegetative canopy and is critical for crop productivity in agricultural ecosystems (Yang et al., 2022). The availability of solar radiation in the cultivation environment differs according to the position of the sun and the angle of incidence of the sun rays, thus determining the parameters between the radiation fluxes and the behavior of the canopy characteristics (Cardoso et al., 2010). Moreover, due to the annual oscillation of the solar declination, the main events that characterize the equinoxes (21/03 to 22/09) and the solstices (21/06 to 21/12) occur, which help to understand the annual variations of incident solar radiation and the length of days depending on the time of year and the latitude of each location (Bergamaschi & Bergonci, 2017). Latitude and period of the year are the main factors that influence the availability of solar energy (Figure 1), which results in the variation in the angle at which the sun rays reach the surface and, finally, in the amount of energy received by area (according to Lambert's cosine law).

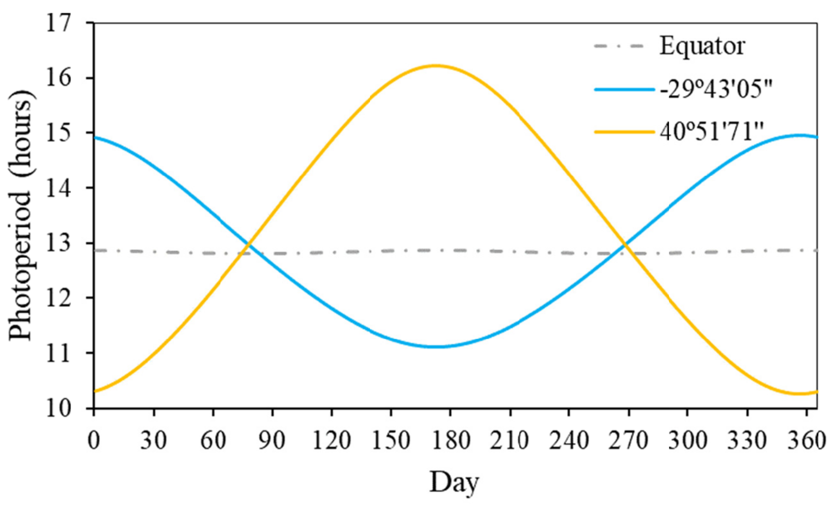

Figure 1. Annual variation of radiation reaching the top of the atmosphere towards the equator and at latitudes 20° and 40° North and South.

In Figure 1, a large variation throughout the year in the amount of energy received for latitudes further away from the Equator is observed. Accordingly, for the entire Equatorial zone, there is less variability. This is due to the higher variation in the angle of inclination of the Earth in relation to the solar orbit plane, at higher latitudes, with a maximum displacement of 23º27′ in relation to the plane.

Furthermore, the exposure of the equatorial region to the sun rays is practically the same throughout the year. Moreover, at latitudes farther from the equator, the variation in the inclination of exposure to sunlight throughout the year is more accentuated, with higher oscillation in the amount of energy received per area, and the higher the latitude, the higher the amplitude in the amount of energy received.

4. Efficiency of Photosynthesis as a Function of Leaf Arrangement

Contextually, photosynthetically active radiation (PAR) is one of the most important factors for the photosynthesis phenomenon (Akitisu et al., 2022). The direct use of radiation by plants is largely affected by climatic and environmental characteristics, such as season, latitude, cloud cover, and plant configuration (Mahakosee et al., 2022). As previously mentioned, the research for higher yields investigates to maximize leaf interception, using the energy absorbed efficiently for photosynthesis (Loomis & Amthor, 1999). The productive yield of agricultural crops is established based on the efficiency of fundamental factors, such as light interception and the use of radiation (Lopes et al., 2022). For irrigated rice genotypes, there is an increase in productivity with a reduction in spacing (40, 30, 20, and 12.5 cm) (Neto et al., 2000). The architecture of these plants directly interferes with grain production, due to the better use of light and nutrients (Marchezan et al., 2005). According to the same author, they are classified according to their architecture as traditional type, intermediate type, and modern-Philippine type, according to the same author.

Currently, in maize, plant arrangement is one of the cultural practices that most interferes with grain yield (Sangoi et al., 2011). Solar radiation directly influences the shoots and roots growth, drastically affecting grain yield. As typical for C4 plants, maize has a higher photosynthetic performance and a significant assimilation between the photosynthetic process and grain production, but in appropriate edaphoclimatic conditions during the maize growing cycle is valuable (Guo et al., 2022). Gomes et al. (2011) emphasize that the solar radiation intercepted by the basal leaves of maize is signinificant at higher spacing (0.9 m). Alterations in plant architecture, such as smaller stature, fewer leaves, and more erect leaves, allowed higher light infiltration into the canopy, even with a high leaf area index (Almeida et al., 2000). This new corn stereotype enabled changes in the arrangement of plants that led to higher efficiency in the use of solar radiation in environments to obtain high yields (Argenta et al., 2001).

