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Research Article
NDVI Response to Water Stress in Different Phenological Stages in Culture Bean

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Abstract
In order to study the response of Normalized Difference Vegetation Index (NDVI) to water stress in different phenological stages in culture bean. The plots consisted up of plastic pots planted with beans IPR Tangara, provided agricultural greenhouse. The humidity was controlled by readings of Time Domain Reflectometry (TDR) probes and beaker assistance irrigation was performed. Water stress was applied in one phenological stage during the development cycle of the culture and the V4, R6, R7, R8 and R9 with the next supply to the wilting point and the other stadiums kept near field capacity. The images were obtained by digital camera with filters in the region of visible light and near infrared, they were used to calculate the NDVI and processed by IDRISI Selva (geographic information system and image processing software). The NDVI vegetation index identified the presence and absence of water stress in all phenological stages before the bean crop development cycle, possessing strong correlation except for the R8. However, you will need more studies using digital cameras in order to identify the water condition of plants.

Key words: Digital camera, GIScience, *Phaseolus vulgaris* L., remote sensing in agriculture, NDVI

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water constitutes one of the most important substances the earth's crust, participating in vital and physical-chemical processes. In addition, it can achieve up to 95% of the cell protoplasm of plants and even participate in important metabolic reactions like photosynthesis and oxidative phosphorylation, thus responsible for maintaining the cell turgor in plant growth (Reichardt and Timm, 2012).

The water deficit occurs so too in various crops, resulting in a negative impact on growth and development of plants (Lecoeur and Sinclair, 1996).

According to Guimaraes (1988), the bean plant has high sensitivity to water stress, which probably has low resilience to drought and also for its root system is poorly developed. Thus, the water stress proves to be a limiting factor for high yields (Rezende *et al*., 2004).

Silveira and Stone (1994), the water deficit occurred in any phenological stage in bean culture may affect their performance in different proportions.

Significant reductions were observed for productivity and Dubetz and Mahalle (1969) with 53, 71 and 53% in the pre-flowering, flowering and post-flowering, respectively. Several researchers obtained similar results as the critical growth stages on the bean with a common periods of pre-flowering, bloom, early pod formation and grain filling stage and these phases the most affected by water stress compared to vegetative growth, as was observed by Shouse *et al*. (1981), Ferreira *et al*. (1991), Fiegenbaum *et al*. (1991), Brito (1993), Amorim Neto *et al*. (1995), Guimaraes *et al*. (1996) and Andrade *et al*. (1999).

Some characteristic features of the leaves of plants as pigments, spaces occupied by water and air, structures composed of grains of starch, mitochondria, ribosomes, nuclei and other plastids have in the context of optical spectrometry, in particular as regards the amount of electromagnetic energy reflected by the sheets and which are possible to measure (Gates *et al*., 1965).

According to Gausman (1985), other factors are directly influential on the reflectance of a canopy, namely: the water content, ripening or plant age, nodal position, lighting condition, pubescence and senescence.

Among the various applications of remote sensing in agriculture, have been used vegetation indices in assessments of the canopy reflectance of cultures (Da Silva *et al*., 2014a, 2015), aimed at detection of biotic and abiotic stresses the environment, for example, assess the nutritional status, growth and estimate monitor the plant conditions as well as to predict the productivity of cultures (Osborne *et al*., 2002; Zhao *et al*., 2003, 2007; Ma *et al*., 2001; Da Silva and Bacani, 2011).

The vegetation indices are combinations of spectral bands, aimed at the enhancement of vegetative features minimizing the effects of soil and atmospheric angular (Epiphanio *et al*., 1996).

According Ponzoni and Shimabokuro (2007), several vegetation indexes in order to exploit the activities of vegetation in spectral regions of visible and near infrared. However, it is noteworthy that on the assumption of optical spectrometry chlorophyll pigments absorb more radiation in the visible spectrum (V) and reflect the radiation in the near infrared (NIR) (Minolta Co., 1989).

