CAPACITANCE (FDR) PROBE UTILIZATION TO ESTIMATE WATER CONSUMPTION AND CROP COEFFICIENT OF FORAGE CACTUS

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ABSTRACT: The irrigated cultivation of forage cactus in Semiarid parts of Brazil has been greatly utilized, generating a demand for information in respect to its management. The goal of this study was to estimate water consumption of forage cactus and its crop coefficient via a capacitance FDR probe. The study was conducted in a forage cactus production field at the Instituto Agronômico de Pernambuco – IPA, em Serra Talhada – PE. The soil water content monitoring was done through a Diviner 2000® capacitive probe and accounted for by integrating the soil profile moisture values each 0.10 m to a depth of 0.50 m. The variation in water storage was estimated through the difference between consecutive readings and the result obtained was considered as the water consumption of the cultivation (ETc). The water consumption values and the crop coefficient for the forage cactus that were estimated via FDR probe were similar to those obtained by other methods and recorded in the literature. The ETc variation achieved an average value throughout the productive cycle of 2.9 mm d^{-1}. The cactus water consumption tended to increase during the changes between crop stages. Throughout the cycle, the average value obtained for Kc was 0.49.

KEYWORDS: *Opuntia stricta.* Evapotranspiration. Irrigation management. CAM plants.

UTILIZAÇÃO DE SONDA CAPACITIVA (FDR) NA ESTIMATIVA DO CONSUMO HÍDRICO E DO COEFICIENTE DE CULTIVO DA PALMA FORRAGEIRA

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RESUMO: O cultivo irrigado de palma forrageira no Semiárido brasileiro tem sido bastante explorado, gerando uma demanda de informações a respeito do seu manejo. O objetivo desse trabalho foi estimar o consumo hídrico da palma forrageira e seus coeficientes de cultivo via sonda capacitiva FDR. O estudo foi conduzido em um campo de produção de palma forrageira do Instituto Agronômico de Pernambuco – IPA, em Serra Talhada – PE. O monitoramento do conteúdo de água do solo foi realizado via sonda capacitiva Diviner 2000® e contabilizado pela integração dos valores de umidade no perfil do solo a cada 0,10 m até a profundidade de 0,50 m. A variação do armazenamento de água foi estimada pela diferença entre leituras consecutivas e o resultado obtido foi considerado como o consumo hídrico da cultura (ETc). Os valores de consumo hídrico e coeficiente de cultivo da palma forrageira estimados via sonda FDR foram similares aqueles obtidos por outros métodos e registrados na literatura. A variação da ETc atingiu um valor médio ao longo do ciclo produtivo de 2,9 mm d^{-1}. O consumo hídrico da palma tende a aumentar nas mudanças de fase da cultura. Ao longo do ciclo, o valor médio obtido para o Kc foi de 0,49.

PALAVRAS-CHAVE: *Opuntia stricta.* Evapotranspiração. Manejo de irrigação. Plantas CAM.

INTRODUCTION

Brazil is the largest world producer of forage cactus (*Opuntia sp*.), a relevant crop in the context of Semiarid Northeast farming, where it is widely used for forage. Its cultivation makes livestock production in the region possible, especially in periods of drought (AMORIM *et al*., 2017).

Forage cactus is a crop that shows resistance in adverse edaphoclimatic conditions. This fact is due to its unique photosynthetic mechanism: Crassulacean acid metabolism – CAM, which makes it highly efficient at using water (HAN & FELKER, 1997), promoting its adaption to regions with low levels of rainfall, such as those in Semiarid Brazil, for example. Although forage cactus develop under highly restricted water conditions, they respond well to the introduction of water to the soil (SILVA et al., 2015).

According to Donato et al. (2014), productivities reached by the forage cactus can be higher, given their high productive potential. Technifying its cultivation would thus be necessary, relying on irrigation technology, for example. According to Medeiros et al. (2014), in the driest regions of Northeast Brazil, where it was not possible to have agricultural production, forage cactus is cultivated with irrigation and achieves high levels of productivity.

Liguori et al. (2013) found that the fresh weight of cladodes from irrigated plants was 2.5 times higher in relation to those from non-irrigated cacti.

