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Canopy Reflectance Indices and its Relationship with Yield in Common Bean Plants (*Phaseolus vulgaris* L.) with Phosphorous Supply

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ABSTRACT

Common bean plants (*Phaseolus vulgaris* L.) were grown under three phosphorous levels (0, 100 & 200 kg ha^{-1}) and under rain fed conditions with the objective to examine the association between vegetative indices (NDVI, normalized difference vegetation index; & GNDVI, green normalized difference vegetation index) and intercepted radiation, leaf area index, biomass and yield during the growing season. The maximum intercepted radiation, leaf area index (LAI) and biomass were reached during the pod filling stage {80 days after sowing (DAS)}, and the P treatment of 200 kg ha^{-1} showed the highest values. The high intercepted radiation was derived from an increase in LAI inducing a major biomass accumulation. Near to physiological maturity LAI decreased as a result of leaf abscission. NDVI and GNDVI were higher with P supply than without P at anthesis and pod filling stage (50 - 80 DAS). Near to physiological maturity NDVI and GNDVI decreased in all the treatments. When the maximum intercepted radiation, LAI, and biomass production were reached during anthesis and pod filling stage, NDVI and GNDVI also had the highest values. The association between the vegetative indices and seed yield during the pod filling stage showed a linear relationship by the P supply. The relationship between GNDVI and seed yield was higher (r^2 = 0.77) than the relationship between NDVI and seed yield (r^2 = 0.61).

Key Words: Near infrared; Normalized difference vegetation index; Green normalized difference vegetation index; Canopy reflectance
Abbreviations: NDVI = Normalized vegetation difference index; GNDVI = Green normalized vegetation difference index.

INTRODUCTION

Phosphorus (P) is one of the most important elements for crop growth. It is a component of many cell constituents and plays a major role in several physiological processes including photosynthesis, respiration, energy storage and transfer, cell division, and cell enlargement (Föhse *et al.*, 1988; Blevins, 1995). Also, P is necessary for seed formation, and it is an essential element in nodule metabolism in legumes (Bethlenfalvay & Yoder, 1981; Ibijbijen *et al.*, 1996).

P is the second most crop limiting nutrient in most soils, and most cropping systems require supplemental P to maximize their yield potential. Bean plants (*Phaseolus vulgaris* L.) showed a strong yield increase due to different rates of P fertilizer in field trials (Föhse *et al.*, 1988; Singh & Singh, 2002; Roy & Partasaranthy, 2003). Variability among *P. vulgaris* genotypes in harvest index, and grain yield has been evaluated in relation to nitrogen and P fertilization (Araújo & Teixeira, 2003). The symbiotic N_2 fixation under P deficiency also has been assessed in common bean plants (Vadez *et al.*, 1999). The growth and yield of *P. vulgaris* genotypes was evaluated under P deficiencies in different soil types (Yan *et al.*, 1995).

The crop growth can be assessed using canopy reflectance indices (remote sensing techniques) linked with yield traits (Wiegand *et al.,* 1991; Araus *et al.*, 2001). The most commonly known index for analyzing vegetation is the normalized difference vegetation index (NDVI; R_{900} - R_{680}/R_{900} + R_{680}) (i.e. Araus *et al.,* 2001). It is used as an indirect assessment of canopy biomass, leaf area index, light-absorption, and potential photosynthetic capacity (i.e. Gamon *et al.,* 1995; Peñuelas, 1998; Araus *et al.,* 2001). Alternatively, Gitelson *et al.* (1996) proposed the use of the green normalized difference vegetation index (GNDVI, R_{780} - R_{550}/R_{780} + R_{550}), which may prove to be more useful for estimating green crop biomass.

By periodic measurements of NDVI during the growing cycle of a crop, the agronomic yield has been predicted in wheat (Rudorff & Batista, 1990) and corn (Wiegand *et al.,* 1991). NDVI and GNDVI were associated with yield and biomass among bread wheat genotypes (Gutiérrez-Rodríguez *et al.,* 2004b). In a previous study with *Phaseolus vulgaris* grown under three nitrogen levels

(0, 100 & 200 kg nitrogen ha^{-1}) we found a positive association between NDVI and seed yield (Gutiérrez-Rodríguez *et al.*, 2004a). However, there are not studies related with the use of spectral reflectance indices to assess the crop growth of *P. vulgaris* varying P supply under field conditions.