With the current sophistication of digital cameras on the market, it has been studied its application to the field of remote sensing studies such as the study of bean growth and banana (Oberthur *et al*., 2007), in nitrogen levels in maize (Gasparotto, 2014), the spectral responses at different stages of an orange orchard (Parise and Vettorazzi, 2005), the reflectance in bermuda grass under different levels of nitrogen (De Lima *et al*., 2012), the vegetation of the study with conventional machines (Disperati *et al*., 2009), in land cover (Velazquez-Garcia *et al*., 2010; Da Silva *et al*., 2014b), the identification of weed realtime (Burgos-Artizzu *et al*., 2011), the estimated growth and nutritional status rice nitrogen (Lee and Lee, 2013) and leaf area index for eucalyptus tree (Macfarlane *et al*., 2007).

Therefore, this study aimed to study the response of NDVI to water stress in different phenological stages in the bean crop, upon achieving images by digital camera during the crop development cycle.

MATERIALS AND METHODS

Locality: The research was conducted in protected environment located in the research unit on irrigated agriculture, Irrigation Technical Center (CTI/UEM) of the State University of Maringa (UEM), located at latitude 23°25' South and longitude of 51°57' West Greenwich. The experiment was conducted from 13 March until 11 June 2014 with total duration of 90 days.

Experimental unit preparation: The soil used was a dystrophic red nitosol having in its composition grading 175 g kg^{-1} of sand, 90 g kg^{-1} silt and 735 g kg^{-1} of clay. The soil for the construction of the plots was collected at a depth of 0.20 m and sifted using a mesh of 0.004 m, yielding air dried

Table 1: Chemical analysis of the soil used in the experimental plots

Variables	Quantity
Phosphorus (mg dm^{-3})	4.53
Potassium ($cmol_c$ dm^{-3})	0.27
Calcium ($cmol_c$ dm^{-3})	3.83
Magnesium ($cmol_c$ dm^{-3})	1.23
Hydrogen+Aluminium ($cmol_c$ dm^{-3})	3.55
Aluminium ($cmol_c$ dm^{-3})	0.00
Copper (mg dm^{-3})	13.50
Zinc (mg dm^{-3})	2.70
Iron (mg dm^{-3})	35.80
Manganese (mg dm^{-3})	59.40
pH in $CaCl_2$	5.10
pH in H_2O	5.80
K (%)	3.04
Ca (%)	43.09
Mg (%)	13.88
Al (%)	0.00
H (%)	39.99

soil (TFSA). The experimental plots were made up of plastic pots with total volume of 0.008 m^3, having a useful soil volume of 0.006 m^3.

Fertilization: The chemical fertilization for the sowing was carried out according to the technical recommendation for the bean crop (De Oliveira and Instituto Agronomico do Parana, 2003), it is recommended the mass of fertilizer per unit area. For the calculation of the need for a plant fertilizer was considered and adopted by plot a seeding density of 200,000 plants ha^{-1} with spacing of 0.5 m between rows and 10 plants per meter corresponding to the recommended population to grow IPR Tangara. Chemical analysis of soil carried out in the laboratory are presented in Table 1.

Seeding: The seed used in this experiment was to cultivate IPR Tangara, the main features being the carioca group, present indeterminate growth habit has the erect with long guides (type IIb) and average cycle of 87 days from emergence to harvest, with potential average production of 3,326 kg ha^{-1}. The seeds were treated with fungicide and insecticide Vitavax® Tiodicarbe 350 SE at doses of 0.3 and 1.5 L/100 kg of seeds. Seeds were sown with five seeds per plot, with subsequent thinning to 15 days after sowing, leaving only one plant per plot.

Water management in soil: The bordering water potential in the soil used in this study were associated with the corresponding soil moisture values based on the model shown in Eq. 1, which describes the water retention curve in soil and has been adjusted by Blainski (2007), as model by Ross *et al*. (1991). The soil of the experimental area, as described, had been subjected to conventional tillage for

Fig. 1: Reading dielectric finds with TDR machine

three consecutive years. Thus, for bulk density of this experiment (1.08 mg m^{-3}), the potential of -60 hPa corresponds to the value of 0.37 m^3/m^3 for soil moisture at field capacity and 0.26 m^3/m^3 for the permanent wilting point, adopted as corresponding to the potential of -15,000 hPa. Regarding the appropriate time to water replacement, it was assumed value of 0.33 m^3/m^3 corresponding to the potential of -300 hPa, regarded as the moisture limit.