To manage irrigated cultivations, attention must be paid to the agrometeorological variables and, using them, the water demand of the cultivation must be estimated - evapotranspiration. This determination or estimation is fundamental for water management in irrigated cultivations, especially in regions with low water availability (PETERSON et al., 2017; XU et al., 2017). This variable can be obtained, among other methods, through the hydric balance of water in the soil, which can be achieved with the use of sensors. Through their measurements, we can estimate the variation in the amount of water stored in the soil over time.

Frequency Domain Reflectometry – FRD is among the indirect methods estimate water content in the soil. This method allows for readings of the water content in the soil in real time, based on dielectric properties of the water, since the dielectric constant will depend on the water content present in the field, influencing the sensor (KANG et al., 2019). Its use is already being applied to irrigation management of some cultivations (SHIBUYA et al., 2018).

Given this context, the goal of this study was to estimate the water consumption of forage cactus and its crop coefficients using a FDR probe.

MATERIALS AND METHODS

The study was conducted in a forage cactus (*Opuntia stricta* Haw.) cv. Orelha de Elefante Mexicana (erect prickly pear) production field at the Instituto Agronômico de Pernambuco – IPA, in Serra Talhada - PE (Lat. 7º59’ S, Long. 38º15’ O and height 431 m). The local climate is characterized as semiarid hot, with high evapotranspiration indices, alternating between a rainy season in the summer-fall and a dry season, and an average annual precipitation of 657 mm (APAC, 2016).

The period of study covered the second cultivation cycle, beginning in July/2012 and ending in May/2013. The cactus was cultivated through irrigation in an Oxisol in a density of 15,625 plants h^{-1}. The irrigation was done through surface dripping, with a rate of 1.32 ± 0.12 L h^{-1} for 10 mca. In the first 6 months, the irrigation layer applied corresponded to 100% of the ETo, with the precipitation values deduced, bringing the reference values for the period in-between irrigation events. Later, the irrigation layer corresponded to 26% of ETo, considering the improved development of the cultivation obtained in layers close to this fraction (QUEIROZ, et al., 2015). The meteorological data were obtained from the EMA from the Instituto Nacional de Meteorologia – INMET, installed 700 m from the experimental area.

To monitor the water quantity of the soil, a capacitive probe was used (Diviner 2000®, Sentek Pty Ltda, Australia), calibrated onsite in accordance with Araújo Primo et al. (2015). In each of the 4 parcels, an access tube was installed for use of the probe. The readings were done in sequential intervals of three days, registering the relative frequency at each 0.10 m in the soil profile to a depth of 0.70 m. Then, each registered value was converted into soil water content (mm) using a calibration curve obtained in a previous study. The moisture values found in each layer were integrated to obtain the water content in the soil profile, in accordance with the methodology proposed by Carvalho & Oliveira (2012), to a depth of 0.50 m (equation 1), with the knowledge that there was not significant variation in the moisture values in the layers from 0.60 and 0.70 m, beside the fact that the forage cactus root reaches a depth of 0.40 m with no water restrictions (EDVAN et al, 2013).

$$L = \int_0^Z \theta i * dZ \qquad \text{Equation (1)}$$

Considering that the cultivation was done in contours and was irrigated by a drip system, the horizontal fluxes, including the surface flow, were considered null, as were the draining and capillary rise, based on studies by Araújo Primo et al. (2015) and Queiroz et al. (2015). Being a cultivation grown in a semiarid environment, reference information on dew was limited. Thus, the variation in water storage in the soil profile was estimated through the difference between the values accumulated in the periods between consecutive readings (equation 2).

$$\Delta ARM = | Li_{-1} - L_i | \qquad \text{Equation (2)}$$

The resulting value was divided by the interval of days between readings and, thus, the water demand of the cultivation (ETc) on a daily scale was obtained. ETo was estimated daily through the Penman-Monteith method, standardized by FAO (ALLEN et al., 1998). The monthly ETo accumulation values were obtained by integrating the daily values. The ETc and ETo values were integrated to estimate the crop coefficient (Kc) in each fenophase of the crop, according to the differentiated proposed by Amorim et al. (2017).

