Agronomía Colombiana
ISSN: 0120-9965
agrocol_fabog@unal.edu.co
Universidad Nacional de Colombia
Colombia

Villa, Pedro Manuel; Sarmiento, Lina; Rada, Fermín José; Machado, Daniel; Rodrigues, Alice Cristina

Leaf area index of potato (Solanum tuberosum L.) crop under three nitrogen fertilization treatments

Agronomía Colombiana, vol. 35, núm. 2, 2017, pp. 171-175
Universidad Nacional de Colombia
Bogotá, Colombia

Leaf area index of potato (*Solanum tuberosum* L.) crop under three nitrogen fertilization treatments

Índice de área foliar del cultivo de papa (*Solanum tuberosum* L.) bajo tres tratamientos de fertilización nitrogenada

Pedro Manuel Villa[1, 2], Lina Sarmiento[3], Fermín José Rada[3], Daniel Machado[4], and Alice Cristina Rodrigues[1]

ABSTRACT

Nitrogen fertilization has considerable effects on growth and yield of potato crop. Leaf expansion is one of the most important growth parameters that can be used to optimize nitrogen fertilization management in agroecological practices. We evaluated the effect of nitrogen fertilization on the leaf area index (LAI) of potato crop during different phenological stages by two different methods. Experimental plots were established in a randomized block design with the following treatments: no nitrogen supply (0-N), 133 kg N ha^{-1} (133-N), and 400 kg N ha^{-1} (400-N), using the Granola variety, at the Andes region, Merida city, Venezuela. We measured leaf area at the main phenological stages of the crop using a plant canopy analyzer. LAI showed significant differences among treatments and phenological stages, except during the emergence stage. The maximum LAI values were obtained 55 days after emergence: 400-N (1.42±0.16) > 133-N (0.92±0.21) > 0-N (0.34±0.08). Nitrogen fertilization had a significant effect on the development of LAI in potato crop along its different phenological stages.

Key words: plant canopy analyzer, leaf area, granola variety, Solanaceae.

RESUMEN

La nutrición con nitrógeno tiene efectos considerables sobre la dinámica de crecimiento y producción del cultivo de papa, siendo el desarrollo del área foliar uno de los parámetros de crecimiento más importantes para optimizar el manejo de recursos agroecológicos. Se evaluó el efecto de la nutrición de nitrógeno sobre el índice de área foliar (IAF) a través de dos métodos durante diferentes fases fenológicas del cultivo. Se establecieron parcelas experimentales bajo un diseño de bloques al azar, con tres replicas por tratamiento de fertilización; sin nitrógeno (0-N), 133 kg N ha^{-1} (133-N), y 400 kg N ha^{-1} (400-N), utilizando la variedad Granola en la región Los Andes, Mérida, Venezuela. En las principales fases fenológicas del cultivo se midió el área foliar con un analizador de dosel. El IAF presentó diferencias significativas entre tratamientos y fases fenológicas del cultivo, excepto durante la etapa de emergencia. Los máximos valores de IAF fueron alcanzados cerca de los 55 días después de la emergencia, 400-N (1,42 0,16) > 133-N (0,92±0,21) > 0-N (0,34±0,08). Se demostró que la fertilización nitrogenada tuvo un efecto significativo sobre el desarrollo del índice de área foliar del cultivo de papa durante diferentes fases de fenológicas.

Palabras clave: analizador de dosel, área foliar, variedad granola, Solanaceae.

Introduction

Potato is one of the most important crops that contribute to food security on a global scale, due to its high yield per unit of cropland and time (Devaux *et al*., 2014). It is also the third most consumed crop in the world, benefiting more than one billion people (FAO, 2015). For those reasons, there has been increasing interest in the study of factors determining growth and yield of potato crop, aiming to optimize management of agroecological resources (Gliessman, 2014). In that sense, fertilization is one the most relevant management practices used in potato, especially fertilization with nitrogen, which is the most important nutrient for this species during it´s different phenological stages (Tiemens-Hulscher *et al*., 2014).

