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Study of the Macronutrient Elements Content in the Soil at a Fertilizer Experiment with Soybean (*Glycine max* (L.) Merr.)

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Abstract— *In the current research has been followed the impact of six fertilizer products on the content of macronutrient elements (nitrogen, phosphorus and potassium) in the soil during a vegetation and after harvesting of the grain-leguminous crop soybean. The experiment is brought out on a training-experimental field of Department „Plant Production" to Technical university – Varna with variety PR91M10 as per the generally accepted methods for specifying the content of ammonium and nitrate nitrogen, mobile phosphates, absorbable potassium and pH. The agrochemical analyses show that after bringing in of MAP are established higher values of ammonium and nitrate nitrogen in the soil during vegetation of the soybean, while after its harvesting the highest content of ammonium nitrogen is reported in the variant, which has been fertilized with NPK, and of nitrate – with urea. Regardless of the used fertilizer product, after the harvesting of the soybean has been reported lower content of ammonium and nitrate nitrogen. At usage of MAP has been established higher content of mobile phosphates in the soil during vegetation of the soybean and after its harvesting, as the differences between MAP and the rest variants are statistically reliable. The values of phosphorus in the soil after collecting of the soybean are higher in four of the experimental plots, as at the variants, which have been fertilized with fertilizers, containing phosphorus (MAP, DAP and NPK) the difference is more substantial. The statistical analysis has not established proof of the differences between the variants as per content of absorbable potassium in the soil. The tendency is analogous as the exposed at the mobile phosphates, something more, in all variants of the experiment the values after harvesting are higher than the reported during vegetation.*

Keywords— nitrogen, phosphorus, potassium, soil, soybean.

I. INTRODUCTION

The three most important nutrient elements for the plants in the agro-ecosystems are nitrogen, phosphorus and potassium [1]. Usually nitrogen is the most limiting factor for the growth of the crops and the production of seeds at the absence of water restrictions [2, 3]. The availability of nitrogen is a critical factor for generating of leaves and photosynthetic fixation of the carbon [4]. It is known that the absorption of nitrogen is the basic lever for the crop at soybean [5, 6]. The nitric absorption of the soybean depends on two alternative nitric sources – the biological nitric fixation and soil absorption of mineral nitrogen. The relative participation of each of the sources is a result of the conditions of the environment, the applied agro-technology and genetic factors [7]. On the average, the percent of nitrogen fixation varies between 40 and 80% from the total nitric absorption [8]. This process usually is reduced under the impact of water stress [9, 10], increased temperature [11] and high nitrate content in the soil [12, 13]. The phosphorus and potassium play a significant role in the growth and development of soybean. The phosphorus is a substantial element and its application is important for the growth, development and crop of soybean [14], as it increases the photosynthetic and enzyme activity, the development of the roots, the absorption and transfer of other nutrient elements and the germination of the seeds [15]. The potassium regulates growth processes like transportation of water and nutrient elements through the cellular wall, transpiration and exchange of CO_2 through the stoma. The deficiency of this element causes retarded growth and chlorosis [16]. Potassium often restricts the crop and it is necessary to be included in the fertilizer programme as a correcting nutrient element. As a result of potassium fertilizing is reported increase of the crop at soybean [17]. The purpose of the present development is to be followed the impact of different fertilizer products on the content of macronutrient elements in the soil during vegetation and after harvesting of soybean.

II. MATERIALS AND METHODS

The experiment is brought out on a training-experimental field of Department „Plant Production" to Technical university – Varna. The experiment is set with variety

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soybean (*Glycine max* (L.) Merr.) PR91M10 (Pioneer Intl.) in two repetitions on 29 April 2015 with the following fertilizer products:

1. Ammonium nitrate (NH_4NO_3) – 34.5% N;
2. Monoammonium phosphate (MAP) – 11% N, 52% P_2O_5;
3. Diammonium phosphate (DAP) – 18% N, 46% P_2O_5;
4. Urea ($CO(NH_2)_2$) – 46 % N;
5. NPK – 14% N : 14% P_2O_5 : 14 % K_2O + 11.5% S;
6. Urea Ammonium Nitrate (UAN) – 32% N.