RESULTS AND DISCUSSION

The analysis of climatic data for the study period allowed for observing that the average air temperature values varied from 23.6°C in August 2012 to 28.9°C in November of the same year, with the lowest daily values being recorded in the first months of the cycle. The relative air humidity values showed an average of 51.6%, with the highest daily values being observed in the initial and final months of the cycle, August/2012 and May/2013, respectively. The Lowest global radiation values were recorded in the initial and final months of the study period, in the fall. Wind speed showed an average value around 2.77 $m.s^{-1}$, with daily averages found in the range between 1.34 $m.s^{-1}$ and 4.73 $m.s^{-1}$ (Figure 1). The precipitation recorded in the period was 388 mm, a value that falls below the local climatological normal (642 mm). Of the total precipitation, 92% was recorded in the months from January to May/2013.

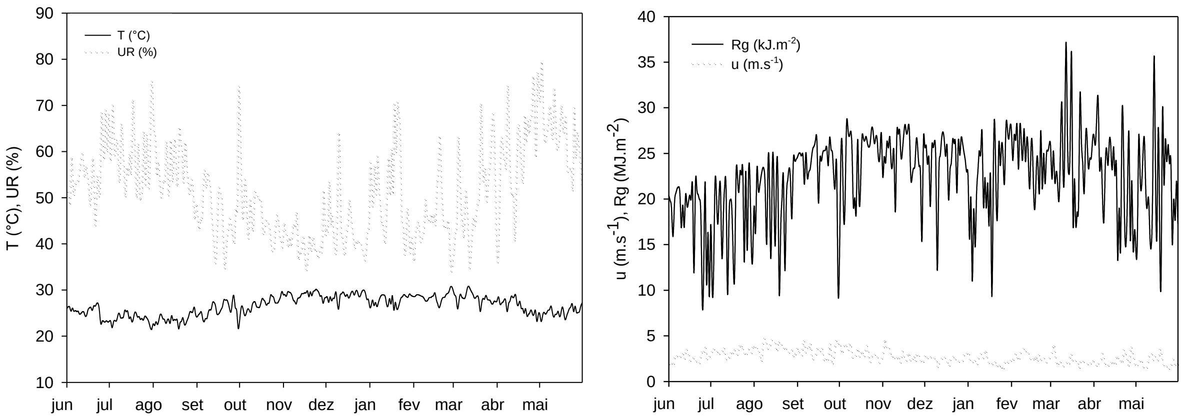

Figure 1. Meteorological variable data throughout the experimental period corresponding to the second forage cactus (*Opuntia stricta*) productive cycle in Semiarid Brazil.

Radiation, air temperature, humidity and wind speed are the main climatic characteristics that affect evapotranspiration (ALLEN et al., 1990). The association of these parameters resulted in a reference evapotranspiration that varied considerably over time, presenting an average minimum of 4.33 $mm.d^{-1}$ in July/2012 and an average maximum of 6.61 $mm.d^{-1}$ in November of the same year. The variation in transpiration for the crop (ETc) achieved an average minimum value of 1.79 $mm.d^{-1}$ in February/2013 and an average maximum value of 3.11 $mm.d^{-1}$ in October/2012 (Figure 2).

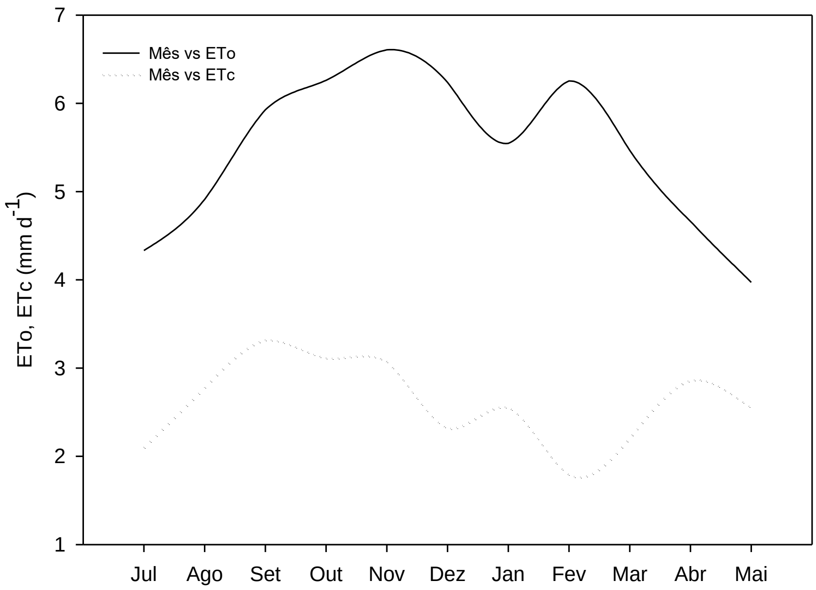

Figure 2. Average monthly reference evapotranspiration values (Penman-Monteith - FAO 56) and crop evapotranspiration obtained through water balance via capacitive probe.

