

Physiological and Yield of Soybean Under Kayu Putih (*Melaleuca cajuputi* subsp. *cumingiana*) Stands with N, P, and K Fertilization on *Lithic Haplustert*

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ABSTRACT

Fertilization of N, P, and K on soybean planted under *Kayu Putih* stands to serve to increase soil nutrients. *Lithic Haplustert* is a subgroup of Vertisol with a relatively low fertility and organic matter with a heavy clay texture. This research aims to determine the response of soybean to the application of N, P, and K fertilizers on the *Lithic Haplustert* in physiology and yield. This research was conducted from February to May 2015 in the Srikoyo hamlet, Menggoran village, Playen district, Gunungkidul regency, Yogyakarta. The experimental design is split-split plot with three levels of fertilization of N (0, 25, 50 kg urea ha⁻¹), P (0, 150, 300 kg SP-36 ha⁻¹), and K (0, 75, 150 kg KCl ha⁻¹). The results showed that the application of 50 kg urea ha⁻¹ and 300 kg SP-36 ha⁻¹ can increase the leaf area and photosynthesis rate. Dosage 150 kg KCl ha⁻¹ fertilizer increased the concentration of N, P, and K in the plant tissues significantly.

Keywords: Soybean; Fertilizer; Photosynthetic rate; Vertisol

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INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is one of the most important crops worldwide. It is a particularly important source of protein (35-40%) and vegetable oil for most people in the world (Day 2013; Janagard et al. 2013). The increase in the world population will increase food needs. World soybean production increased by 4.6% from the year 1961 to 2007 and is expected to continue to increase every year (Masuda and Goldsmith 2009). The increase of soybean production can only partly be attained using the available land under forestry bringing to agriculture (Gibbs et al. 2010; Tschardt et al. 2012).

The soil is the medium for plants to grow. In addition, the soil has a role in providing nutrients for plants. Many kinds of soil fertility vary depending on the environment and the soil-forming material. Soil classification has been done to make it easier to understand the types of soil in the world, one of which soil classification systems conducted by the United States Department of Agriculture (USDA). *Lithic Haplustert* is a subgroup of Vertisols that have Lithic contact within 50 cm of the mineral soil surface. Boundaries Lithic contact between

the ground and underlying material is coherent, while Ustert (soil moisture regime Ustic) is Vertisol which, if not irrigated throughout the year, had a crack width of 5 mm or more, reaching a thickness of 25 cm or more within 50 cm of the mineral soil surface, for a cumulative 90 days or more each year in normal years (Soil Survey Staff 2014). This causes the Vertisol to have low fertility rates such as nitrogen, phosphorus, potassium, and organic matter content to affect the growth of soybean (Novelli et al. 2011).

The response of soybean plants to deficient nitrogen (N) would affect the photosynthetic process and growth. The growth parameters such as LAI, plant biomass, and leaf photosynthesis reduced due to limited nitrogen availability (Valentine et al. 2018). Phosphorus is the second important element that limits plant growth in the case of unavailability. The most important phosphorus sources in arable soils are chemical fertilizers, but 75 to 90 percent of the phosphorus combines with Fe, Ca, and Al in soil (Ao et al. 2014). Phosphorus (P) deficiency will affect soybeans leaf initiation stage (Singh and Reddy 2016).

The main role of potassium is to activate many enzymes in plants, and such enzymes act as a catalyst for making materials such as starch and protein. Potassium also plays a role in photosynthesis, osmotic adjustment, cell growth, stomatal regulation, water

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system of the plant, downloading hydrocarbons made in the leaves into the phloem, transporting them within the plant, anion cation balance, and as accompanying cation in nitrogen transfer (Motaghi and Nejad 2014). Potassium (K) deficiency will affect the yield and quality of seed production (Putra, Saporso, Rohadi, et al. 2019). Fertilization management is needed to provide the availability of nutrients in the Vertisol, especially nitrogen (N), phosphorus (P), and potassium (K) (Putra, Saporso, Suparto, et al. 2019). This study aimed to determine the physiological responses that affect the soybean yields with the application of N, P and K fertilizers in the *Lithic Haplustert*.

MATERIALS AND METHODS

Site description

The research was conducted from February to May 2015 in the Srikoyo Hamlet, Menggoran Village, Playen District, Gunungkidul Regency, Yogyakarta (07° 55' 17,3" S, 110° 34' 35,7" E). The average of rainfall, air temperature, and air relative humidity from February to May 2015 is 215 mm/month, 26°C, and 86%, respectively. The soil profile was prepared and used to classify the soil based on the soil morphology; the result is presented in Table 1.