Nitrogen supply also plays a determining role in the development of different growth attributes which affect potato yield (Gastal and Lemaire, 2002; Lemaire *et al*., 2008). For instance, total biomass production depends on the amount of photosynthetically active radiation intercepted by the plant, which is directly proportional to its leaf area index

Received for publication: 21 January, 2017. Accepted for publication: 20 July, 2017

Doi: 10.15446/agron.colomb.v35n2.62110

[1] Pós-Graduação em Botânica, Universidade Federal de Viçosa (UFV). Viçosa (Brasil). pedro.villa@ufv.br
[2] Fundación para la Conservación de la Biodiversidad. Merida (Venezuela).
[3] Instituto de Ciencias Ambientales y Ecológicas (ICAE), Universidad de los Andes (ULA). Merida (Venezuela).
[4] Departamento de Química, Universidad de los Andes (ULA). Merida (Venezuela).

(LAI) (Geremew *et al*., 2007; Sadras and Lemaire, 2014; Fischer *et al*., 2016). Analogously, nitrogen has been shown to influence directly on the LAI of potato, a functional trait that has already been used in crops management (Gastal and Lemaire, 2002; Lemaire *et al*., 2007; de la Casa *et al*., 2011; Machado and Sarmiento, 2012). In that sense, LAI has been considered one of the most important predictors of plant growth and yield, as it has direct effects on different ecophysiological processes of several crops (Yin *et al*., 2003; Sadras and Lemaire, 2014). Nevertheless, studies that evaluate temporal variations in LAI of the potato crop related to different nitrogen fertilization treatments on tropical Andean areas are still scarce.

Thus, we aimed to evaluate the effect of different nitrogen supply treatments on LAI during different phenological stages of the potato crop. We hypothesized that the LAI of such crop would respond proportionally to different nitrogen fertilization treatments under severe deficit conditions, being lower with increasing nitrogen deficit conditions and enhancing proportionally with increasing nitrogen fertilization.

Material and methods

Field experiments were conducted in Mérida city, Merida state, Venezuela (8°35'30" N and 71°08'30" W, 1,920 m a.s.l.), from April through July 2004. The study area had monthly air temperatures between 13 and 19°C. Precipitation followed a tetra-seasonal regime, with a yearly mean of 2,000 mm distributed along two light-rainfall periods (December-March and June-August) and two heavy-rainfall periods (April-June and September-November). Soil had a loamy-sandy texture, 0.09% total nitrogen, 2.2 ppm available phosphorous, 1.1 meq 100 g interchangeable potassium, and pH of 5.8. Soil profile depth was approximately 60 cm, and the surface horizon (0-27 cm) had a bulk density of 0.94 g cm^{-3}.

The variety used was Granola, one of the most cultivated in the region due to its high yield and consequent economic importance. This variety has a growth cycle of 3½ to 4 months until harvest. Tuber formation starts at 30 d after emergence (DAE), and tuber filling continues until maximum leaf expansion, which takes place at approximately 60 d after sowing (Villa and Sarmiento, 2009). The crop was considered emerged when 50% of plants were arisen.

Plots (27 m^2) were established with a planting density of 4.44 plants per m^2 in a randomized block design with three replicates and three treatments (Tab. 1): no nitrogen supply (T1 = 0-N), 133 kg N ha^{-1} (T2 = 133-N), and 400 kg N ha^{-1} (T3 = 400-N), from all of which LAI measurements were taken. Nitrogen was supplied by both organic fertilization source with chicken manure (3% N) and inorganic fertilization source with ammonium sulfate (46% N, $(NH_4)_2SO_4$). Analogously, potassium sulfate (17% assimilable K_2O) and phosphate rock (25% assimilable P_2O_5) were applied to all plots. A total 33.3 kg N ha^{-1} were applied in treatment 133-N and 100 kg N ha^{-1} in treatment 400-N, both during hilling and in the ammonium sulfate form (Tab. 1). While sowing was performed, we also applied 100 kg ha^{-1} P_2O_5 as phosphate rock (400 kg ha^{-1}) and 200 kg ha^{-1} K_2O as potassium sulfate (476 kg ha^{-1}) to all experimental plots (Tab. 1).

LAI was determined by a non-destructive method using a portable plant canopy analyzer (LAI-2000, LI-COR Inc., Lincoln, NE, USA) directly in the field. Eight LAI measurements were taken at 25, 34, 46, 50, 59, 66, 75, and 86 d after sowing (DAS). Measurements were taken from each plot by randomly selecting plant rows but disregarding the first rows on each side of the plots to avoid border effect. On each sampling, 16 measurements were taken at two different canopy heights: at the canopy mid region (to estimate LAI of the upper layer) and at the canopy low region, at the soil level (to estimate total canopy LAI), thus, totaling 32 measurements per plot. Finally, LAI (m^2 m^{-2}) was calculated for each canopy layer along crop development, in each replicate from each treatment. Lower canopy LAI was calculated as the difference between total canopy LAI and upper canopy LAI.