In the forage cactus, the photosynthetic functions occur in the cladodes and, being a CAM species, this crop opens its stomates in the nocturnal period to meet the demand for CO2 necessary for its metabolism, which diminishes water transfer to the atmosphere (BARBOSA et al., 2017), resulting in low evapotranspiration indices (figure 2), especially when compared to C3 of C4 plant indices.

In the initial growth period of the crop (July to October/2012), in which there was only the cladode base and the beginning of the first cladode emission, ETc and ETo behaved similarly, both increasing. From November to December there was a decreasing trend for ETc and beginning in December the water demand of the crop increased, possibly due to the beginning of the cactus' fenophase II, in which the rate of second order cladode emission overtakes emission of cladodes of the first order, according a study by Amorim et al. (2017). In January the ETc decreased and it reached its lowest indicator in February, showing an increasing trend after this period. The peaks observed in the month of January, March and April can also be attributed to the fact that the rainfall indicators in the months were high (Figure 3). Additionally, in precipitation situations, the cactus develops temporary roots, "rain roots", thus resulting in a higher water absorption in the soil profile by these roots (SILVA et al., 2015).

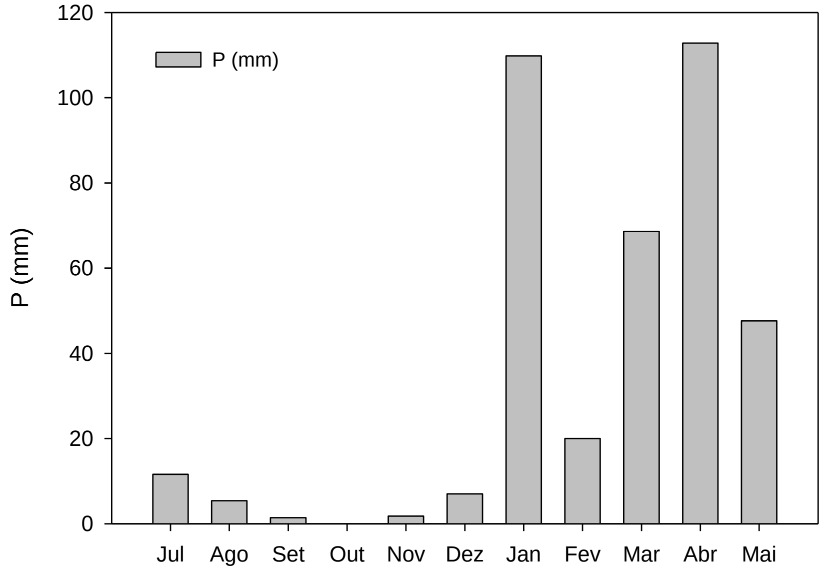

Figure 3. Monthly rain precipitation values during the study period, in Serra Talhada-PE.

The beginning of the emission of third order cladodes recorded in the month of March likely also contributed to a higher water requirement for the cultivation for this period – March/April, with an average indicator of 2.5 mm.d^{-1}. On the other hand, ETo presented a decreasing trend, which can be attributed to lower solar radiation and air temperature values.

According to Silva et al. (2015), the evapotranspiration rates in Semiarid Brazil vary from 1.2 to 7.5 mm d^{-1}. For *Opuntia stricta*, Pereira et al. (2017) indicate an average ET of 1.5 mm d^{-1} and Consoli et al. (2013) indicate an average value of 2.5 mm d^{-1}. In this study, the daily average found for ET was 2.9 mm d^{-1}.

The relationship between actual evapotranspiration of the crop and that of the reference (ETc/ETo) was obtained, generating values for the cultivation coefficient. Its variation over the course of the plants' development followed, to some extent, the variation in ETc (Figure 4).