In the present study, common bean plants (*Phaseolus vulgaris* L.) were grown under three phosphorous levels (0, 100, & 200 kg ha^{-1}) and rain fed conditions to: (i) examine the association between vegetative indices (NDVI & GNDVI) and intercepted radiation, leaf area index, and biomass during the growing season; and (ii) determine the relationship between vegetative indices and seed yield by the P supply.

MATERIAL AND METHODS

The study was carried out in Montecillo, Mexico (19°19' N, 98°54' W, 2250 m above sea level) with a temperate climate, and a fluvisol soil (FAO, 1974). Seeds of *Phaseolus vulgaris* L. cv. Flor de Durazno were sown in a plant density of 25 plants m^{-2} under rain fed conditions (June-September, 2001). During seed sowing, three P rates were applied (0, 100 & 200 kg of P_2O_5 ha^{-1}) given as triple superphosphate, and a nitrogen level of 100 kg of nitrogen ha^{-1} as urea in all the treatments. The experimental design was a random block with four replications.

Canopy reflectance was measured from 350 to 1100 nm using a FieldSpec spectroradiometer (Analytical Spectral Devices, Boulder, CO). All data collected were expressed as spectral reflectance after standardization by radiance of a leveled reference standard ($BaSO_4$) (Labsphere Inc., North Sutton, USA). Canopy reflectance measurements were taken 0.5 m above the canopy with a 10° field of view foreoptic, and were taken at random places on cloud-free days near solar noon. The measurements were taken on different occasions during the growing season corresponding to distinct phenological stages; four leaf stage (25 DAS [days after the sowing]), appearance of racimes (32 DAS), appearance of floral buds (39 DAS), beginning of anthesis (50 DAS), pod filling stage (80 DAS), and late pod filling stage (90 DAS).

SR indices were calculated following the equations with the wavelength (nm) described by several authors; NDVI = R_{900} - R_{680}/R_{900} + R680 (Araus *el al.,* 2001); and GNDVI = R_{780} - R_{550}/R_{780} + R_{550} (Gitelson *et al.,* 1996).

Leaf area index (LAI), and intercepted radiation were determined on the same dates when spectral reflectance was taken on the canopy. All the trifoliate leaves were removed from the shoot to measure area using a leaf area meter Licor LI- 3100 (Licor Instruments, NE). Leaf area index was calculated as follows: LAI = leaf area per plant*plant density/land area.

Intercepted radiation (400 - 700 nm) was measured with a line quantum sensor model LI- 1915B (Licor Instruments, NE) collocated in a perpendicular orientation to the rows. The radiation (µmols m^{-2} s^{-1}) was measured above and at the base of the canopy, and the intercepted radiation was calculated following the equation described by Adams and Arkin (1977):

*Transmitted radiation = radiation above the canopy*100/radiation under the canopy, and Ground cover = 100 -Transmitted radiation*

At physiological maturity, aboveground biomass and seed yield were determined in every plot. Other yield components also were determined such as seed number, seed weight, pod number, and seeds per pod. The samples were oven-dried, weighed, and threshed, and the seed weight was recorded.

Meteorological data (maximum & minimum temperature, & precipitation) were recorded during the growing season.

Coefficient of determination (r^2) and analysis of variance were carried out using SAS procedure (SAS Institute, 1990).

RESULTS

The length of the growing season was 98 days (physiological maturity) after the sowing date, and there were no differences in phenology as a result of the P fertilization. The beginning of anthesis was reached at 50 DAS, and mid pod filling stage around 80 DAS.

The precipitation accumulated during the growing season was 445 mm, and mean daily temperature oscillated from 11 to 20°C.

Biomass and yield. Pod and seed number were increased by the P fertilization (100 & 200 kg ha^{-1}) and they had a direct influence in seed yield (Table I). Seed per pod and the weight of 100 seeds did not show differences among the three P treatments. Biomass also showed an increase from P fertilization.

