Effects of Phosphorus Fertilization Rates on Several Morphological and Yield Indicators of Potato (*Solanum Tuberosum* L.) cultivar Agria

Defrime Berisha [a*], Nikollaq Bardhi [b], Imer Rusinovci [c], Bakir Kelmendi [a], Lush Susaj [d]

[a] Kosovo Agricultural Institute – Pejë, Rr. Adem Jashari, 30000 Pejë, Kosovo, Albania

[b] Agricultural University of Tirana, Faculty of Agriculture and Environment, Department of Plant Production, Kodër Kosovo Kamëz 1032, Tirana, Albania

[c] University of Prishtina, Faculty of Agriculture and Veterinary, Department of Crop Science, Prishtina, Albania

[d] Agricultural University of Tirana, Faculty of Agriculture and Environment, Department of Horticulture, Kodër Kamëz 1029, Tirana, Albania

Corresponding author: Defrime Berisha [a*]

Abstract

The study on the effects of different phosphorus fertilizer rates on several morphological and yield indicators of potato cultivar Agria was conducted during three consecutive years, 2011-2013, in the Arbnesh Farm of Kosovo Agriculture Institute of Peja. A randomized complete block design (RCBD) with four replications and five variants (five levels of diammonium phosphate – DAP), consisting on 0, 30, 60, 90, 120 kg ha^{-1} active matter P_2O_5, with a plot size of 240 m^2 (12 m^2 for each variant in each replication) was used. Except phosphorus rate, the other common agro-technological practices were the same, as farmers guide, all over the study period. Plants were observed throughout the growing period. The observed data showed that phosphorus fertilizer rate significantly affected the yield (quintals ha^{-1}), dry matter content (%), starch content (%) and other yield quality indicators of potato cultivar Agria, grown under Peja agro-climatic conditions. The highest potato tuber yield (395.2 quintals ha^{-1}) and the highest quality tubers [dry matter content (19.11%) and starch content (14.47%)] were achieved using 90 kg ha^{-1} P_2O_5. Recommended phosphorus rate for Agria potato cultivar in the studied region is 60-90 kg ha^{-1} active matter P_2O_5, or 130.4-195.7 kg per hectare diammonium phosphate [$(NH_4)_2HPO_4$].

KEYWORDS*:* Agria, cultivar, diammonium phosphate, fertilizer, [$(NH_4)_2HPO_4$], potato, yield.

INTRODUCTION

Nutrition is crucial in determining potato yield and quality, as well as influencing the potato plant's ability to withstand negative effects from pests, water, temperature, and other stresses. Phosphorus is one of the seventeen essential elements required for plant growth and reproduction (Marschner, 1995). Phosphorus is an essential element which plays an important role in basic plant carbohydrate metabolism and energy transfer systems since it is a part of the structure of DNA, RNA, ATP and phospholipids in membranes. Following tuber initiation, phosphorus is an essential component for starch synthesis, transport and storage. Phosphorus deficiencies leads to a general reduction of most metabolic processes including cell division, cell expansion, respiration and photosynthesis (Marschner, 1995), resulting on poor root systems, darker green, stunted plants with shortened internodes, spindly leaves with younger leaflets that turn upward or curl (Tindall *et al.*, 2001), reduced yield and crop quality, and delayed maturity (Grewal and Trehan, 1993; Rowe, 1993). Large differences between symptoms among potato cultivars occurs, and some will show purple colour even though they are not deficient (Ekelöf, 2007). Phosphorus, nitrogen and potassium are classified as primary macronutrients. They are needed in relatively large quantities and are often deficient in crops without fertilizer application. Nitrogen and phosphorus chemistry in the soil are totally different. Plant available nitrogen in the soil exists primarily as nitrate, which is a very soluble and mobile compound. Nitrate is readily leached downward or moved laterally with water movement, which is especially a problem for shallow rooted crops such as potatoes. In addition, nitrate can be lost in atmosphere under saturated condition, as gaseous. "Spoon-feeding" nitrogen was proven to be a good management practice in potato production (Stark and Westermann, 2003). In contrast to nitrogen, phosphorus is neither mobile nor subject to gaseous losses. Phosphorus fertilizers dissolve in the soil solution and result in an increase of phosphorus. Due to equilibrium chemistry, the soil solution do not tolerate high levels of phosphorus, and most of the phosphate (PO_4^{3-}) in soil quickly precipitates, forming a mineral deposit, as it reacts with calcium and other positively charged ions in the soil solution (Hopkins and Ellsworth, 2003). High pH and $CaCO_3$ (lime) content reduce phosphorus solubility and availability to plants. Potato plant roots readily absorb P in the form of phosphate from the soil (water) solution. The absorbed phosphate moves upward and downward in the plant. Phosphorus-deficient potato plants transfer P from older tissues to actively growing, younger tissues. Maximum potato yield occurs when sufficient P is available during early vegetative development and the entire period of tuber growth. Total plant P uptake increases rapidly during tuber initiation, levels off to a constant rate during tuber bulking, and stops with plant maturation. Tuber P uptake during maturation occurs primarily through the transfer of P reserves from the vine and roots. Phosphorus uptake by potatoes is relatively low compared with uptake of potassium or nitrogen, but similar to uptake of sulphur. The amount of P in the soil solution that is readily available for plant uptake is very small compared with the total amount of P in the soil. The calcium in soils combines quickly with P fertilizer, causing reduced P availability to plants and very restricted P mobility in soil. Therefore, P fertilizer use efficiency is quite low compared with that of most other available fertilizers (Tindall *et al.*, 2001). Potato has a relatively small nutrient exploration area because of its shallow root system and low root/foliage ratio. Applications of P fertilizers are therefore recommended to potato crops and are believed to increase yield, quality, tuber set and early leaf development (Jenkins and Ali, 2000; Khiari *et al.*, 2001). While potatoes are very responsive to fresh soil phosphate, the economic optimum rate is often very difficult to define. Suggested phosphorus fertilizer recommendation rates for potatoes for pre-plant application are related to soil type and soil P test results, amount of free or excess lime available, and estimated yield (Davis *et al.*, 2009). Crop responses to applied P are most likely on soils with low or medium levels of extractable P, although lower P rates may be effective for potatoes on soils high in extractable P because of cool soil temperatures in the spring (Davis *et al.*, 2009; Essah, 2009).