The humidity of experimental plots was monitored twice a day and in the early morning and late afternoon, using the TDR device (Time Domain Reflectometry) Model 6050X1 TRASE SYSTEM 1. In the plots contained handmade probes with rods of 0.20 m long fixed after the completion of saturation with water according to the methodology described by Trintinalha *et al*. (2001). The measures of the apparent dielectric constant (Ka) were obtained each day (Fig. 1) and the plots of bulk density (bd) were included in the model shown in Eq. 1, proposed by Trintinalha (2005), for the amount of soil moisture. This value has made possible the irrigation with the aid of a measuring cylinder in milliliters.

$$\theta = (0.842538-0.725175\times bd)+(-0.049601+0.060353\times bd)\times ka+(0.001044-0.004061\times bd)\times Ka^2 \quad (1)$$

During the experiment was monitored humidity of experimental plots, which were kept close to Field Capacity

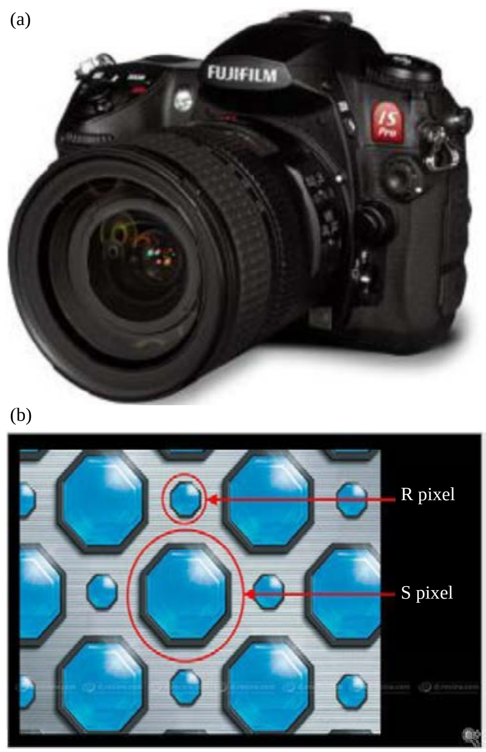

Fig. 2(a-b): (a) Camera Fujifilm IS PRO and (b) Super CCD SR Pro sensor scheme

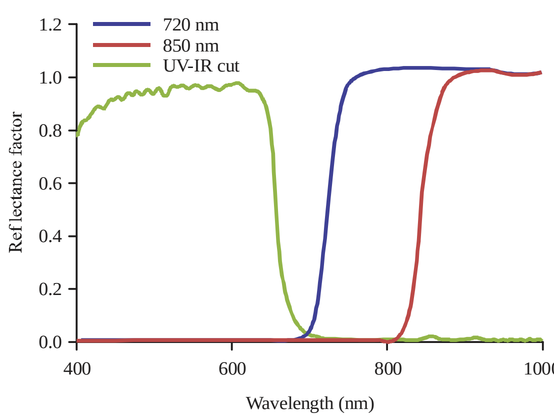

Fig. 3: Spectral curves from the reflectance standard espectralon plate with the presence of infrared filters in lengths 720 and 850 nm for visible and UV-IR cut

(FC), but when arriving at V4 phenological stage (28 Days After Seeding (DAS)) moisture was kept close to the Wilting Point (WP). Later, after the growth stage irrigation is returning to try and keep the soil moisture close to FC by the end of the cycle. For the phenological stages R6 (41 DAS), R7 (47 DAS), R8 (54 DAS) and R9 (80 DAS) water management was held in this same manner, consisting of applying water stress in one phenological stage during the development of culture. To better compare the results, it was considered a control treatment that has remained in the next irrigation for the entire cycle FC.

Cultural tracts: During the execution of the experiment was applied Abamectina insecticide in dose of 1.8 mL L^{-1} against the incidence of mite (*Polyphagotarsonemus latus*). Entering a tutor was necessary as the advancement of the cycle for the best development of plants.