Intercepted radiation, leaf area index (LAI), and biomass. Intercepted radiation showed differences after 50 DAS (Fig. 1a). The maximum intercepted radiation was reached during the pod filling stage (80 DAS). The

Table I. Yield of common bean plants (*Phaseolus vulgaris* L.) cv. Flor de Durazno grown under three phosphorous levels and rain fed conditions

Phosphorous (Kg ha^{-1})	Pod number	Seeds pod^{-1}	Seeds m^{-2}	100 seeds (g)	Seed yield (g m^{-2})	Biomass (g m^{-2})
0	337.5 c†	3.6 a	581.5 c	42.3 a	245.7 c	851.7 c
100	405.0 b	3.7 a	744.0 b	43.3 a	322.5 b	932.4 b
200	450.0 a	3.8 a	1044.0 a	44.9 a	468.1 a	1058.8 a
MSD	63.81	0.38	35.91	2.26	15.51	36.37

† Means with different letters are significantly different from one another ($p \leq 0.05$), (n=4). MSD, Minimum Significant Difference.

200 kg ha^{-1} treatment showed the highest value (80%), the 100 kg ha^{-1} treatment showed 74% and the control treatment 68%. The high intercepted radiation associated with P supply was derived from an increase in LAI inducing a more biomass accumulation (Fig. 1b, c). Higher biomass production also occurred at the pod filling stage. The treatment of 200 kg ha^{-1} had the highest biomass (1059 g m^{-2}) at physiological maturity (98 DAS), while the other treatments accumulated less biomass (932 g m^{-2} for 100 kg ha^{-1}, & 852 g m^{-2} for 0 kg ha^{-1}) (Fig. 1c).

Leaf abscission occurred when the plants started to maturate, and intercepted radiation, LAI, and biomass decreased after 90 DAS in all the treatments reflecting the difference in the P supply.

Vegetative indices (NDVI and GNDVI). NDVI did not show differences in early growth stages due to P supply (Fig. 2). But 100 and 200 kg ha^{-1} treatments showed higher NDVI than the treatment without P at anthesis and pod filling stage (50 - 80 DAS). Near to the physiological maturity NDVI decreased in all the treatments.

GNDVI showed a similar tendency as NDVI. It increased from early growth stages (less than 50 DAS) and reached a maximum at pod filling stage (80 DAS) (Fig. 2). The P supply increase GNDVI from anthesis to pod filling (50 - 80 DAS). Near to the physiological maturity GNDVI also decreased.

Association between vegetative indices and intercepted radiation, leaf area index, and yield. The relationships between vegetative indices (NDVI & GNDVI) and intercepted radiation, LAI and biomass is shown in the Fig. 3. During early growth stages the vegetative indices and the other parameters (intercepted radiation, LAI, & biomass) increased until reaching a maximum at anthesis and pod filling stage (50 - 80 DAS). The treatments of 100 and 200 kg P ha^{-1} were always higher than the treatment without P.

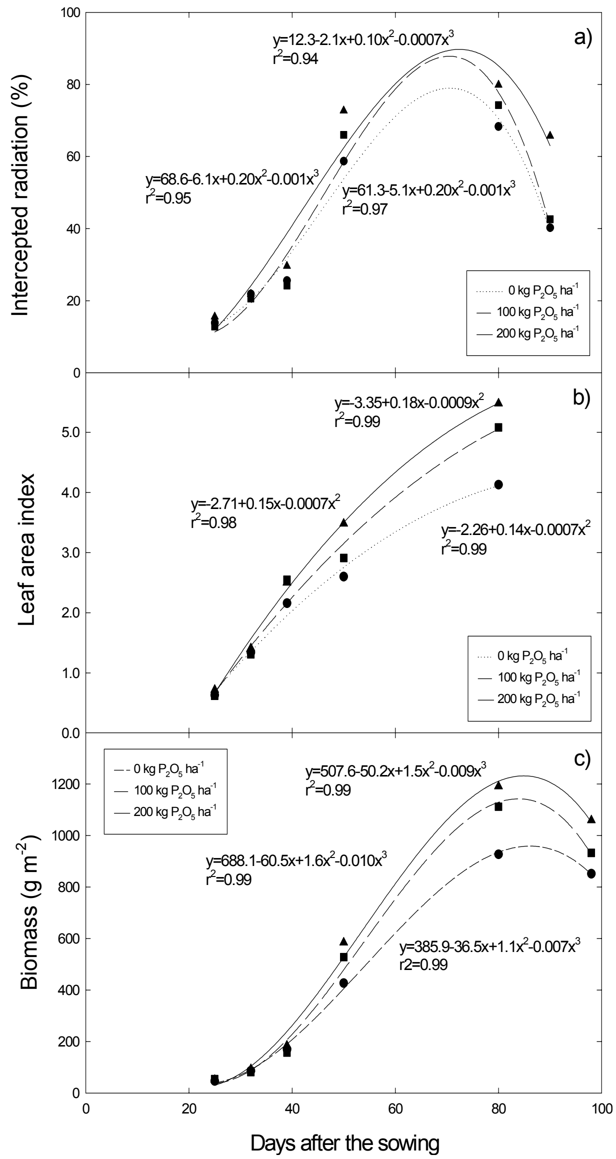
The association between the vegetative indices and intercepted radiation, and biomass showed an increase in early stages and a decrease near to the physiological maturity due to leaf abscission (Fig. 3a, b, e & f). The association between vegetative indices and LAI (except at physiological maturity) was described with a quadratic model showing an r^2 that ranged from 0.76 - 0.85 and 0.88 - 0.95 for NDVI and GNDVI, respectively (Fig. 3c, d).