For bigger objectivity of the study and comparability of the results are set two control plots.

The fertilizer products are brought in before sowing-time, as the fertilizer norm is 7 kg/dka nitrogen active substance for the soybean, recalculated for each of the repetitions.

Before setting of the experiment, during the vegetation (phase R2 – complete flowering) and after harvesting of the crop are taken soil samples for each of the variants, for specifying of the content of:

- Ammonium nitrogen (NH_4 – N);
- Nitrate nitrogen (NO_3 – N);
- Mobile phosphates (P_2O_5);
- Absorbable potassium (K_2O);
- pH.

The laboratory analyses are carried out in the laboratory in pedology of Technical University – Varna.

The content of ammonium nitrogen (NH_4 – N) is specified photometrically by indophenol blue as a result of an extraction with solution of calcium dichloride ($CaCl_2$). The nitrate nitrogen (NO_3 – N) is specified photometrically by Nitrospectral as a result of extraction with solution of calcium dichloride ($CaCl_2$).

The content of phosphorus and potassium is specified as per double-lactate method of Egner-Reem. The method is based on extraction of the mobile compounds of phosphorus and potassium by a solution of calcium lactate $(CH3CH.OH.COO)_2Ca$, which is buffered by hydrochloric acid up to pH 3.5-3.7, at proportion soil-resolvent 1:50 and time of interaction 90 min.

The values of the soil reaction are measured potentiometrically by a pH-meter in compliance with the requirements of the methods for measuring pH of the soil as per the international standard ISO 10390:2011.

The obtained agrochemical data are statistically processed and the results are included in a dispersion analysis with calculation of the smallest proven difference between the variants at p = 0.05 ($LSD_{0.05}$). The values of the variational coefficients (VC) are also specified. The statistical processing is carried out with the help of programme product STATISTICA, version 10.

III. RESULTS AND DISCUSSION

The obtained data from the analysis of the soil before the bringing in of the fertilizers are: ammonium nitrogen (NH_4 – N) – 0.50 mg/kg soil, nitrate nitrogen (NO_3 – N) – 1.37 mg/kg soil, absorbable potassium – 28.67 mg/100 g soil and mobile phosphates – 2.73 mg/100 g soil. The active reaction of the soil is pH 7.7 (slightly alkaline). Consequently the soil is slightly stored with nitrogen and phosphorus, but it is with good degree of nutrient reserve regarding potassium, and the soil reaction is relatively favourabe for the development of the plants.

In Table 1 are inserted the results for the content of ammonium and nitrate ions in the studied soil samples during vegetation of soybean.

Table 1: Values of pH, content of ammonium and nitrate nitrogen in the soil during vegetation of soybean

Fertilizers	pH	Average		Coefficient of variation	
		NH_4 mg/kg	NO_3 mg/kg	NH_4 %	NO_3 %
Control	7.51	7.17	22.53	0.79	0.78
NH_4NO_3	7.67	6.99	24.31	6.77	4.33
MAP	7.55	8.48	25.66	13.04	18.90
DAP	7.86	7.34	15.45	7.13	3.71
$CO(NH_2)_2$	7.84	7.66	21.76	3.32	0.16
NPK	7.83	5.15	22.57	41.47	0.94
UAN	7.68	5.43	21.50	52.87	3.03
$LSD_{0.05}$		3.33	6.05		