Data was statistically analyzed by one-way ANOVA and Tukey's multiple comparison test at the 95% confident

TABLE 1. Nitrogen (N) dose across different fertilization treatments from sources of organic (OF) and inorganic fertilization (IF) during sowing and hilling of potato crop.

Treatment (kg N ha^{-1})	IF sowing (kg ha^{-1})	OF hilling (kg ha^{-1})	IF N (kg ha^{-1})	OF N (kg ha^{-1})	N sowing (kg ha^{-1})	N hilling (kg ha^{-1})
0-N	0	0	0	0	0	0
133-N	159	2,220	33.3	66.6	100	33.3
400-N	476	6,666	100	200	300	100

level ($P \leq 0.05$) using software R version 2. 3.2.4 (R Core Team, 2016).

Results and discussion

Total and lower canopy LAI showed a very similar pattern in all fertilization treatments, yet with statistically significant differences ($P \leq 0.05$), except at 13 DAE (Fig. 1). Maximum LAI values were obtained at approximately 55 DAE in all treatments: 400-N (1.42±0.16) > 133-N (0.92±0.21) > 0-N (0.34±0.08). Otherwise, LAI showed striking significant differences ($P \leq 0.05$) among phenological stages, except between 36 and 57 DAE at treatment 0-N (Fig. 1). Presumably, the decrease in LAI at 60 DAE was mainly due to the onset of senescence, as previously reported to this potato variety (Machado and Sarmiento, 2012).

In this study, we confirm that nitrogen supply is a determining factor for canopy development in potato crop, as LAI increases with increasing nitrogen amounts in soil. This result corroborates different studies performed with such crop (Biemond and Vos, 1992; Alba *et al.*, 2002; Machado and Sarmiento, 2012). Furthermore, the importance of LAI as a functional trait is further enhanced by the strong relationship it has with the amount of solar radiation intercepted by plants (De la Casa *et al.*, 2011; Machado and Sarmiento, 2012), such interception being, to date, one of the most studied ecophysiological processes in crop plants (Gastal and Lemaire, 2002).

We obtained LAI values much lower than those reported to the same variety by Machado and Sarmiento (2012), who used a lower dose of nitrogen fertilization (250 kg N ha^{-1}), yet we found the same developmental pattern reported by those authors, with highest leaf expansion being observed at approximately 55 DAE. The authors also demonstrated how nitrogen fertilization, from an agroecological perspective, affects LAI development, by detecting significant differences among treatments with inorganic fertilization (LAI = 2.0) and with combined fertilization from both organic and inorganic sources (LAI values of 2.5 and 2.8, respectively). Moreover, Haverkort *et al.* (1991) studied the relationship between cover, LAI, and intercepted solar radiation along potato crop development throughout consecutive harvests, and found LAI values higher than 3 in crops with a 100% cover. The low LAI values observed in this study, even at the treatment with highest fertilizer supply, enabled us to presume that there may be other environmental factors influencing crop growth.