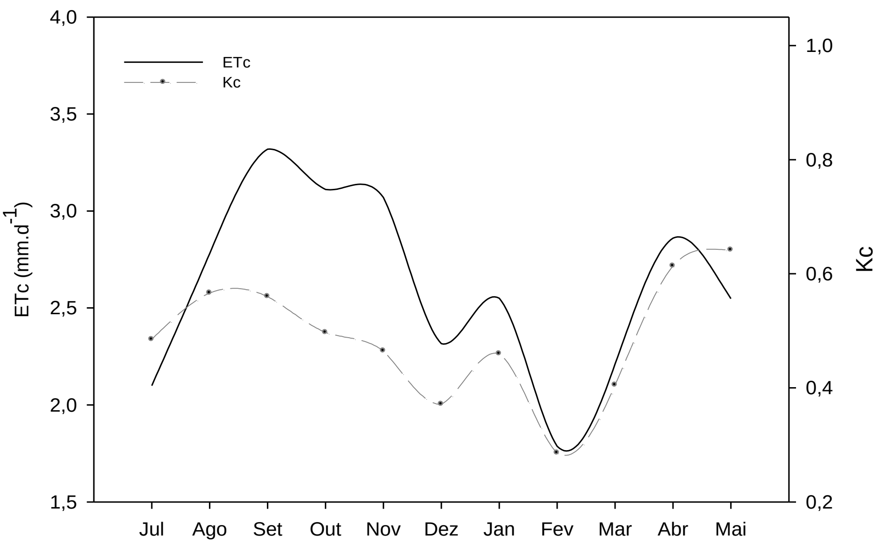

Figure 4. Average ETc and Kc values for forage cactus (*Opuntia stricta*).

The highest Kc values were observed in the crop's vegetative fenophase change periods, in which the rate of cladode emission of the "nth" power surpassed the cladode emission of "n-1" (AMORIM et al., 2017). For fenophase I, the Kc was 0.51 and for fenophase II, the Kc was 0.43. Consoli et al. (2013) estimated evapotranspiration for forage cactus and obtained an average Kc of approximately 0.40. Pereira et al. (2017), despite variation encountered that occurred in the cycle with Kc in values from 0.16 to 0.50, recorded an average value of 0.29.

CONCLUSION

The water consumption and the crop coefficient values of the forage cactus estimated via FDR probe were similar to those obtained through other methods and recorded in the literature. Over the course of the second productive cycle of the forage cactus, its cumulative water consumption was 974 mm, with an average of 2.9 mm d^{-1}. This variable tends to increase during the crop's phase changes. Considering the management adopted in this study, the average value obtained for Kc was 0.49.

REFERENCES

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMUTH, M. Crop Evapotranpiration - Guidelines for 385 computing crop water requirements - Irrigation and Drainage Paper 56. Rome: FAO, 1998, p. 386-301.

AMORIM, D. M.; SILVA, T. G. F.; PEREIRA, P. C.; SOUZA, L. S. B.; MINUZZI, R. B. Phenophases and cutting time of forage cactus under irrigation and cropping systems. **Pesquisa Agropecuária Tropical**. Goiânia, v.47, n.1, p.62-71, 2017.

AGÊNCIA PERNAMBUCANA DE ÁGUAS E CLIMA (APAC). Sistema de geoinformação hidrometeorológico de Pernambuco. 2016. Available at:<http://www.apac.pe.gov.br/sighpe/>. Access on: May 25, 2016.

ARAÚJO PRIMO, J.T. de A.; SILVA, T.G.F. da; SILVA, S.M.S. e; MOURA, M.S.B. de; SOUZA, L.S.B. de. Calibração de sondas capacitivas, funções fisico-hidricas e variação do armazenamento de água em um argissolo cultivado com palma forrageira. **Revista Ceres**, v.62, p.20-29, 2015.

BARBOSA, M. L.; SILVA, T. G. F.; ZOLNIER, S.; SILVA, S. M. S.; MORAIS, J. E. F.; ASSIS, M. C. S. Association of morphological and water factors with irrigated forage cactus yield. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.21, n.9, p.600-605, 2017.