The results of the soil analysis show that with highest content of ammonium nitrogen is the variant, which has been fertilized with MAP (8.48 mg/kg), followed by the variant, at which has been brought in urea (7.66 mg/kg) and DAP (7.34 mg/kg). Regarding the nitrate nitrogen the highest value is registered at the variant with MAP (25.66 mg/kg) (but with most variable data from the separate repetitions), followed by the variant with NH_4NO_3 (24.31 mg/kg) and combined fertilizers NPK (22.57 mg/kg). In the control has been established the presence of 7.17 mg/kg ammonium ions and 22.53 mg/kg nitrate nitrogen. The active soil reaction varies from pH 7.51 up to 7.86. At fertilizing with NPK has been established the lowest content of ammonium nitrogen, and lowest values of nitrate nitrogen in the soil are established at the variant with DAP. The data for content of ammonium nitrogen show statistical proof of the differences only between the variants with highest (MAP) and lowest value (NPK). Regarding the nitrate nitrogen there is available authenticity of the differences between each of the variants and DAP.

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In Table 2 are presented the data for the content of ammonium and nitrate ions in the soil after harvesting of the crop.

Table 2: Values of pH, content of ammonium and nitrate nitrogen in the soil after harvesting of the soybean

Fertilizers	pH	Average		Coefficient of variation	
		NH_4 mg/kg	NO_3 mg/kg	NH_4 %	NO_3 %
Control	7.54	1.41	0.80	62.19	35.36
NH_4NO_3	7.35	0.76	0.49	26.81	25.98
MAP	7.45	0.76	0.60	18.61	47.14
DAP	7.40	1.75	0.97	68.48	2.18
$CO(NH_2)_2$	7.72	1.93	0.99	92.93	0.71
NPK	7.53	0.74	1.78	53.51	14.30
UAN	7.55	0.54	1.26	39.28	34.10
$LSD_{0.05}$		-	0.66		

Out of the carried out analyses has been established that highest values of ammonium nitrogen there are at the variant, fertilized with urea (1.93 mg/kg), followed by the variant with brought in DAP (1.75 mg/kg), and the values, obtained at the variants with NH_4NO_3 and MAP are identical (0.76 mg/kg). In the control has been established the presence of 1.41 mg/kg ammonium nitrogen. Among the studied variants for content of ammonium nitrogen there are not statistically proven differences, as the values of the variational coefficients are the lowest in the whole experiment. Highest values for nitrate ions are reported in the experimental plots, fertilized with combined fertilizer NPK (1.78 mg/ kg), followed by the variant with brought in UAN UAN (1.26 mg/kg) and the variant with urea (0.99 mg/kg), as a statistical authenticity has been established between NPK and urea. In the control are reported 0.80 mg/kg nitrate nitrogen. Regarding the soil reaction, it varies from pH 7.35 up to pH 7.72, but within the framework of the slight alkalinity. It makes an impression, that the highest values of ammonium and nitrate nitrogen, reported during the vegetation of soybean in the plots, which have been fertilized with MAP, at the end of the vegetation after the harvesting are substituted with some of the lowest values. The common with all variants is the lower content of ammonium and nitrate nitrogen after harvesting of the soybean.

On Fig. 1 are presented graphically the data for the content of ammonium and nitrate nitrogen during the vegetation and after the harvesting of the soybean.

In series of researches is observed net depletion of soil nitrogen after harvesting of soybean. The balance of the soil nitrogen between the sowing-time and the harvesting can vary from +9 to -133 kg N ha^{-1} [18, 19, 20]. Goss et al. (2002) [21], have established, that at different levels of fertilizing with nitrogen (from 20 to 180 kg N ha^{-1}), a negative nitric balance after harvesting (from -81 to -13kg N ha^{-1}) has been established at applying of the lower levels of fertilizing.