In soybean, aiming to increase productivity, dense planting has been chosen, with spacing between rows of less than 45 cm, or the largest number of plants in the crop row in the spacing of 40 cm between rows (Petter et al., 2016). The same author concludes that the densities of 20 and 30 plants m^2 provide the best results in terms of efficiency in the use of photosynthetically active radiation and, consequently, higher productivity. Furthermore, it is possible to reduce the height of plants by using a growth regulator and making the plant architecture more erect, associated with a higher potential for soybean grain yield, in which more compact plants can be more efficient in photosynthesis (Souza et al., 2013).

Finally, in wheat, increasing plant density (46, 60, 75, and 90 plants m^2) reduces the number of tillers and the number of spikelets per ear (Senger, 2013). Studies indicated that there was an increase in productivity due to the morphological alterations caused by the application of trinexapac-ethyl, which, by decreasing the height of the plants, leaves them with a more suitable architecture to take advantage of the resources of the environment (Zagonel & Fernandes, 2007).

5. Radiation Interceptation Efficiency × Leaf Area Index (LAI)

LAI is the ratio between the foliage area and the soil surface occupied by it. Varies according to plant species, climate, seasons, and stage of plant development (Câmara & Heiffig, 2000). Furthermore, the density of plants contributes to the distribution of leaf area in the canopy and the way in which solar radiation is intercepted (Stewart et al., 2003). This phenomenon exertes direct influences on the development and architecture of plants, showing differences in spacing and/or arrangements worked (Ataíde et al., 2010). As the LAI increases, up to a critical value, there is a joint increase in a light interception and net photosynthesis (Heiffig et al., 2006). The "critical LAI" is defined as the amount of leaf required to intercept 95% of solar radiation at noon. When the growth rate is decreasing, below a given LAI and, no longer has a net contribution to the accumulation of photosynthesis, it is designated as "optimal LAI" (Müller, 1981). Finally, the variation over time of the leaf area usually increases up to a maximum limit, in which it remains for some time, then decreases due to the senescence of the old leaves (Manfron et al., 2003).

5. Conclusions

Studies aimed at a better comprehension of radiation in crops demonstrate that the plant growth and development depend on the intensity and duration of solar radiation. Scientific research on the performance of light in plants has actively contributed to the emergence of strategies and alternatives to exploit the maximum productive potential of agricultural systems. Studies have been developing a parameterization of the requirements of productive potential and quality of the final product related to the optimization of natural resources, such as solar radiation. Accordingly, the key purpose of this review was to report on the processes that involve the conversion of solar energy into potential phytoenergy to express plant productivity. Furthermore, this study provided valuable information regarding the effects of exposure to solar radiation on plant growth and development and established a brief understanding of the knowledge gaps on the theme. Appropriately, more surveys are required on the subject for a higher development of the culture, aiming to guarantee that the plants have better conditions to express their potential.

References

Akitsu, T. K., Nasahara, K. N., Ijima, O., Hirose, Y., Takagi, K., & Kume, A. (2022). The variability and seasonality in the ratio of photosynthetically active radiation to solar radiation: A simple empirical model of the ratio. *International Journal of Applied Earth Observation and Geoinformation, 108*. https://doi.org/10.1016/j.jag.2022.102724

Almeida, L. P., Alvarenga, A. A., Castro, E. M., Zanela, S. M., & Vieira, C. V. (2004). Crescimento inicial de plantas de *Cryptocaria aschersoniana* Mez. submetidas a níveis de radiação solar. *Ciência Rural, 34*, 83-88. https://doi.org/10.1590/S0103-84782004000100013

Amthor, J. S. (2010). From sunlight to phytomass: on the potential efficiency of converting solar radiation to phyto-energy. *New Phytologist, 188*, 939-959. https://doi.org/10.1111/j.1469-8137.2010.03505.x

Araújo Júnior, G. N., Gomes, F. T., Silva, M. J., Jardim, A. M. F. R., Simões, V. J. L. P., Izidro, J. L. P. S., … Guidolin, A. F. (2000). Incremento na densidade de plantas: uma alternativa para aumentar o rendimento de grãos de milho em regiões de curta estação estival de crescimento. *Ciência Rural, 30*, 23-29. https://doi.org/10.1590/S0103-84782000000100004

Argenta, G., Da Silva, P. R. F., & Sangoi, L. (2001). Arranjo de plantas em milho: análise do estado-da-arte. *Ciência Rural, 31*, 1075-1084. https://doi.org/10.1590/S0103-84782001000600027

Ataíde, M. G., Castro, R. V. O., Santana, R. C., Dias, B. A. S., Correia, A. C. G., & Mendes, A. F. N. (2010). Efeito da densidade na bandeja sobre o crescimento de mudas de eucalipto. *Revista Trópica, 4*. https://doi.org/10.0000/rtcab.v4i2.152

Badmus, U. O., Ač, A., Klem, K., Urban, O., & Jansen, M. A. (2022). A meta-analysis of the effects of UV radiation on the plant carotenoid pool. *Plant Physiology and Biochemistry, 183*, 36-45. https://doi.org/10.1016/j.plaphy.2022.05.001

Bergamaschi, H., & Bergonci, J. I. (2017). *As plantas e o clima. Princípios e aplicações*. Porto Alegre, RS: Agrolivros.