The association between the vegetative indices (NDVI & GNDVI) and seed yield during the pod filling stage showed a linear relationship associated with P supply. The relationship between GNDVI and seed yield was higher (r^2 = 0.77) than the relationship between NDVI and seed yield (r^2 = 0.61) (Fig. 4).

DISCUSSION

The P supply (100 & 200 kg ha^{-1}) increased yield of common bean plants grown under rain fed conditions (Table I). The P treatment of 200 kg ha^{-1} showed the highest seed

Fig. 1. Intercepted radiation, leaf area index, and biomass during the growing season of common bean plants (*Phaseolus vulgaris* L.) cv. Flor de Durazno grown under three phosphorous levels, and rain fed conditions



yield, and biomass. Several studies have demonstrated that P fertilization increases seed yield and dry matter in common bean plants (Föhse *et al.*, 1988; Singh & Singh, 2002; Roy & Partasaranthy, 2003).

Association between vegetative indices and intercepted radiation, leaf area index and yield. Both vegetative indices (NDVI & GNDVI) showed a similar tendency during the growing season of common bean plants grown under three P treatments (Fig. 2, 3). The P treatments of 100 and 200 kg ha^{-1} gave higher NDVI values than the zero P treatment. The maximum values of NDVI were reached during the pod filling stage (80 DAS) when

Fig. 2. NDVI (normalized difference vegetation index), and GNDVI (green normalized difference vegetation index) during the growing season of common bean plants (*Phaseolus vulgaris* L.) cv. Flor de Durazno grown under three phosphorous levels and rain fed conditions.

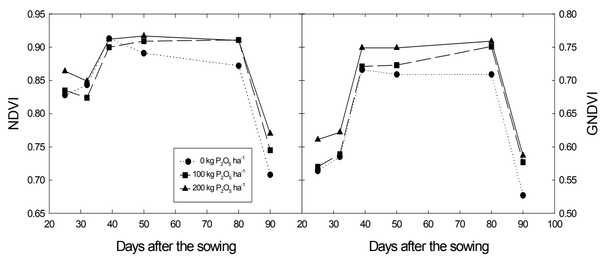
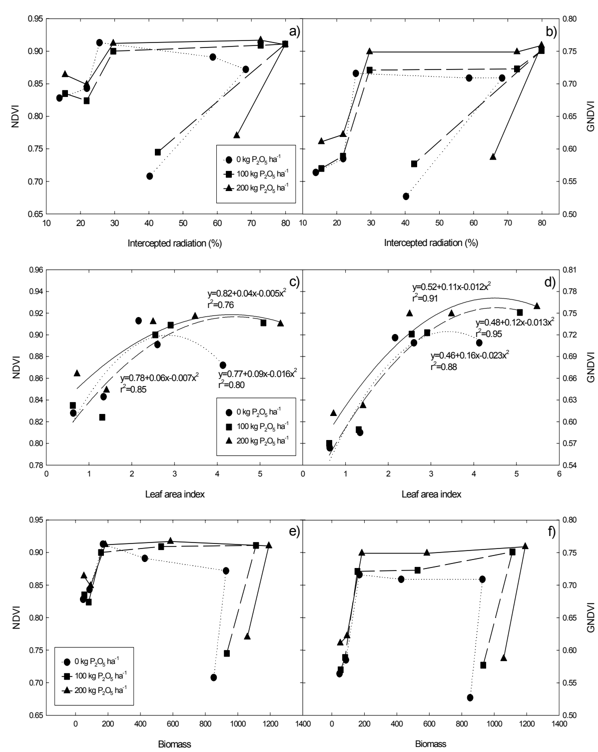