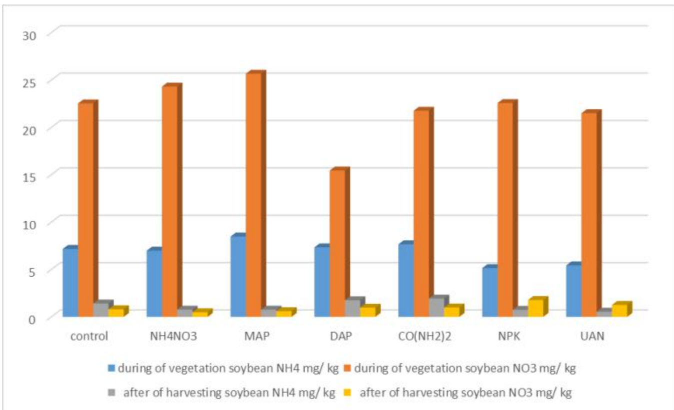

Fig.1: Comparative analysis of the content of ammonium and nitrate nitrogen during the vegetation and after harvesting of the soybean

The present results as a result of fertilizing with 70 kg N ha^{-1} correspond with earlier obtained data from other researchers and indicate for negative nitric balance after harvesting of the soybean. Besides, Bloem and Barnard (2001) [22] have established that the grain-leguminous, which produce more seeds (like soybean) leave less nitrogen in the soil, than these, which show energetic vegetative growth and produce little quantity of seeds. A possible explanation about this is that the leguminous plants, which produce more seeds transfer more nitrogen to them, while less remains in the roots for mineralization later in the soil.

In the present research during the vegetation of the soybean (phase R2 – complete flowering) has been established a higher content of nitrates in the soil. According to Streeter (1988) [23] the higher content of nitrates suppresses the symbiotic nitrogen fixation, in consequence of which from the soil is delivered mainly nitrogen for the plants, and after harvesting of the soybean there remains less nitrogen. In the world scientific literature there exist data, that besides the content of nitrates, the nitrogen fixation is reduced also from the following abiotic factors of the soil: moisture [24], pH [25] and temperature [26]. The lower results for content of nitrogen in the soil after harvesting of the soybean, obtained in the present research, can be explained and by the poor nutrient reserve of the soil with moisture during the periods of the most intensive nitrogen fixation. It is known that the maximum nitrogen fixation passes between R3 (beginning of beans formation) and R5 stage (beginning of formation of the seeds), which in the present research coincides with month July, and namely during this month has been reported minimum quantity of the precipitations (9.6 l/m^2) (Fig. 2).

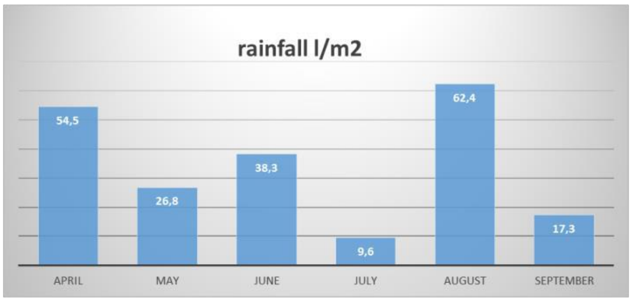

Fig.2: Average quantity of the precipitations for the experimental period

The results from the analysis of mobile phosphates during vegetation of the soybean are presented in Table 3.

Table.3: Content of mobile phosphates in the soil during vegetation of the soybean

Fertilizers	Average	Coefficient of variation
	P_2O_5 mg/100 g	%
Control	3.49	16.61
NH_4NO_3	3.35	12.24
MAP	6.49	8.72
DAP	4.09	7.95
$CO(NH_2)_2$	4.47	16.14
NPK	2.83	33.48
UAN	2.72	2.34
$LSD_{0.05}$	1.37	

High values of phosphorus have been established in the variant, which has been fertilized with MAP (6.49 mg/100 g), followed by the variants fertilized with urea (4.47 mg/100 g) and DAP (4.09 mg/100 g), as there is available statistically proven difference between MAP and the rest variants. Lowest result has been established in the variant with UAN (2.72 mg/100 g), as the data from the analysis are with lowest values of the variational coefficient. In the control have been established 3.49 mg/100 g mobile phosphates.