CARVALHO, D. F.; OLIVEIRA, L. F. C. Planejamento de manejo da água na agricultura irrigada. Viçosa, MG: UFV, 2012. 240 p.

CONSOLI, S.; INGLESE, G.; INGLESE, P. Determination of evapotranspiration and Annual Biomass Productivity of a Cactus Pear [Opuntia ficus-indica L. (Mill.)] Orchard in a Semiarid Environment. **Journal of Irrigation and Drainage Engineering**, New York, v. 139, n. 8, p. 680-690, 2013.

DONATO, P. E. R.; PIRES, A. J. V.; DONATO, S. L. R.; BONOMO, P.; Silva, J. A.; Aquino, A. A. Morfometria e rendimento da palma forrageira ‘Gigante’ sob diferentes espaçamentos e doses de adubação orgânica. **Revista Brasileira de Ciências Agrárias**. Recife, v.9, n.1, p.151-158, 2014.

EDVAN, R. L.; FERNADES, P. D.; CARNEIRO, M. S. S.; NEDER, D. G.; ARAÚJO, J. S.; ANDRADE, A. P.; SOUTO FILHO, L. T. Acúmulo de biomassa e crescimento radicular da palma forrageira em diferentes épocas de colheita. Revista Acadêmica: **Ciências Agrárias e Ambientais**. Curitiba, v.11, n.4, p.373-381, 2013.

HAN, H.; FELKER, P. Field validation of water-use efficiency of the CAM plant Opuntia ellisiana in south Texas. **Journal of Arid Environments**, Amsterdam, v. 36, n. 1, p. 133-148, 1997.

KANG, S.; VAN IERSEL, M. W.; KIM, J. Plant root growth affects FDR soil moisture sensor calibration. **Scientia Horticulturae**, v. 252, p. 208 – 211, 2019.

LIGUORI, G.; INGLESE, G.; PERNICE, F.; SORTINO, G.; INGLESE, P. CO2 uptake of Opuntia ficus-indica (L.) Mill. whole trees and single cladodes, in relation to plant water status and cladode age. **Italian Journal of Agronomy**, v.8:e3, 2013.

MEDEIROS, J. F.; FERREIRA NETO, M.; LEMOS, M.; Lira, R. B. Sistema localizado de baixa pressão para irrigação de palma forrageira utilizando água de esgoto tratada. II Inovagri International Meeting, II Simpósio Brasileiro de Salinidade, II Reunião Brasileira sobre Engenharia da Irrigação, 2014, Fortaleza, CE. **Anais**. Fortaleza: INOVAGRI, INCT-EI, INCTSAL, 2014. v. único. p. 1-7.

PEREIRA, P. C.; SILVA, T. G. F.; ZOLNIER, S.; SILVA, S. M. S.; SILVA, M. J. Water balance in soil cultivated with forage cactus clones under irrigation. **Revista Caatinga, Mossoró**, v. 30, n. 3, p. 776-785, 2017.

PETERSON, K. W.; BREMER, D. J.; SHONKWILER, K. B.; HAM, J. M. Measurement of evapotranspiration in turfgrass: a comparison of techniques. **Agronomy Journal**, v. 109, n. 5, 2017.

QUEIROZ, M. G.; SILVA, T. G. F.; ZOLNIER, S.; SILVA, S. M. S.; LIMA, L. R.; ALVES, J. O. Características Morfofisiológicas e produtividade da palma forrageira em diferentes lâminas de irrigação. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 19, n.10, p.931-938, 2015.

SHIBUYA, D. H.; MATSURA, E. E.; CAMARGO, A. P.; NAZARIO, A. A. Manejo de irrigação do café com a utilização de uma sonda capacitiva (FDR). **Revista dos Trabalhos de Iniciação Científica da Unicamp**, Campinas, SP, n.26, out. 2018.

SILVA, T. G. F.; ARAÚJO PRIMO, J. T.; MOURA, M. S. B.; SILVA, S. M. S.; MORAIS, J. E. F.; PEREIRA, P. C.; SOUZA, C. A. A. S. Soil water dynamics and evapotranspiration of forage cactus clones under rainfed conditions. **Pesquisa Agropecuária Brasileira**, Brasília, v. 50, n. 7, p. 515-525, 2015.