Acquisition of spectral images: Image acquisition and processing for reflectance (ρ) was performed according to the methodology proposed by Gasparotto (2014) by using a digital camera Fujifilm IS Pro® 5 UVIR (12.1 megapixels), which has non-blocking internal filter infrared light. The camera consists of a sensor SR PRO Super CCD (16 bits) (Fig. 2) with sensitivity to capture the light from the ultraviolet (UV) to infrared (IR) spectrum (380-1000 nm) and having a long range increased uptake of wavelengths than conventional digital cameras. This sensor has pixels "S" with normal sensitivity, capturing the same range of light as a conventional CCD photosites, but the pixels "R" present are even smaller, designed to capture details of the pixel above the saturation point "S". The information of the "S" and "R" pixels are combined to produce a wide dynamic range and avoid losing details due to over exposure (Joinson *et al*., 2007).

To catch the infrared images we used the 720 nm filter that allowed the registration of images from the reflectance of the targets in a spectral range above 720 nm. The efficiency of this filter was studied by Gasparotto (2014), performing spectral readings espectralon plate by means of a spectroradiometer, as shown in Fig. 3.

White Balance (WB) was carried out so that there would standardize the quality of the images according to the brightness present to the environment, so personalized and pre-set for each used filter and also along with the use of the ISO sensitivity index 100 secured less noise to the image.

For purposes of calculation of the vegetation indexes, images were captured with the visible light in the red band (UV-IR cut filter) to prevent recording of shorter wavelengths than 350 nm and greater than 700 nm.

Therefore, all photographic records were made with two filters (720 nm IR and UV-IR cut) in all treatments with their phenological stages studied. The equipment was always mounted at the same location between 12:00-14:00 h to solar lighting standardization purposes and using a tripod with a distance of 0.5 m from the plant with 45° angle (Fig. 4), the which were chosen and adapted according to Souza *et al*. (2009) and Crimmins and Crimmins (2008).

Vegetation index calculations: The NDVI index was calculated by the Eq. 2 (Rouse *et al*., 1974), where their values range from -1 to 1, so that the closer to 1 more healthy vegetation is as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} \quad (2)$$

where, ρ_{NIR} and ρ_R are reflectance in the spectral range of the near infrared and red, respectively.

All processes related to vegetation indices and gray level transformation to reflectance were executed in IDRISI Selva platform, developed by the Graduate School of Geography at the University of Clark. The platform provides resources for environmental management of natural resources. For the module vegetation index was used VegIndex plug and the remaining calculations are made using Macro Modeler, a calculator by means of the flowchart.

Treatments and statistical design: The design was adopted entirely to chance, offering up to 6 treatments with 8 repetitions, totaling 48 experimental plots. The treatments consisted of T1: Water stress in V4 stage, T2: Water stress in the R6 stage, T3: Water stress at R7 stage, T4: Water stress in the stadium R8, T5: Water stress in R9 and T6 stadium: No stress in any cycle (control treatment).

Fig. 4: Equipment used for capturing images

RESULTS AND DISCUSSION

Table 2 shows the average NDVI vegetation index on condition of absence of water stress in growth stages V4, R6, R7, R8 and R9 for the test at 5% probability.

There has been a gradual increase in NDVI values as the development of culture. Among the V4 and R6 stages, an increase of 14.86%, from 0.63-0.74. R6 and R7 stages were 0.74-0.80 which corresponds to an increase of 7.93% coinciding with the phase of the bean plant has its largest size. However, when reached the end of the cycle there was a decrease of 5.02% between the stages R7 to R8 and 23.43% among the stages R8 to R9 (Table 2). The coefficient of variation was 8.45%, considered low as Gomes (1985).

The NDVI behavior over the studied stages are similar to that found by Neiverth *et al*. (2013), where there were higher values of the index to the stage of formation and pod filling in soybean grown in the greenhouse. The higher biomass results in increased photosynthetic rate and thus greater absorption of atmospheric CO_2 (Beltrao *et al*., 2007). According to Liu *et al*. (2012), the chlorophyll content in the plant is the most influential factor in NDVI.