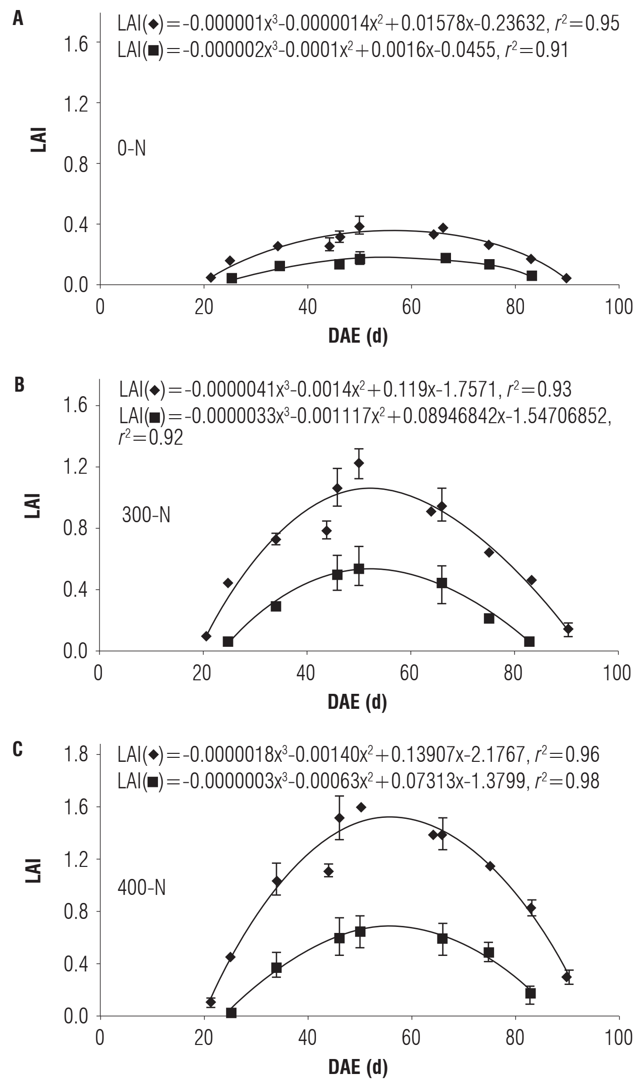

FIGURE 1. Leaf area index (LAI) of potato crop along the days after emergence (DAE) at different fertilization treatments: 0 kg N ha^{-1} (a), 133 kg N ha^{-1} (b), and 400 kg N ha^{-1} (c). Large parabolas represent total LAI (♦) while small parabolas represent lower canopy LAI (■, lower half) fit to third-degree polynomials (means±SD, n=3). Parabolas were obtained using polynomial equations with parameters and correlation coefficients.

De la Casa *et al.* (2007), however, evaluated the use of LAI and soil cover as alternative measurements of canopy development in the potato crop aiming to estimate the fraction of intercepted radiation by establishing two plant density treatments: commercial density (CD = 6.0±0.6 plants/m^2) and low density (LD = 3.9±0.2 plants/m^2). The authors found contrasting values between treatments (LAI-CD = 4.5; LAI-LD = 2.9) at approximately 40 DAE. Later on, in another study conducted at the same region and with the same potato variety, De la Casa *et al.* (2011) evaluated the effect of plant density on LAI, with the following treatments of density of emerged stems: double density (DD = 17 stems/m^2), commercial density (CD = 11 stems/m^2), and low density (LD = 6 stems/m^2). The authors observed that until approximately half the cycle (50 DAE) the LAI is higher at double density (LAI-DD: 4.47), intermediary at commercial density (LAI-CD: 4.19), and lowest at low density (LAI-LD: 3.54). All these results indicate there is high LAI variability in response to nitrogen supply and crop management. Thus, it is fundamental to comprehend LAI dynamics to enhance the efficiency in nitrogen use and increase yield.

Our results showed that LAI values along potato crop development at different fertilization treatments showed an even distribution across the canopy layers. The highest LAI values were found in the upper canopy (Fig. 1). LAI in such layer was highest at the treatment with the highest nitrogen supply (400-N), while in the lower canopy differences were not so contrasting among treatments. Several researchers have stated that uneven LAI distribution across canopy layers is a common pattern observed in different plant species. The fact that LAI distribution in potato crop canopy was uneven probably represents a strategy to maximize carbon assimilation (Gastal and Lemaire, 2002; Yin *et al*., 2003).

Conclusions

Nitrogen supply had a significant effect on LAI of the potato crop across different phenological stages, maximum values being reached at approximately 55 DAE at the different treatments. Striking differences were found among phenological stages, except between 36 and 57 DAE at treatments with no nitrogen supply. LAI distribution between the upper and lower canopy layers in response to nitrogen fertilization treatments was uneven.

Acknowledgments

The authors acknowledge the collaboration of all employees from the Institute of Agricultural Research (Instituto de Investigaciones Agropecuarias - IAP) and the Institute of Environmental and Ecological Sciences (Instituto de Ciencias Ambientales y Ecológicas - ICAE) of the Universidad de Los Andes (ULA) for their unconditional help during the experimental stages of the study. We specially acknowledge Johnny Marques, Francis Guillen, Zulay Méndez, Luis Cedeño, Kleira Quintero, and Wilmer Espinosa. We also thank the researcher José Salas and the producer Luis Castillo for providing certified seeds.