Bexaira, N. P., Streck, N. A., Cera, J. C., & Prestes, S. D. (2018). Coeficientes de Angströn-Prescott para estimar a radiação solar no Rio Grande do Sul. *Revista Brasileira de Meteorologia, 33*, 401-411. https://doi.org/10.1590/0102-7786333001

Câmara, G. M. S., & Heiffig, L. S. (2000). Fisiologia, ambiente e rendimento da cultura da soja. In G. M. S. Câmara (Eds.), *Soja: Tecnologia da produção*. Piracicaba: ESALQ/LPV.

Cardoso, L. S., Bergamaschi, H., Comiran, F., Chavarria, G., Marodin, G. A. B., Dalmago, G. A., ... Mandelli, F. (2010). Padrões de interceptação de radiação solar em vinhedos com e sem cobertura plástica. *Revista Brasileira de Fruticultura, 32*, 161-171. https://doi.org/10.1590/S0100-29452010005000029

Caron, B. O., Schmidt, D., Manfrom, P. A., Eloy, E., & Busanello, C. (2014). Eficiência do uso da radiação solar por plantas *Ilex paraguariensis* A. St. Hil. cultivadas sob sombreamento e a pleno sol. *Ciência Florestal, 24*, 257-265. https://doi.org/10.5902/1980509814563

Decker, J. P. (1957). Further evidence of increase carbon dioxide production accompanying photosynthesis. *Solar Energy Sciences Engineering, 1*, 30-33. https://doi.org/10.1016/0038-092X(57)90052-X

Duarte, V. A., & Wollmann, C. A. (2021). Análise de eventos climáticos extremos e impactos nas lavouras de tabaco na bacia hidrográfica do Alto Jacuí/RS. *ACTA Geográfica, 15*, 17-41.

Duvick, D. N., & Cassman, K. G. (1999). Post-green revolution in yield potential of temperate maize in the north-central united states. *Crop Science, 39*, 1622-1630. https://doi.org/10.2135/cropsci1999.3961622x

Filgueiras, R., Oliveira, V. M. R., Cunha, F. F., & Mantovani, E. C. (2018). Variabilidade temporal de parâmetros do balanço hídrico no manejo de culturas agrícolas. *Engenharia Agrícola, 38*.

Gomes, K. R., Amorim, A. V., Ferreira, F. J., Filho, F. L. A., Lacerda, C. F., & Gomes-Filho, E. (2011). Respostas de crescimento e fisiologia do milho submetido a estresse salino com diferentes espaçamentos de cultivo. *Revista Brasileira de Engenharia Agrícola e Ambiental, 15*, 365-370. https://doi.org/10.1590/S1415-43662011000400006

Guo, X., Yang, Y., Liu, H., Liu, G., Liu, W., Wang, Y., … Hou, P. (2022). Effects of solar radiation on dry matter distribution and root morphology of high yielding maize cultivars. *Agriculture, 12*. https://doi.org/10.3390/agriculture12020299

Heiffig, L. S., Câmara, G. M. S., Marques, L. A., Pedroso, D. B., & Piedade, S. M. S. (2006). Fechamento e índice de área foliar da cultura da soja em diferentes arranjos espaciais. *Bragantia, 65*, 285-295. https://doi.org/10.1590/S0006-87052006000200010

Hendges, E. R., Follador, F. A. C., & Andres, J. (2020). Estudo de correlação entre o uso e cobertura da terra com a temperatura de superfície registrada pelo satélite Landsat 8. *Sociedade & Natureza, 32*, 357-366. https://doi.org/10.14393/SN-v32-2020-42828

Inoue, M. T., & Ribeiro, F. A. (1988). Fotossíntese e transpiração de clones de *Eucalyptus grandis* E E. saligna. *IPEF, 40*, 15-20.

Junior, R. A. F., De Souza, J. L., Teodoro, I., Lyra, G. B., De Souza, R. C., & Neto, R. A. A. (2014). Eficiência do uso da radiação em cultivos de milho em Alagoas. *Revista Brasileira de Engenharia Agrícola e Ambiental, 18*, 322-328. https://doi.org/10.1590/S1415-43662014000300012

Kimmins, J. P. (1987). *Forest ecology*. New York: Macmillan.