The images obtained by digital camera in accordance with the development of bean crops are observed in Fig. 5 and 6 and in the absence and presence of water stress in phenological stages.

Notably, NDVI index showed the green color indicating water conditions in soil at field capacity, in which the plant performs photosynthesis water without impediment, i.e., in the absence of stress as seen in Fig. 5a-e. the yellowing of bean leaves in water conditions in the soil next to the wilting point was predominant as seen in Fig. 6a-e thus possible to quantify NDVI image upon water conditions plants.

Table 3 shows the analysis of variance of regression of the condition of water stress in one phenological stage during the cycle (V4, R6, R7, R8 and R9) during the bean crop cycle and the NDVI index.

Table 2: Index average NDVI without water stress in phenological stages V4, R6, R7, R8 and R9 in the bean crop

Phenological stages					
V4	R6	R7	R8	R9	Coefficient of variation
0.63[c*]	0.74[b]	0.80[a]	0.77[ab]	0.62[c]	8.45

NDVI: Normalized difference vegetation index, *Lowercase letters in the same line do not differ to 5% by t-test

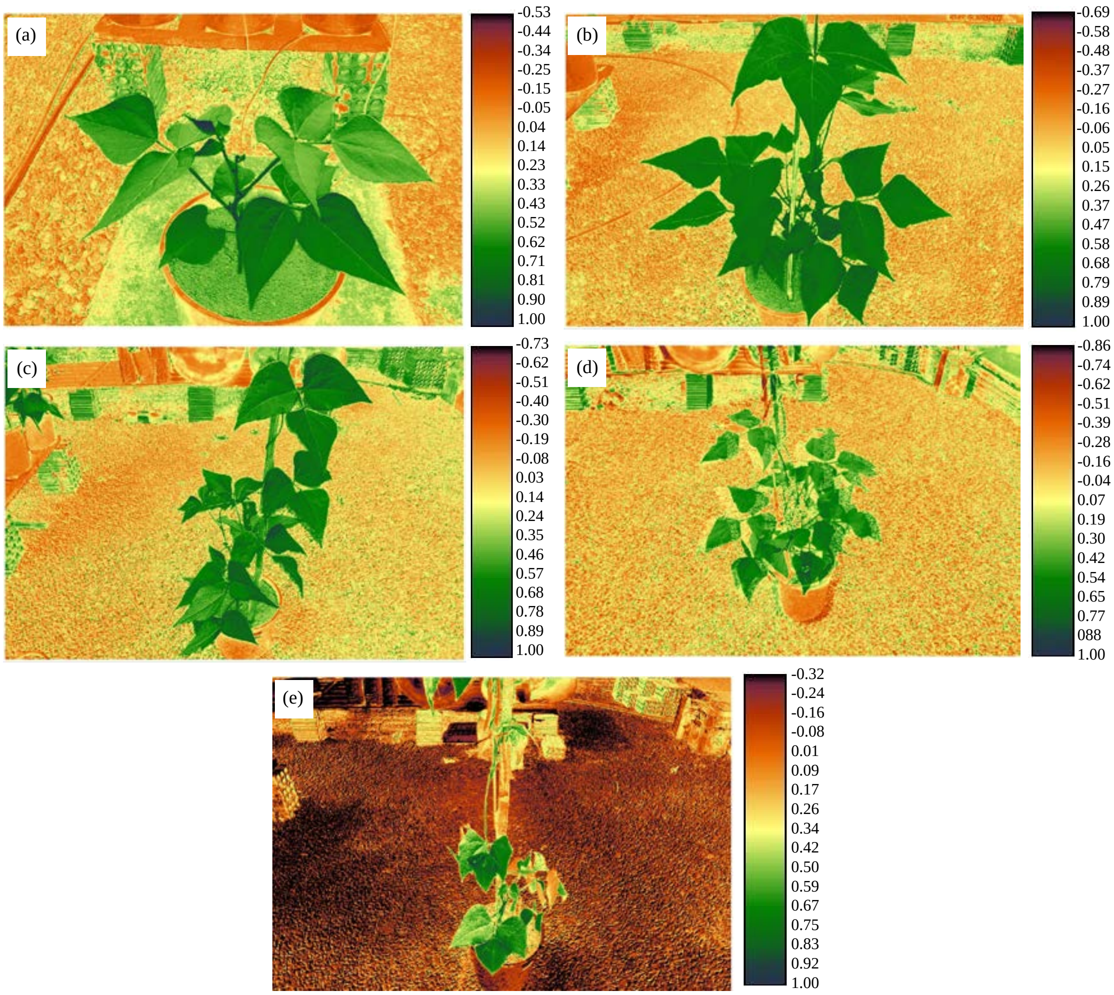

Fig. 5(a-e): Images taken by digital camera rendered to the NDVI vegetation index provided no stress (NE) water in the phenological stages bean (a) V4, (b) R6, (c) R7, (d) R8 and (e) R9