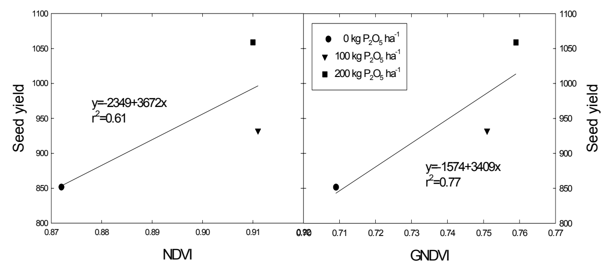
Fig. 3. Relationships between vegetative indices (NDVI and GNDVI) and intercepted radiation, leaf area index, and biomass during the growing season of common bean plants (*Phaseolus vulgaris* L.) cv. Flor de Durazno grown under three phosphorous levels and rain fed conditions



intercepted radiation, LAI, and biomass had the highest values. Other studies have found that NDVI and GNDVI are increased in early stages reaching a maximum during anthesis and decreased near to the physiological maturity (Aase & Siddoway, 1981; Shanahana *et al.*, 2001).

Although the association between the vegetative indices and intercepted radiation and biomass was not

Fig. 4. Relationship between vegetative indices (NDVI and GNDVI) and seed yield at the pod filling stage (80 days after the sowing) in common bean plants (*Phaseolus vulgaris* L.) cv. Flor de Durazno grown under three phosphorous levels and rain fed conditions



explained with a model, they were associated. When maximum intercepted radiation, LAI and biomass production are reached during anthesis and pod filling stage, NDVI and GNDVI also had the highest values. Both indices showed a positive correlation with LAI measured until pod filling stage with a quadratic model (r^2 ranged from 0.76 to 0.85 for NDVI, & from 0.88 to 0.95 for GNDVI) (Fig. 3). Several studies have found that NDVI can be associated with yield; for example, NDVI measured at any crop stage is highly associated with yield in durum wheat genotypes under rain fed conditions in several environments (Royo *et al.,* 2003). In another study, grain yield was highly positively correlated with NDVI in soybean genotypes (r^2 up to 0.80) during the reproductive stage (Ma *et al.,* 2001). In a previous study, we found a positive association between NDVI and seed yield in common bean plants varying nitrogen levels. In the current study, the two vegetative indices showed an association with seed yield during the pod filling stage (Fig. 4). The relationship between NDVI and seed yield was weaker ($r^2 = 0.61$) than the relationship between GNDVI and yield ($r^2 = 0.77$). The index GNDVI has been reported for estimating green canopy biomass and grain yield in corn varying nitrogen levels (Gitelson *et al.,* 1996). Shanahana *et al.* (2001) found in maize hybrids that the relationship between GNDVI and yield was higher ($r^2 = 0.50 - 0.85$) than NDVI and yield (< 0.50) during the grain filling stage. In another study, we found a positive relationship between yield and NDVI and GNDVI in wheat genotypes (Gutierrez-Rodriguez *et al.*, 2004b). In our study, GNDVI had a stronger relationship than NDVI with yield during the growing season of common bean plants grown under different levels of P supply, and this is the first study reporting the association for common bean plants.

CONCLUSIONS

The P supply increased yield and biomass in common bean plants grown under rain fed conditions, and the vegetative indices (NDVI & GNDVI) showed association with intercepted radiation, leaf area index, and biomass during the growing season. GNDVI had a higher relationship than NDVI with seed yield at the pod filling stage varying P supply. The vegetative indices could be used to identify high agronomic yield in common bean plants varying P supply, and they provide additional analytical tools for interpreting crop growth, and yield.

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