As a result of the carried out agrochemical analysis of the soil samples for content of phosphates after harvesting of the crop (Table 4), has been established that there are highest values of phosphates in the variant with brought in MAP (7.74 mg/100 g) and the variant, fertilized with DAP (5.49 mg/100 g), as the data between the separate repetitions are with minimum variation. There is present statistical authenticity of the difference between MAP and the rest variants once again. In the variant, with UAN there has also been reported the lowest value – 2.41 mg/100 g, and in the control – 3.62 mg/100 g.

Table 4: Content of mobile phosphates in the soil after harvesting of the soybean

Fertilizers	Average	Coefficient of variation
	P_2O_5 mg/100 g	%
Control	3.62	2.54
NH_4NO_3	2.85	23.61
MAP	7.74	1.10
DAP	5.49	2.36
$CO(NH_2)_2$	4.27	7.29
NPK	4.61	4.29
UAN	2.41	2.93
$LSD_{0.05}$	0.77	

The comparative analysis of the values of mobile phosphates (Fig. 3) is with contrary tendency to the one at the nitric forms. In four of the seven experimental plots the value of the phosphorus in the soil is higher after the harvesting of the studied grain-leguminous crop in comparison with the established values during the vegetation.

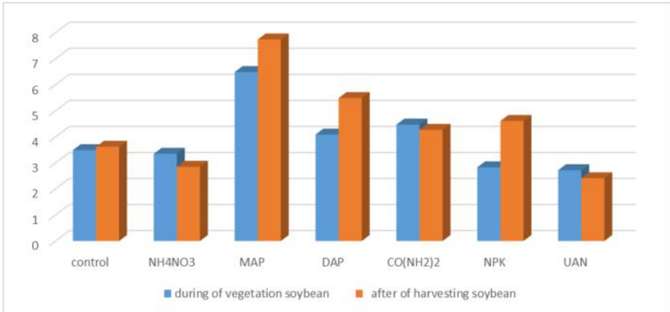

Fig.3: Comparative analysis of the content of mobile phosphates during the vegetation and after harvesting of the soybean

Most distinct is the difference in the variants, which have been fertilized with phosphorus containing fertilizers (MAP, DAP and NPK), and smallest – in the control. It is known, that the absorption of the phosphorus happens through a diffusion process (movement of the nutrient elements from high towards low concentration) and if the phosphorus is not at least in average concentration in the soil, the absorption of the nutrient element from the soil shall be limited [15]. Aulakh et al. (2002) [27] in their research have proven, that the presence of low nutrient reserve with phosphorus in the soil is connected with bad efficiency of usage of the added with the mineral fertilizers phosphorus. In the present study the content of phosphorus during the whole experiment is with low values, which obviously impedes the absorption of the

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nutrient element from the soil. On the availability of the macroelement exercises influence also pH. According to Tisdale et al. (2005) [28] the highest availability of phosphorus is established at pH from 5.5 up to 7. At higher values of pH, the phosphorus can interact with Ca and to become inaccessible for the plants. In the brought experiment the values of pH are >7, which causes difficulties at the absorption of the nutrient element by the plants, because of which after harvesting the content of phosphorus in the separate variants does not differ significantly from the established values during vegetation.

The results from the analyses for the content of absorbable potassium during vegetation are presented in Table 5.

Table 5: Content of absorbable potassium in the soil during vegetation of the soybean

Fertilizers	Average	Coefficient of variation
	K_2O mg/100 g	%
Control	18.58	0.88
NH_4NO_3	20.05	19.22
MAP	23.56	15.65
DAP	19.62	14.02
$CO(NH_2)_2$	21.69	23.73
NPK	22.80	1.92
UAN	23.35	0.94
$LSD_{0.05}$	-	

There have been established higher results in the variant with brought in MAP (23.56 mg/100 g soil), followed by the one fertilized with UAN (23.35 mg/100 g soil) and the variant with combined fertilizers NPK (22.80 mg/100 g soil). In the control soil sample the value of the absorbable potassium is 18.58 mg/100 g soil, as the varying of the data of the separate repetitions is the lowest. The statistical analysis has not established proof of the differences between the separate variants.

In Table 6 are published the data from the analysis of potassium after harvesting of the soybean.