Table 1. Soil condition in Srikoyo Hamlet, Menggoran Village, Playen District, Gunungkidul Regency, Yogyakarta

Soil Classification	
Landform	Flat/Inter-mountain valley
Elevation	177 m above sea level
Parent material	Limestone
Land use	Cultivation of <i>Kayu Putih</i> forests and seasonal crops
Ordo	Vertisol
Sub-ordo	Ustert
Great group	Haplustert
Sub-group	Lithic Haplustert

Soil fertility and experimental treatment

Observations of soil fertility based on soil chemical and physical properties are obtained by taking soil samples at a depth of 0-20 cm and 20-40cm. Soil samples as much as 5 kg were collected at a depth of 0-20 cm and 20-40 cm, respectively. The appropriate methods used for soil properties analysis are as follows: pH H₂O (2:1), C-Organic (Walkley-Black), N-total (Kjeldahl), P-available (Olsen), Exchangeable K⁺ (Flame photometer), Exchangeable Ca²⁺ (EDTA), CEC, and base saturation (saturation with ammonium acetate 1 N pH 7.0). Results of chemical analysis of soil indicated that the pH value at a depth of 0-20 cm and 20-40 cm is 7.19 and 7.17, respectively, at the rate of a neutral condition. The content of C-organic and N-total at a depth of 0-20 cm (1.20% and 12.10%) and 20-40 cm

(1.30% and 12.11%), in a low condition. The content of P-available and exchangeable K⁺ at a depth of 0-20 cm (24.58 ppm and 0.45 cmol kg⁻¹) and 20-40 cm (30.35 ppm and 0.50 cmol kg⁻¹), these values are considered as the moderate condition. The exchangeable Ca²⁺, CEC and base saturation at a depth of 0-20 cm (45.56 cmol kg⁻¹, 55.20 cmol kg⁻¹ and 86.67%) and 20-40 cm (45.25 cmol kg⁻¹, 55.80 cmol kg⁻¹ and 85.43%), in a very high condition. Soil texture is considered heavy clay due to be dominated by clay at a depth of 0-20 cm (72.80%) and 20-40 cm (74.13%). The results of soil chemical and physical properties are presented in Table 2.

Table 2. The physico-chemical analysis of soil before application of fertilizer

Soil Properties	Depth		Rating
	0-20 cm	20-40 cm	
pH H ₂ O	7.19	7.17	Neutral
C-Organic (%)	1.20	1.30	Low
N (%)	0.10	0.11	Low
P-available (ppm)	24.58	30.35	Moderate
Exch. K ⁺ (cmolkg ⁻¹)	0.45	0.50	Moderate
Exch. Ca ²⁺ (cmolkg ⁻¹)	45.56	45.25	Very High
CEC (cmolkg ⁻¹)	55.20	55.80	Very High
Base saturation (%)	86.67	85.43	Very High
Texture	-	-	
- Clay (%)	72.80	74.13	Heavy Clay
- Silt (%)	11.95	12.00	
- Sand (%)	15.25	13.87	

The experimental treatments were arranged in a split-split plot design with Latin Square Design (LSD) as an environmental experiment. The main plot, subplots, and sub-sub plots are fertilization of urea (N), SP-36 (P), and KCl (K), respectively. Each one of fertilization consists of three levels (0, 25, 50 kg urea ha⁻¹), (0, 150, 300 kg SP-36 ha⁻¹) and (0, 75, 150 kg KCl ha⁻¹).

Measurement of physiological variables

The soybean variety used is Grobogan. The physiological parameters were observed until 63 days after sowing, while the yield components were determined at 72 days after sowing. The parameters of physiological processes and yield components were determined using the appropriate methods. Leaf area (m²) was determined by using a leaf area meter, N, P, and K concentration of plant's tissue (%) was determined by using samples of the leaf, photosynthetic rate (μmol CO₂ m⁻² s⁻¹) was determined by using photosynthetic analyzer type LI-COR LI 640.

Data analysis

Data were analyzed using the analysis of variance (ANOVA) at 5% and 1% levels with SAS 1.9 software. The relationship between variables was obtained using regression analysis. A stepwise regression analysis was used to determine the physiological parameters that affect the yield and yield components (SAS Institute Inc. 2001).