Literature cited

Alva, A.K., T. Hodges, H.P. Collins, and R.A. Boydston. 2002. Dry matter and nitrogen accumulation and partitioning in two potato cultivars. J. Plant Nutr. 25, 1621-1630. Doi: 10.1081/PLN-120006047

Biemond, H. and J. Vos. 1992. Effects of nitrogen on the development and growth of the potato plant. 2. The partitioning of dry matter, nitrogen and nitrate. Ann. Bot. 70, 37-45.

De la Casa, A., G. Ovando, L. Bressanini, A. Rodríguez, and J. Martínez. 2007. Uso del índice de área foliar y del porcentaje de cobertura del suelo para estimar la radiación interceptada en papa. Agric. Téc. 67, 78-85. Doi: 10.4067/S0365-28072007000100010

De la Casa, A., G. Ovando, L. Bressanini, J. Martínez, and A. Rodríguez. 2011. Eficiencia en el uso de la radiación en papa estimada a partir de la cobertura del follaje. Agriscientia 28(1), 21-30.

Devaux, A., P. Kromann, and O. Ortiz. 2014. Potatoes for Sustainable Global Food Security. Potato Res. 57, 185-199. Doi: 10.1007/s11540-014-9265-1

Fischer, G., F. Ramírez, and F. Casierra-Posada. 2016. Ecophysiological aspects of fruit crops in the era of climate change. A review. Agron. Colomb. 34, 190-199. Doi: 10.15446/agron.colomb.v34n2.56799

FAOSTAT - Food and Agriculture Organization of the United Nations. 2015. Database-Agricultural Production. Retrieved from: http://apps.fao.org; consulted: February, 2015.

Gastal, F. and G. Lemaire. 2002. N uptake and distribution in crops: an agronomical and ecophysiological perspective. J. Exp. Bot. 53, 789-799. Doi: 10.1093/jexbot/53.370.789

Geremew, E.B., J.M. Steyn, and J.G. Annandale. 2007. Evaluation of growth performance and dry matter partitioning of four processing potato (Solanum tuberosum) cultivars. N. Z. J. Crop Hortic. Sci. 35, 385-393. Doi: 10.1080/01140670709510204

Gliessman, S.R. 2014. Agroecology: The ecology of sustainable food systems. CRC Press, Boca Raton, FL, USA.

Haverkort, A.J., D. Uenk, H. Veroude, and M. van de Waart. 1991. Relationships between ground cover, intercepted solar radiation, leaf area index and infrared reflectance of potato crops. Potato Res. 34, 113-121. Doi: 10.1007/BF02358105

Lemaire, G., E. van Oosteromb, J. Sheehyc, M.H. Jeuffroyd, A. Massigname, and L. Rossatof. 2007. Is crop N demand more closely related to dry matter accumulation or leaf area expansion during vegetative growth? Field Crops Res. 100, 91-106. Doi: 10.1016/j.fcr.2006.05.009

Lemaire, G., M.H. Jeuffroy, and F. Gastal. 2008. Diagnosis tool for plant and crop N status in vegetative stage Theory and practices for crop N management. Eur. J. Agro. 28, 614-624. Doi: 10.1016/j.eja.2008.01.005

Machado, D. and L. Sarmiento. 2012. Respuesta del cultivo de papa a la combinación de diferentes fuentes de fertilización nitrogenada: evaluando la hipótesis de la sincronización. Bioagro 24(2), 83-92.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Sadras, V.O. and G. Lemaire. 2014. Quantifying crop nitrogen status for comparisons of agronomic practices and genotypes. Field Crops Res. 164, 54-64. Doi: 10.1016/j.fcr.2014.05.006

Tiemens-Hulscher, M., E.T.L. van Buere, and P.C. Struik. 2014. Identifying nitrogen-efficient potato cultivars for organic Farming. Euphytica 199, 137-154. Doi: 10.1007/s10681-014-1143-z

Villa, P.M. and L. Sarmiento. 2009. Recomendación alternativa para la fertilización nitrogenada del cultivo de papa en los altos Andes venezolanos. INIA Hoy. 6, 191-199.

Yin, X., E.A. Lantinga, C.M. Schapendonk, and X. Zhong. 2003. Some relationships between leaf area index and canopy nitrogen content and distribution. Ann. Bot. 91, 893-903. Doi: 10.1093/aob/mcg096