By the tests carried out has been established, that the highest results are reported in the variants, which have been fertilized with DAP (29.35 mg/100 g soila) and MAP (29.28 mg/100 g soil), followed by the variant, fertilized with urea (27.17 mg/100 g soil) and UAN (27.11 mg/100 g soil). In the control have been reported 21.90 mg/100 g soil absorbable potassium. The lowest is the variation of data in the plots, which have been fertilized with MAP and DAP. Likewise the analysis for content of absorbable potassium during vegetation, after harvesting there is not available statistical authenticity of the obtained differences between the variants.

Table 6: Content of absorbable potassium in the soil after harvesting of the soybean

Fertilizers	Average	Coefficient of variation
	K_2O mg/100 g	%
Control	21.90	23.89
NH_4NO_3	25.93	15.14
MAP	29.28	4.32
DAP	29.35	7.27
$CO(NH_2)_2$	27.17	10.02
NPK	24.75	12.54
UAN	27.11	7.56
$LSD_{0.05}$	-	

The presented graphical data (Fig. 4) about the content of absorbable potassium during the vegetation and after harvesting of the soybean have common tendency similar to the one of the mobile phosphates. The concentrations of potassium in the soil are higher after the harvesting of the soybean in all variants in comparison with the values during the vegetation.

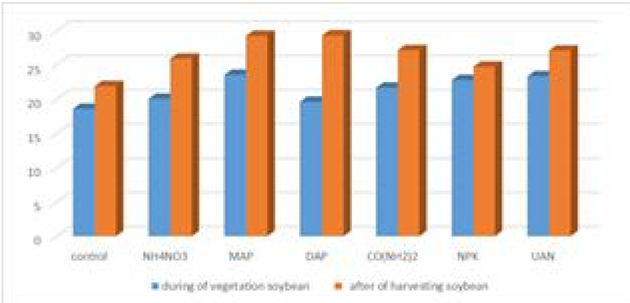

Fig.4: Comparative analysis of the content of absorbable potassium during the vegetation and after harvesting of the soybean

At explanation of the reasons for this there has to be emphasized the fact that the high soil moisture leads to greater accessibility of potassium, as it increases the mobility of the macroelement towards the roots of the soybean plants. According to Brandy and Weil (1999) [29] the factor moisture is necessary for the passing of a diffusion process of potassium towards the roots with purpose of absorption. For example Gene et al. (2010) [30] have established, that the increase of the soil moisture from 10 up to 28% increases double the total potassium transport. Consequently the deficiency of the soil moisture, what has been reported in the present experiment, is capable of restricting the potassium transport and its absorption by the soybean plants, as this explains the high values of the element in the soil after harvesting. Still more, that is known the fact, that the leguminous crops absorb better the potassium than Ca, Mg and P [31]. Another factor, which has an impact on the potassium nutrition is pH, as at values >7, Ca and Mg react with K (as well as with P) and the accessibility is decreased [32]. According to Cox et al. (1982) [33] potassium deficiency can be established rarely at cultivation of soybean, since the crop is effective at obtaining of potassium, even at low levels of this element in the soil.

In conclusion should be marked, that in the scientific literature there is information, that the grain-leguminous plants (in particular the soybean) supply themselves the macronutrient elements phosphorus and potassium almost only from the soil. Thanks to their powerful and deeply penetrating root system they can supply themselves these elements from the lower soil layers and from more difficult soluble compounds [34]. Consequently, we can deem, that the reasons for the obtained higher results, regarding the content of mobile phosphates and absorbable potassium after the harvesting of the soybean are namely connected with the botanical, physiological and biochemical peculiarities of this crop.

IV. CONCLUSION

As a result of bringing in of MAP there have been established higher values of ammonium and nitrate nitrogen in the soil during vegetation of the soybean, while after its harvesting the highest content of ammonium nitrogen has been reported in the variant fertilized with NPK, and of nitrate – with urea. Regardless of the used fertilizer product, after harvesting of the soybean there has been reported lower content of ammonium and nitrate nitrogen.