Table 3: F-test result analysis of variance of regression between the NDVI vegetation index and the condition of water stress in one phenological stage during the cycle

AWS	Shapiro-Wilk W_{calc}	Hartley F_{calc}	Lack of adjustment F_{calc}	LR F_{calc}	QR F_{calc}	CV (%)
V4	0.953^{ns}	6.023^{ns}	9.214^{ns}	4.913^{ns}	52.208*	14.85
R6	0.979^{ns}	4.646^{ns}	20.884^{ns}	0.263^{ns}	3.182*	6.66
R7	0.987^{ns}	6.023^{ns}	2.122^{ns}	0.146^{ns}	14.769*	13.09
R8	0.980^{ns}	6.023^{ns}	39.896*	-	-	-
R9	0.963^{ns}	2.299^{ns}	1.101^{ns}	108.80^{ns}	3.16*	8.75

*Significant ($p<0.05$) by t-test, ^{ns}Not significant, LR: Linear regression, QR: Quadratic regression, CV: Coefficient of variation, NDVI: Normalized difference vegetation index

Note that most studied phenological stages received no significance for normality and homogeneity of variance lack of fit being considered as valid regressions (Table 3). Only the growth stage R8 presented significance for the lack of fit of the regression invalidating it. However, among the variation coefficients were considered average according to the classification proposed by Gomes (1985).

In Fig. 7, it is observed that the regressions a, b, c and d have a quadratic behavior, possessing correlation coefficients of 0.94, 0.53, 0.73 and 0.99, respectively. Thus, it is considered that there was a strong correlation between NDVI index and the water stress induced in only one of the phenological stages (V4, R6, R7 or R9) during the bean crop cycle.