RESULTS AND DISCUSSION

Soybean treated with nitrogen (N) and phosphorus (P) fertilizers on *Lithic Haplustert* showed a positive response in the expansion of leaves. Leaves are the primary photosynthetic organs of the plant in which the process of change of light energy into chemical energy and the production of carbohydrates in dry matter occurred. The combination rates of 50 kg urea ha⁻¹ and 300 kg SP-36 ha⁻¹ produced a maximum leaf area of 0.25 m² (Figure 1). The leaf area is strongly influenced by environmental factors, among which the light and the availability of N and P in the soil (Suryanto et al. 2017). Sunlight is optimally obtained by soybeans because there is no shade produced by *Kayu Putih*. The foliage pruning to harvest *Kayu Putih* causing no shade effects in the area of soybeans fields (Suryanto et al. 2017). The photosynthetic rate also increased at the application rates of 50 kg urea ha⁻¹ and 300 kg SP-36 ha⁻¹ is about 41.22 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ (Figure 1).

The relationship between leaf area and photosynthetic rate in various N and P rates shows a linear curve (Figure 2); thus, increasing the leaf area will be followed by an increase in the photosynthetic rate. Photosynthetic rate is one of the physiological variables related to crop production. During photosynthesis, the necessary light and nitrogen (N) are an ingredient in the photosynthetic process. Chlorophylls, as the light receptor in photo-systems II and I, need the nitrogen (N) (Oliveira et al. 2013). The light reaction in the photosynthetic process will generate ATP and NADPH-requiring Phosphorus (P) as an ingredient. Nitrogen (N) and phosphorus (P) are indispensable plants in the photosynthetic process as a constituent of chlorophyll and the establishment of energy used when carrying out the photosynthetic process, so that when the content of these two elements in plant's tissues increases, will optimize photosynthetic rate (Reich et al. 2009; Domingues et al. 2010).

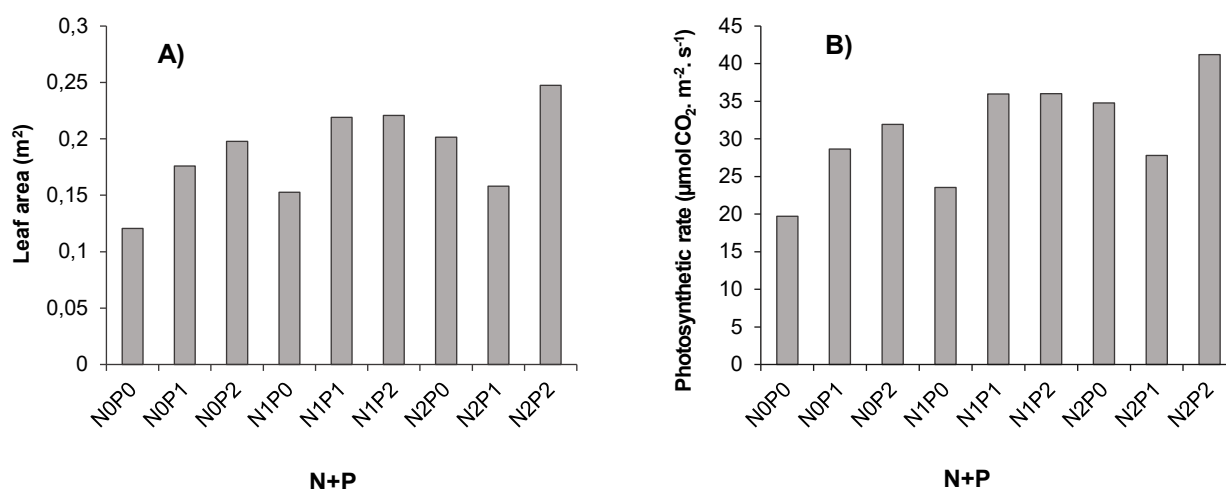


Figure 1. A) Leaf area and **B)** Photosynthetic rate at various N and P fertilizer combinations: N0P0= 0 kg urea ha⁻¹ and 0 kg SP-36 ha⁻¹, N0P1= 0 kg urea ha⁻¹ and 150 kg SP-36 ha⁻¹, N0P2= 0 kg urea ha⁻¹ and P 300 kg SP-36ha⁻¹, N1P0= 25kg urea ha⁻¹ and 0 kg SP-36 ha⁻¹, N1P1= 25 kg urea ha⁻¹and 150 kg SP-36 ha⁻¹, N1P2= 25 kg urea ha⁻¹and 300 kg SP-36 ha⁻¹, N2P0= 50 kg urea ha⁻¹ and 0 kg SP-36 ha⁻¹, N2P1= 50 kg urea ha⁻¹ and P 150 kg SP-36 ha⁻¹, N2P2= 50 kg urea ha⁻¹ and 300 kg SP-36 ha⁻¹