At the usage of MAP there has been established higher content of mobile phosphates in the soil during vegetation of the soybean and after its harvesting as the differences between MAP and the rest variants are statistically authentic. The values of phosphorus in the soil after harvesting of the soybean are higher in four of the experimental plots, as at the variant fertilized with phosphorus-containing fertilizers (MAP, DAP and NPK) the difference is more significant.

The statistical analysis has not established proof of the differences between the variants as per content of absorbable potassium in the soil. The tendency is analogous as the exposed one at the mobile phosphates, something more, in all variants of the experiment the values after harvesting are higher than the reported ones during vegetation.

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REFERENCES

[1] V. O. Chude, W. B. Malgwi, I. V. Amapu and O. A. Ano, 2004. Manual on Soil Fertilit Assessment, Federal Fertilizer Department (FFD) Incollaboration with FAO/National Special Programme for Food Security. Abuja, Nigeria.

[2] R.M. Gifford and L.T. Evans, 1981. Photosynthesis, carbon partitioning, and yield. Ann Rev Plant Physio, 32, 485-509.

[3] B. Hirel, J. Le Gouis, B. Ney and A. Gallais, 2007. The challenge of improving nitrogen use efficiency in crop plants: towards a more central rule for the genetic variability and quantitative genetics within integrated approaches. J Exp Bot, 58, 2369-2387.

[4] T.R. Sinclair and T. Horie, 1989. Leaf nitrogen, photosynthesis, and crop radiation use efficiency: a review. Crop Sci, 29, 90-98.

[5] T.R. Sinclair and P.D. Jamieson, 2006. Grain number, wheat yield, and bottling beer: an analysis. Field Crop Res, 98, 60-67.

[6] J.L. Rotundo, L. Borras, J. De Bruin and P. Pedersen, 2014. Soybean nitrogen uptake and utilization in Argentina and united states cultivars. Crop Sci 54: 1153-1165.

[7] G. Santachiara, L. Borras and J.L. Rotundo, 2017. Physiological processes leading to similar yield in contrasting soybean maturity groups. Agron J, 109, 158-167.

[8] F. Salvagiotti, K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss and A. Dobermann, 2008. Nitrogen uptake, fixation and response to fertilizer N in soybeans: a review. Field Crop Res 108: 1-13.

[9] L.C. Purcell, R. Serraj, T.R. Sinclair and A. De, 2003. Soybean N_2 fixation estimates, ureide concentration, and yield responses to drought. Crop Sci, 44, 484-492.

[10] T.R. Sinclair, C.D. Messina, A. Beatty and M. Samples, 2010. Assessment across the United States of the benefits of altered soybean drought traits. Agron J, 102, 475-482.

[11] T. George, P.W. Singleton and B. Bohlool, 1988. Yield, soilnitrogen uptake, and nitrogen-fixation by soybean from 4 maturity groups grown at 3 elevations. Agron J, 80, 563–567.

[12] F. Salvagiotti, K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss and A. Dobermann, 2008.

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Nitrogen uptake, fixation and response to fertilizer N in soybeans: a review. Field Crop Res, 108, 1–13.

[13] F. Salvagiotti, J.E. Specht, K.G. Cassman, D.T. Walters, A. Weiss and A. Dobermann, 2009. Growth and nitrogen fixation in highyielding soybean: impact of nitrogen fertilization. Agron J, 101, 958–970.

[14] K. M. Kakar, M. Tariq, F. H. Taj, and K. Nawab, 2002. Phosphorous use efficiency of soybean as affected by phosphorous application and inoculation. Pakistan Journal of Agronomy, 1(1), 49–50.

[15] C.S. Snyder, 2000. Raise soybean yields and profit potential with phosphorus and potassium fertilization. PPI.

[16] R. George and S. Michael, 2002. Potassium for crop production. Minnesota crops. University of Minnesota.