Excess phosphorus rate decrease yield and quality, while researches in other crops show that excessive phosphorus does not create phosphorus toxicity (Hopkins and Ellsworth, 2003; Loneragan *et al.*, 1979; Loneragan *et al.*, 1982), rather excessive phosphorus induces micronutrient deficiencies, such as zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), etc. Although phosphorus interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with zinc (Lu *et al.*, 1998). Zinc is taken up by plants as a cation (Zn^{2+}) and phosphorus is taken up as the phosphate anion (PO_4^{3-}). Positively and negatively charged ions (Zn^{2+} and PO_4^{3-}), because of electrical attraction to each other, can form a relatively strong chemical bond phosphorus-zinc in either the soil or plant tissue, which does not readily break without dramatic changes in the physical or chemical environment. If excess phosphorus binds a large amount of the zinc normally used by plants, result can be a phosphorus-induced zinc deficiency (Hopkins and Ellsworth, 2003; Zhu *et al.*, 2001).

Many environmental stresses influence plant P uptake during the growing season. These include Verticillium *wilt*, blackleg, *Fusarium* and other diseases of roots; root pruning during cultivation; cool soil temperatures; and soil properties such as low available P, lime content, restrictive layers, and pH. Excessive pre-plant P fertilization may slightly improve P uptake during some stresses, but is generally expensive and inefficient. A better solution is to prevent pathogens from infesting potato roots by careful management (Tindall *et al.*, 2001). Phosphorus-deficient potato crops may have lower specific gravity. Specific gravity declines with greater P deficiency and greater nitrogen availability. Phosphorus and nitrogen also influence net development (skin set) on tubers. Phosphorus deficiency reduces netting when nitrogen levels are adequate or excessive. Maintaining adequate soil P concentrations keeps specific gravity high and reduces net development (Tindall *et al.*, 2001).

Phosphorus fertilization increased total yield and tuber quality of potato US Nr. 1 (Hopkins and Ellsworth, 2003), increased starch concentration (Hahlin & Johnsson, 1973), increased leaf area index and dry-matter accumulation (Singh *et al.*, 2004), etc. Effect of phosphorus in the number of tubers is not clear, eventhough some authors have found that P concentration in potato plant is pozitively related with number of tubers (Allison *et al.*, 2001).