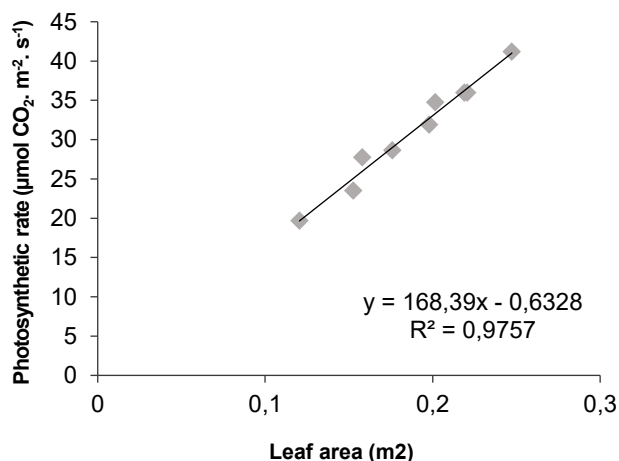


Figure 2. Relationship between Leaf Area and the Photosynthetic Rate in a Combination of N and P Fertilization Treatment

When N, P, and K fertilizer's application rate increased, the concentration of these three elements in the tissues also increased (Figure 3). Less than optimal availability of N, P, and K in the *Lithic Haplustert* given thought to cause fertilization could complete the lack of these elements in the soil solution. Proper management of Vertisol will result in maximum crop growth and yield (Cuvaca et al. 2015). On potato plants grown in Vertisol treated with N and P fertilizers, significantly increased the growth and yield (Zelalem et al. 2009; Putra, Sapparso, Rohadi, et al. 2019). While the process of translocation in plants is inseparable from the role of potassium (K) because, in a case of K deficiency in the soil and the plant tissue, it will interfere with the absorption of other elements such as N, P and assimilates translocation from source to sink (Kanai et al. 2011; Jati et al. 2017).