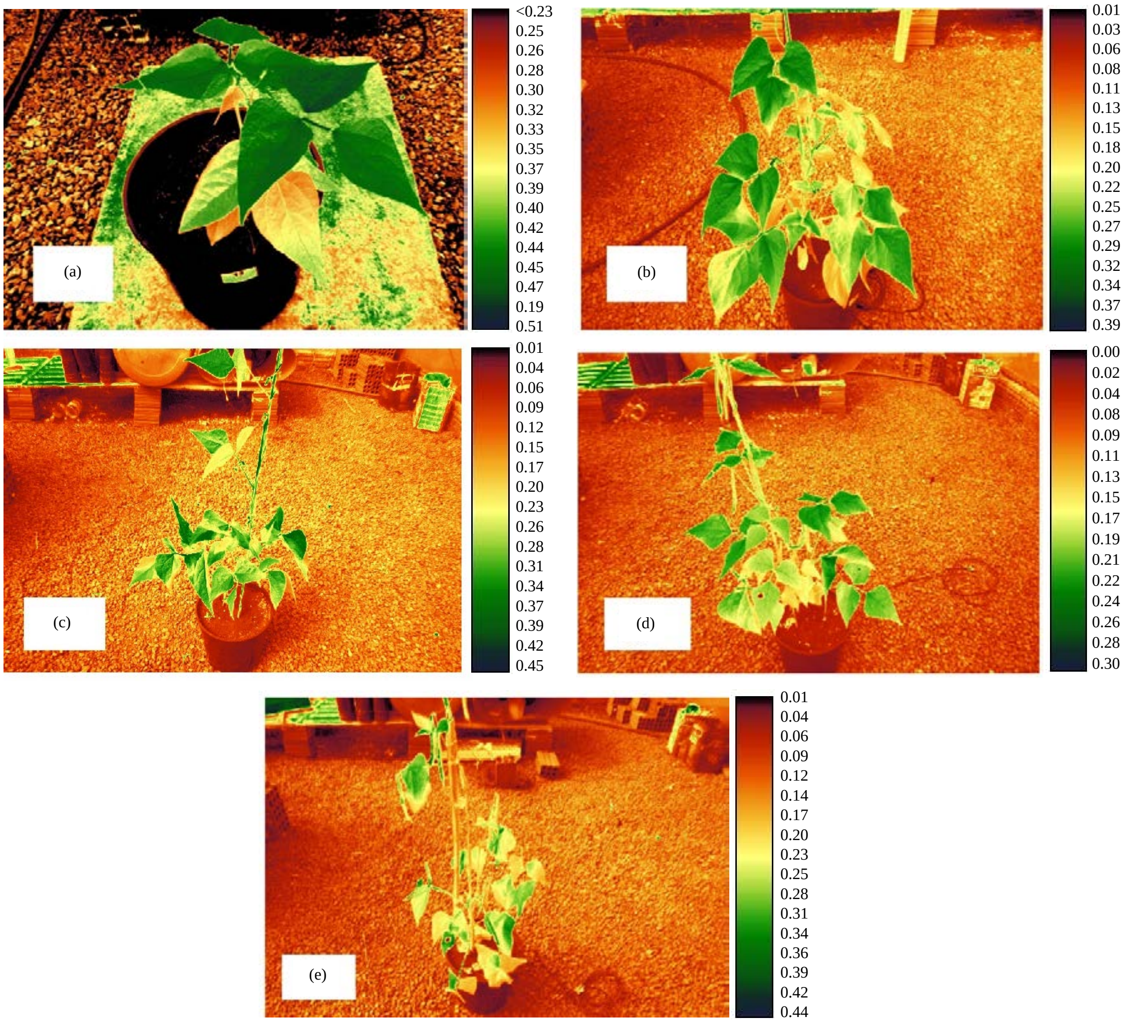

Fig. 6(a-e): Images obtained by digital camera rendered to the NDVI vegetation index on condition the presence of stress in phenological stages bean (a) V4, (b) R6, (c) R7, (d) R8 and (e) R9

The presence of water stress on growth stage V4, where the plant has its first fully expanded trifoliate, resulted in lower value of NDVI in relation to water stress for the same stage, from 0.63-0.33 (Fig. 7a). This difference corresponded to a 48% decrease in the value of NDVI compared the plant water status next to field capacity.

The same thing happened to the phenological stages of flowering (R6), pod formation (R7) and physiological maturity (R9) with decreases in NDVI values of 0.74 to 0.61; 0.80 to 0.68 and 0.62 to 0.49 corresponding decreases 18, 15.7 and 21.2%, respectively compared to without water stress occurred to the same stages (Fig. 7b-d).

These results corroborate Ritchie (1981), where plants under severe water stress conditions may occur partial death of the leaves and reduce leaf area decreasing their ability to capture sunlight. It is the acceleration of senescence and abscission of leaves, as well as other physiological responses that result indirectly in water conservation on the ground, as if they were saving for later periods (McCree and Fernandez, 1989; Taiz and Zeiger, 1991).

For Petry (1991), the importance of maintaining turgor is to allow the cells were continuity of plant growth processes, expansion, photosynthesis and cell division.

According to Ghorashy *et al*. (1971), the apparent linear decrease of photosynthesis, the net photosynthesis and transpiration and are reduced when the water potential of the common bean leaves attain the range -0.3 and -0.5 MPa and is practically nil when between - 0.9 to -1.0 MPa (Guimaraes, 1988).