Potato cultivars differ in their ability to grow in low P soil because of their different internal or external P requirements among cultivars (Trehan & Sharma, 2002; Grewal and Trehan, 1993; Jenkins and Ali, 2000). Jenkins and Ali (1999) found that cultivars with longer growth period had lower P fertilizer demand than early varieties. Phosphorus fertilizers in potato can be applied in several ways, by banding, through fertigation, broadcasting, and soaking seed tubers or by spraying liquid fertilizers on to the leaves (Allison *et al.*, 2001; Tindall *et al.*, 2001; Tukaki and Mahler, 1990). The placement of P fertilizer near the active root zone (banding) is the most recommended method, since most of the applied P is fixed by the soil and not mobile. Placing the fertilizer near the active root zone reduces the contact with soil, thus avoiding fixation (Marchner, 1995), increase P uptake use efficiency and leads to a decreased P fertilization requirement with ≈50% (Grewal and Trehan, 1993). Higher tuber yield can be attained if P fertilizers are placed 5 cm to the sides of the seed pieces instead of below or mixed into the ridges. Recent studies have shown that P fertilizer use efficiency can be increased by 45% with the use of fertigation compared to broadcasting and with 25% compared to banding (Singh *et al.*, 2004). Broadcasting is the least efficient, but most widely used application method since high capacity machines, which brings down costs for the application, can be used. The fertilizer is spread prior to planting and cultivated into the ridges as they are formed. However, when the fertilizers are mixed into the soil; the fertilizer contact area increase which results in more P being fixed. The aim of the study was to investigate the effect of different phosphorus applications rates on morphological and yield indicators of potato cultivar Agria, under agro-climate conditions of Peja.

MATERIAL AND METHODS

The study on the effects of phosphorus fertilization rates on several morphological and yield indicators of potato cultivar Agria was conducted during three consecutive years, 2011-2013, in the Arbnesh Farm of Kosovo Agriculture Institute in Peja. A randomized complete block design (RCBD) with four replications and five variants (five levels of diammonium phosphate – DAP), consisting on 0, 30, 60, 90, 120 kg ha^{-1} active matter P_2O_5, with a plot size of 240 m^2 (12 m^2 for each variant in each replication) was used. Except phosphorus rate, the other common agro-technological practices were the same, as farmers guide, all over the study period. Variants were as below:

V1 = 0 kg ha^{-1} P_2O_5 (or 0 kg DAP) + 140 kg NH_4NO_3 + 300 kg K_2SO_4 (control)
V2 = 30 kg ha^{-1} P_2O_5 (or 65.2 kg DAP) + 140 kg NH_4NO_3 + 300 kg K_2SO_4
V3 = 60 kg ha^{-1} P_2O_5 (or 130.4 kg DAP) + 140 kg NH_4NO_3 + 300 kg K_2SO_4
V4 = 90 kg ha^{-1} P_2O_5 + (or 195.7 kg DAP) + 140 kg NH_4NO_3 + 300 kg K_2SO_4
V5 = 120 kg ha^{-1} P_2O_5 + (or 260.9 kg DAP) + 140 kg NH_4NO_3 + 300 kg K_2SO_4

Diammonium phosphate [DAP, with chemical formula $(NH_4)_2HPO_4$], International Union of Pure and Applied Chemistry (IUPAC) name diammonium hydrogen phosphate, is one of a series of water-soluble ammonium phosphate salts that can be produced when ammonia reacts with phosphoric acid. Solid diammonium phosphate shows a dissociation pressure of ammonia as given by the following expression and equation (Van Wazer, 1958) and Figure 1:

$$(NH_4)_2HPO_4(s) \rightleftharpoons NH_3(g) + NH_4H_2PO_4(s) \quad \log P_{mmHg} = -3063/T + 175 \log T + 3.3$$

Where: P = the resultant dissociation pressure of ammonia and T = absolute temperature (K)

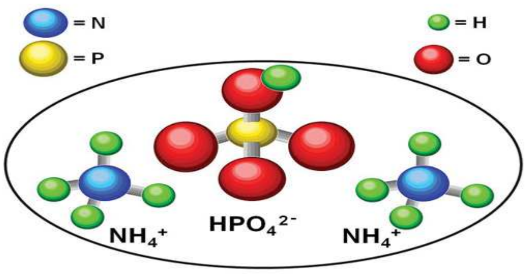

Figure 1. $(NH_4)_2HPO_4$ dissociation (IPNI, 2012).