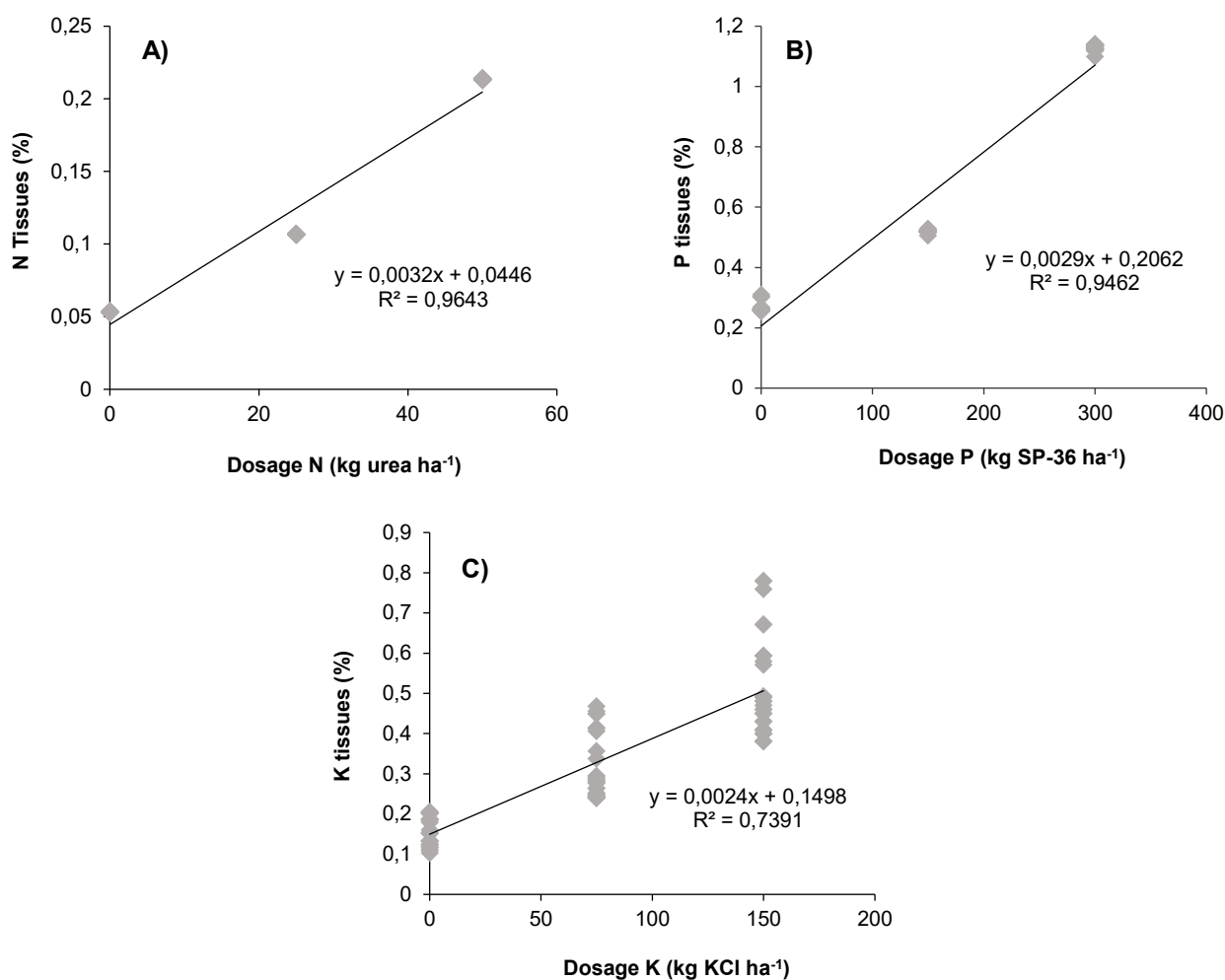


Figure 3. Relationship between the Application Rate of Fertilizer and the Concentration of **A)** Nitrogen (N), **B)** Phosphor(P) and **C)** Potassium (K) in the Plant Tissues, respectively

Physiological components affecting seed yield of soybean

The relationship is shown by physiological variables that affect the yield and yield components, i.e., the number of pods plant⁻¹, the number of seed plant⁻¹ and seed weight (g plant⁻¹) and seed yield (t ha⁻¹) are affected by photosynthetic rate and P content in tissues (Table 3). Based on equations in Table 3, as much as 22.79 pods plant⁻¹, 42.56 seeds plant⁻¹, 7.64 g seeds plant⁻¹ and seed weight of 1.95 t ha⁻¹, with a maximum photosynthetic rate of 41.22 μmol CO₂ m² s⁻¹ (Figure 1) and the maximum of concentration of P in plant's tissues of 1.08% (Figure 3) as independent variables.

One of the P roles in plant tissues for photosynthesis, is that the higher P content in the plant tissues will increase photosynthetic rate. Increasing the amount of

assimilates produced can be used to transition from the vegetative phase to the generative phase. The greater the organ of vegetative growth that serves as a producer of assimilates (source), the more the growth of the user organ (sink) will give optimum yields. Assimilates produced during the photosynthetic process then be translocated to all organs of the plant. If the soybean crop is still in the vegetative phase, then most assimilates formed in photosynthetic process will be translocated to the newly formed organs, and some will be stored as energy reserves (Putra et al. 2017). At the time soybean plants began to enter the generative phase, assimilates stored as energy reserves can be reused for the formation of seed and pods (Atkins and Smith 2007; Araújo et al. 2012).

Table 3. Stepwise regression analysis, relationship between physiological and yields components of soybean

Dependent Variable	Independent Variable	R ²
Yield Component	Physiological Component	
Number of pods plant ⁻¹	Y = 16.20** + 0.16**(Pr)	0.15**
Number of seeds plant ⁻¹	Y = 31.02** + 0.28**(Pr)	0.12**
Seed weight plant ⁻¹	Y = 4.41** + 0.05**(Pr) + 1.09*(P)	0.19**
Seed yield	Y = 1.20** + 0.01*(Pr) + 0.32*(P)	0.17**

Based on the results of the regression analysis [Figure 4](#), the relationship between the number of pods plant⁻¹ and seeds plant⁻¹ showed a linear curve. Increasing the number of pods plant⁻¹ will be followed by an increase in the seeds plant⁻¹.

[Figure 5](#) and [Figure 6](#) show a linear relationship between the number of seeds plant⁻¹ with seed weight (g plant⁻¹) and seed weight (g plant⁻¹) with seed yield (t ha⁻¹). The Increasing number of seeds plant⁻¹ will produce a high seed weight (g plant⁻¹). While the increase in seed weight (g plant⁻¹) will produce high seed yield (t ha⁻¹).