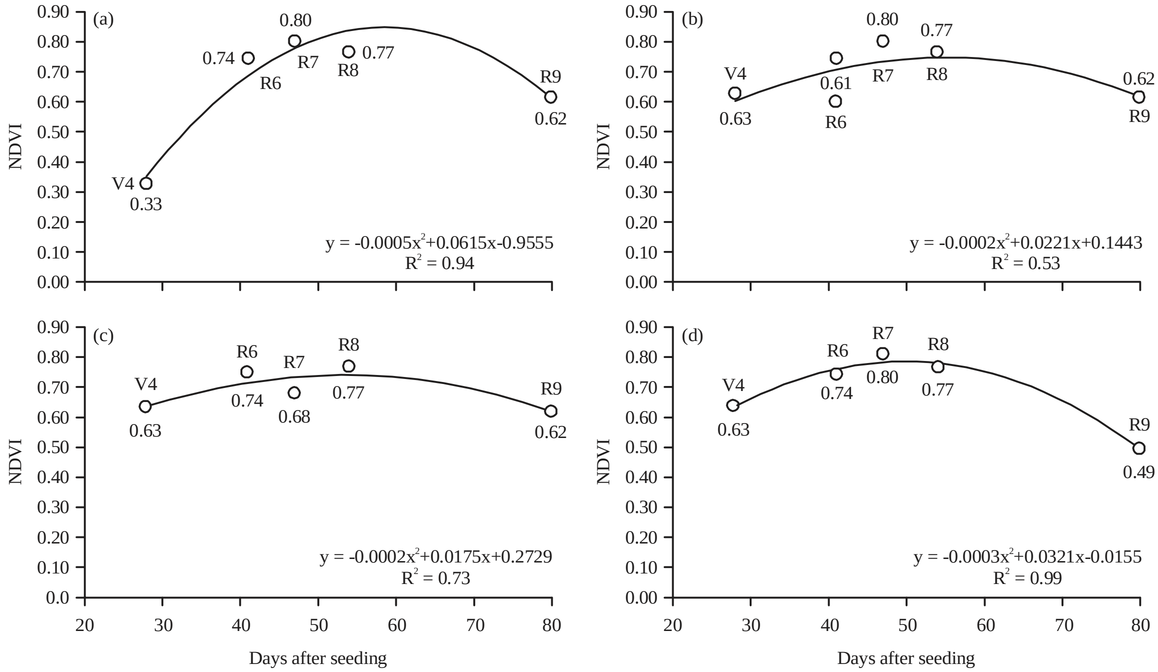

Fig. 7(a-d): Average NDVI values depending on water stress in (a) 28, (b) 41, (c) 47 and (d) 80 days after seeding of in their phenological stages V4, R6, R7, R8 and R9 of the bean crop

Millar and Gardner (1972) also found that stomatal resistance of the upper face of the leaves increased with the reduction of water potential to 0.8 MPa and that this point coincides with the rapid decrease of the yield of dry matter. Among the similar behavior between net photosynthesis and transpiration under water stress conditions, O'Toole *et al*. (1977) concluded that stomatal aperture is the factor of photosynthesis controller. However, increased resistance of mesophyll and the decrease of the ribulose 1,5-diphosphate carboxylase activity (RuDPc), low water potential in conditions, stomatal suggest that factors are involved in reducing photosynthesis.

According to Knipling (1970), when the water fills the air cavities form a liquid medium on the sheet causing significant changes in bean leaves. In the infrared region, it is evident that the internal reflection mechanism of sheets because there is a drastic reduction of the reflectance of a leaf infiltrated with water.

Therefore, the water deficiency causes decreased budding and pollination reflecting the low grain yield by abortion pods (Ritchie, 1981). Thus, it is possible to infer that there was a pattern of photosynthetic activity in bean crop under water stress at different growth stages, made by the regression models. The behavior of the NDVI, based on the bands from near and visible infrared, identified the presence of water stress and stress in different phenological stages studied except for the R8 before the development cycle of the bean crop.

CONCLUSION

The vegetation index NDVI identified the presence of water stress and stress in different phenological stages studied before the bean crop development cycle, possessing strong correlation except for the R8.

However, studies using digital cameras with a view to identifying the water conditions of the plants are ignorant, necessitating further studies in order to identify the water condition of plants.

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