At 100°C, the dissociation pressure of diammonium phosphate is approximately 5 mmHg (McKetta and John, 1990). The typical formulation is 18-46-0 (18% N, 46% P_2O_5, 0% K_2O) (IPNI, 2012). Every year, there were carried out the soil tests for the main macroelements. Results were presented in Table 1.

Table 1. Soil tests data for the experimental plot before potato sowing

Year	Profile deepth (cm)	pH	$CaCO_3$ (%)	Nutrition elements (mg/100 g dry soil)					
				N-NH_4^+	N-NO_3^-	P_2O_5	K_2O	Ca	Mg
2011	0-30 cm	6.1 Slightly acid	5 Medium	4.1 high	6.0 high	12.4 medium	14.1 medium	371.4 high	20.8 high
2012	0-30 cm	6.1 Slightly acid	5 Medium	4.2 high	6.0 high	12.4 medium	14.7 medium	376.4 high	21.6 high
2013	0-30 cm	6.2 Slightly acid	5 Medium	4.2 high	6.4 high	12.1 medium	14.1 medium	371.4 high	20.6 high

Pre-plant diammonium phosphate was applied using banding method, since most of the applied P is fixed by the soil and not mobile (Marchner, 1995), in order to increase P uptake use efficiency (Grewal and Trehan, 1993).

Class A seeds with dimensions 35-45 mm of Agria potato cultivar, imported from Netherland (AGRICO), were used for planting. Agria potato cultivar is one of the most used in Kosovo. Potato seeds were sown on April 17 and were harvested on September 4 to 9 of both years of the study. Potato plants were observed throughout the growing period for several morphological and yield indicators, such as:

- duration of the vegetative period from emergence to harvest (days),
- plant height (cm)
- number of stems per plant
- yield (quintals ha^{-1})
- dry matter and ash content (%)
- cellulose content
- and starch content (%).

Plant height (cm), the number of shoots per plant and yield (quintals ha^{-1}) were determined using a representative sample of 10 successive plants taken randomly in the row from each variant in each replication. All data were recorded and mean values were calculated.

Dry matter content (%) was determined at harvesting at the Lab Factory Pestovë, using an analytic balance PR, type METTELER TOLEDO LC-P 43 (Switzerland), as it was described by AOAC (1990).

Starch content (%) of fresh potatoes was determined in compliance with the official EC Commission Directive 86/174/EEC and Council Directive 96/25/EC using polarimetric method (Paar, 2013; ISI, 2013) with a MCP/200/300/500 tool with 200 mm polarimeter tube with Peltier option, accuracy 0.01^o optical rotation. Starch content (%) was calculated by following formula:

$$\text{Starch content (\%)} = \frac{2000 * (P - P')}{[\alpha]^{20}_D}$$

Where:

P = total optical rotation in angular degrees

P' = optical rotation in angular degrees of the substances soluble in 40% (v/v) ethanol

$[\alpha]^{20}_D$ = specific rotation of pure starch at 20^oC, measured in a polarimeter with the wavelength of 589 nm (sodium D-live).

Observed data were statistically analyzed using MSTAT-C-1990 (PROC ANOVA function of SAS) and means were compared using least significant differences method (LSD) at a probability level of 5% and 1% (Snedecor & Cochran, 1980; Papakroni, 2001).

RESULTS AND DISCUSSION

Effect of phosphorus fertilization rates [$(NH_4)_2HPO_4$ doses] on plants phenology** (duration of the vegetative period), **plant height (cm) and stem number per plant

Duration of the vegetative period (from emergence to full maturity and harvest)**.** Observed results showed that phosphorus fertilization rates did not significantly affect the time of emergence, but they affected significantly the time of 50% flowering and of 50% physiological maturity. Potato seeds for all variants were sown in the same day (April 17) and were fully matured and harvested on September 4 for phosphorus fertilized variants and on September 9 for variant 1 (control) of both years of the study. Fifty percent of potato emergence for all variants occurred 12 days after sowing, corresponding to April 29, and 50% of physiological maturity occurred in August 25 for phosphorus fertilized variants and in August 30 for control. Duration of the vegetative period (from emergence to full maturity and harvest) was 129 days for phosphorus fertilized variants and 134 days for control. Differences were statistically confirmed between phosphorus fertilized variants and control, but not between phosphorus fertilized variants.