In soybean crops, pods and seeds are formed during the flowering period. Pods are one of the accumulations

of the photosynthetic process in addition to the seed. The accumulation of photosynthate strongly influences the weight of the seed. The photosynthetic process results in pods can be maximized if the availability of water and plant nutrients is provided during photosynthesis. The pods are produced will be filled by assimilates formed in the photosynthetic process for seed formation. The number of formed seeds will depend on the number and size of the pod, so the more pods formed, the seed will also be an increase ([Saeed et al. 2007](#); [Khajudparn and Piyada 2013](#)). A significant relationship between the number of pods formed and the number of seeds is also found in Mung bean (*Vigna radiata L.*).

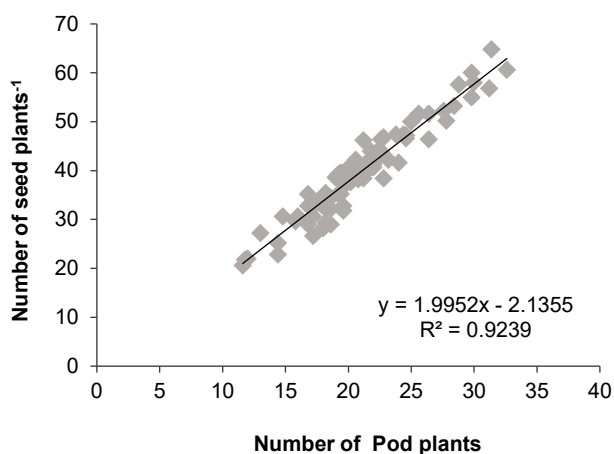


Figure 4. Relationship between number of pods plant⁻¹ and number of seeds plant⁻¹

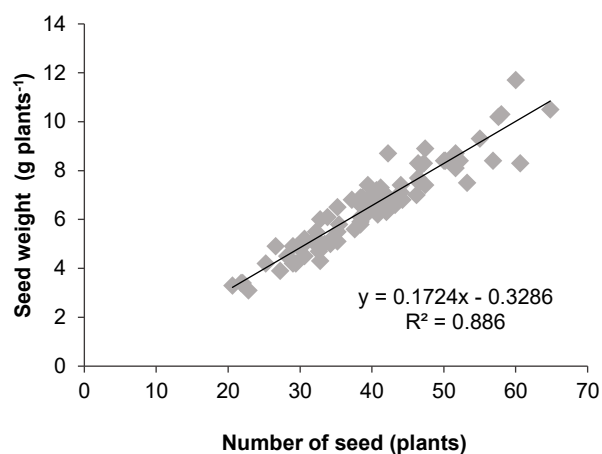


Figure 5. Relationship between number of seeds plant⁻¹ and seed weight (g plant⁻¹)

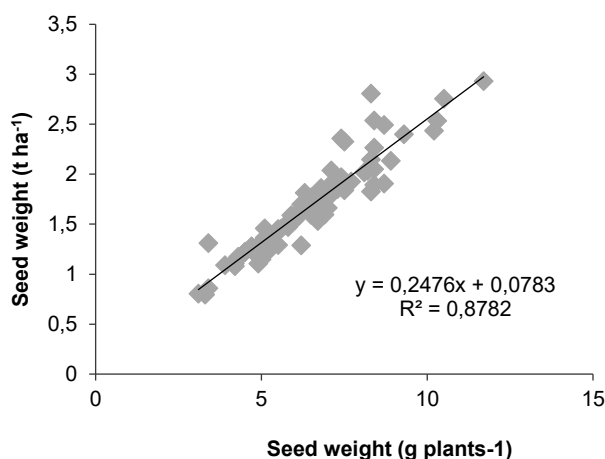


Figure 6. Relationship between Seed Weight (g plant⁻¹) and Seed Yield (t ha⁻¹)

CONCLUSIONS

The application of 50 kg urea ha⁻¹ and 300 kg SP-36 ha⁻¹ can increase the leaf area and photosynthesis rate. Dosage 150 kg KCl ha⁻¹ fertilizer significantly increased N, P, and K concentrations in the plant tissues. There is a linear relationship between Number of Pods plant⁻¹ and Number of Seeds plant⁻¹, Number of Seeds plant⁻¹ and Seed Weight (g plant⁻¹), Seed Weight (g plant⁻¹), and Seed Yield (t ha⁻¹).

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