[17] I. S. M. Farhad, M. N. Islam, S. Hoque, and M. S. I. Bhuiy, 2010. Role of potassium and sulphur on the growth, yield and oil content of soybean (*Glycine max* L.). An Academic Journal of Plant Sciences, 3(2), 99–103.

[18] F. Zapata, S.K.A. Danso, G. Hardarson and M. Fried, 1987. Time course of nitrogen fixation in field-grown soybean using nitrogen–15 methodology. Agron. J., 79, 172–176.

[19] T. George and P.W. Singleton, 1992. Nitrogen assimilation traits and dinitrogen fixation in soybean and common bean. Agron. J., 84, 1020–1028.

[20] Y. Jefing, D.F. Herridge, M.B. Peoples and B. Rerkasem, 1992. Effects of N fertilization on N2 fixation and N balances of soybean grown after lowland rice. Plant Soil, 147, 235–242.

[21] M.J. Goss, A. de Varennes, P.S. Smith and J.A. Ferguson, 2002. N_2 fixation by soybeans grown with different levels of mineral nitrogen, and the fertilizer replacement value for a following crop Canadian Journal of Soil Science, 82(2), 139-145.

[22] A.A. Bloem and R.O. Barnard, 2001. Effect of annual legumes on soil nitrogen and on the subsequent yield of maize and grain sorghum. South African Journal of Plant and Soil, 18:2, 56-61.

[23] J. Streeter, 1988. Inhibition of legume nodule formation and N_2 fixation by nitrate. CRC Crit. Rev. Plant Sci., 7, 1–23.

[24] L.C. Purcell, R. Serraj, T.R. Sinclair and A. De, 2004. Soybean N_2 fixation estimates, ureide concentration, and yield responses to drought. Crop Sci., 44, 484–492.

[25] M.B. Parker and H.B. Harris, 1977. Yield and leaf nitrogen of nodulating and non-nodulating soybeans as affected by nitrogen and molybdenum. Agron. J., 69, 551–554.

[26] M.C. Soares Novo, R.T. Tanaka, H.A.A. Mascarenhas, N. Bortoletto, P.B. Gallo, J.C.V.N. Alves Pereira and A.A. Teixeira Vargas, 1999. Nitrogênio e potassio na fixação simbiotica de N_2 por soja cultivada no inverno, Scientia Agricola, 56(1), 143–156.

[27] M.S. Aulakh, N.S. Pasrich and A.S. Azad, 2002. Phosphorus-solphur interrelationships for soybean on phosphorus and sulphur deficient. Soil Sci., 150, 705-709.

[28] S.L. Tisdale, J.L. Halvin, W.N. Nelson and J.D. Beaten, 2005. Soil fertility and fertilizers. An introduction to nutrient management (7th eds). Pearson education. USA.

[29] N.C. Brandy and R.P. Weil, 1999. The nature and properties of soils (12th eds). Prentice Hall, New Jersey.

[30] E.L. Gene, L.J. John and J.M. Donald, 2010. Impact of potassium nutrition on food quality of fruits and vegetables. Dept. of Agric. and Res. Service. USA.

[31] A. Venter, 2003. Comparing plant yield and composition with soil properties using classical and geostatistical techniques. M.Sc. Thesis. Dept. of Plant Prod. and Soil Sci. UP.

[32] F. Rooyani and B. Badamchian, 1986. General soil science. L.A.C. Lesotho.

[33] F.R. Cox, F. Adams and B.B. Tucker, 1982. Liming, fertilization and mineral nutrition. In: H.E. Pattee and C.T. Young (eds). Peanuts Sci. and Tech. American Peanut Research and Education Society, Inc., Yoakum, Texas, U.S.A.

[34] B. Yankov, Zh. Terziev, H. Yancheva, R. Ivanova, I. Yanchev, T. Georgieva, T. Kolev, N. Tahsin, V. Delibaltova and H. Kirchev, 2013. Plant production. AU – Plovdiv.