Krieger, J. M., Vieira, I. S., Silva, W. O. A., Souza, J. L., & Lyra, G. B. (2019). Balanço de radiação utilizando métodos de estimativa da radiação solar em cultivo de cana-de-açúcar. *Agrometeoros, 27*, 123-133. https://doi.org/10.31062/agrom.v27i1.26594

Liu, Q., Yang, Z., Zhou, W., Fu, Y., Yue, X., Chen, H., … Chen, Y. (2022) Solar radiation utilization of five upland–paddy cropping systems in low-light regions promoted by diffuse radiation of paddy season. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4074626

Loomis, R. S., & Amthor, J. S. (1999). Yield potential, plant assimilatory capacity, and metabolic efficiencies. *Crop Science, 39*, 1584-1596. https://doi.org/10.2135/cropsci1999.3961584x

Lopes, M. Á., Moreira, F. F., Hearst, A., Cherkauer, K., & Rainey, K. M. (2022). Physiological breeding for yield improvement in soybean: Solar radiation interception‑conversion, and harvest index. *Theoretical and Applied Genetics, 135*, 1477-1491. https://doi.org/10.1007/s00122-022-04048-5

Mahakosee, S., Jogloy, S., Vorasoot, N., Theerakulpisut, P., Holbrook, C. C., Kvien, C., & Banterng, P. (2022). Light interception and radiation use efficiency of cassava under irrigated and rainfed conditions and seasonal variations. *Agriculture, 12*. https://doi.org/10.3390/agriculture12050725

Manfron, P. A., Neto, D. D., Pereira, A. R., Bonnecarrère, R. A. G., Medeiros, S. L. P., & Pilau, F. G. (2003). Modelo do índice de área foliar da cultura de milho. *Revista Brasileira de Agrometeorologia, 11*, 333-342.

Marchezan, E., Martin, T. N., Dos Santos, F. M., & Camargo, E. R. (2005). Análise de coeficiente de trilha para os componentes de produção em arroz. *Ciência Rural, 35*, 1027-1033. https://doi.org/10.1590/S0103-84782005000500007

Monteiro, J. E. B. A. (2009). *Agrometeorologia dos cultivos: O fator meteorológico na produção agrícola*. Brasília, DF: INMET.

Monteith, J. L. (1977). Climate and the efficiency of crop production in Britain. *Proceedings of the Royal Society of London, 281*, 277-294. https://doi.org/10.1098/rstb.1977.0140

Müller, L. (1981). Fisiologia. In S. Miyasaka & J. L. Medina (Eds.), *A soja no Brasil* (pp. 109-129). Campinas, Brazil.

Neto, R. R. S., Da Silva, P. R. F., Menezes, V. G., & Mariot, C. H. P. (2000). Resposta de genótipos de arroz irrigado ao arranjo de plantas. *Pesquisa Agropecuária Brasileira, 35*, 2383-2390. https://doi.org/10.1590/S0100-204X2000001200008

Regina, M. A., & Carbonneau, A. (1995). Fotorrespiração em folhas de *Vitis vinifera* por dois métodos, baseados em medidas de trocas gasosas. *Brazilian Journal of Plant Physiology, 7*, 159-164.

Sangoi, L., Schweitzer, C., Da Silva, P. R. F., Schmitt, A., Vargas, V. P., Casa, R. T., & De Souza, C. A. (2011). Perfilhamento, área foliar e produtividade do milho sob diferentes arranjos espaciais. *Pesquisa Agropecuária Brasileira, 46*, 609-616. https://doi.org/10.1590/S0100-204X2011000600006

Souza, C. A., Figueiredo, B. P., Coelho, C. M. M., Casa, R. T., & Sangoi, L. (2013). Arquitetura de plantas e produtividade da soja decorrente do uso de redutores de crescimento. *Bioscience Journal, 29*, 634-643

Stewart, D. W., Costa, C., Dwyer, L. M., Smith, D. L., Hamilton, R. I., & Ma, B. L. (2003). Canopy structure, light interception and photosynthesis in maize. *Agronomy Journal, 95*, 1465-1474. https://doi.org/10.2134/agronj2003.1465

Varlet-Grancher, C., Gosse, G., Chartier, M., Sinoquet, H., Bonhomme, R., & Allirand, J. M. (1989). Mise au point: Rayonnement solaire absorbé ou intercepté par um couvert végétal. *Agronomie, 9*, 419-439. https://doi.org/10.1051/agro:19890501

Zagonel, J., & Fernandes, E. C. (2007). Doses e épocas de aplicação de redutor de crescimento afetando cultivares de trigo em duas doses de nitrogênio. *Planta Daninha, 25*, 331-339. https://doi.org/10.1590/S0100-83582007000200013

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