Plant height (cm) and ***stems number per plant*** were determined using a representative sample of 10 successive plants taken randomly in the row from each variant in each replication. All data were recorded and mean values were calculated. There were observed significant differences form year to year for the same variant, but not between variants in the same year. The highest mean value of plant height (cm) was observed for variants 4 and 5 (90 and 120 kg ha^{-1} P_2O_5) by 67.8 cm, and the lowest value was observed for control and variant 2 (30 kg ha^{-1} P_2O_5), by 66.5 cm and 66.6 cm, respectively, but differences were not significant between variants at $p \leq 0.05$ (Table 2).

Results showed that stem number of potato cultivar Agria was affected by the application of P fertilizer. In all P treatments were observed higher stem number than control, but the stem number did not follow a decreasing or increasing trend with increasing rates of P application. The highest numbers of stems were observed for variants 3 and 4 (60 and 90 kg ha^{-1} P_2O_5) (4.6), while the lowest stem number was observed for control (0 kg ha^{-1} P_2O_5) by 4.2. There were observed not significant differences were between P treatments (Table 2, Figure 2).

Table 2. Effects of different phosphorus rates (P_2O_5 active matter) on plant height (cm) and stem number of Agria potato cultivar (different uppercase letters indicate significant differences between variant's three years means, different lowercase letters indicate significant differences between years for the same variant at $p \leq 0.05$).

№	Phosphorus rates (P_2O_5 active matter)	Plant height (cm)			Mean	Stem number $plant^{-1}$			Mean
		2011	2012	2013		2011	2012	2013	
1	0 kg ha^{-1} P_2O_5 (control)	67.7^{a}	63.2^{b}	68.5^{a}	66.5^{A}	4.4^{a}	3.8^{b}	4.3^{a}	4.2^{B}
2	30 kg ha^{-1} P_2O_5	68.2^{a}	63.3^{b}	68.3^{a}	66.6^{A}	4.8^{a}	4.0^{b}	4.6^{a}	4.5^{A}
3	60 kg ha^{-1} P_2O_5	69.1^{a}	64.3^{b}	69.2^{a}	67.5^{A}	4.8^{a}	4.4^{ab}	4.6^{a}	4.6^{A}
4	90 kg ha^{-1} P_2O_5	69.3^{a}	64.3^{b}	69.8^{a}	67.8^{A}	4.9^{a}	4.1^{b}	4.7^{a}	4.6^{A}
5	120 kg ha^{-1} P_2O_5	69.5^{a}	64.1^{b}	69.8^{a}	67.8^{A}	4.9^{a}	4.1^{c}	4.6^{b}	4.5^{A}

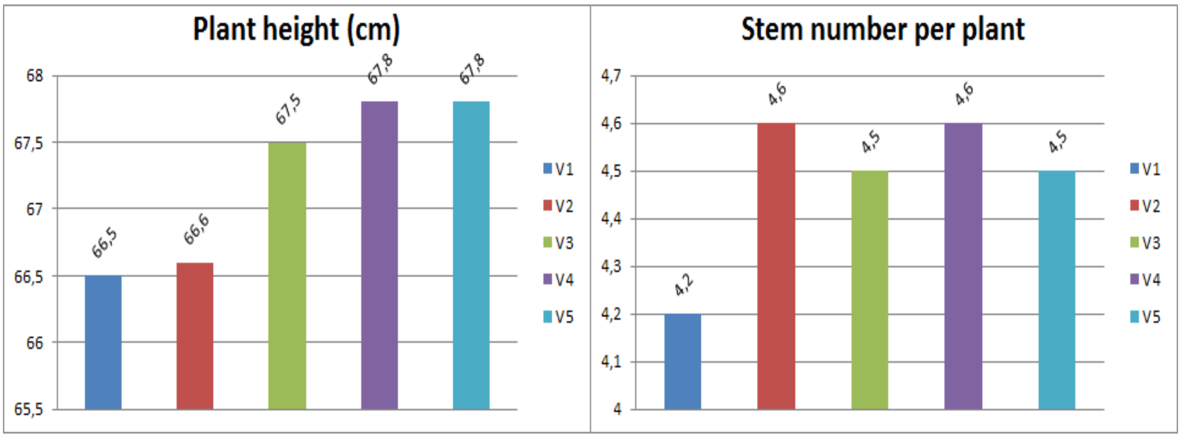

Figure 2. Plant height (cm) and stem number per plant (mean values).

Potato tuber yield (quintals ha^{-1}). High tuber production is the final objective of potato cultivation. Tubers of each variant in each replication were separately harvested and weighted, and was calculated the yield (quintals ha^{-1}). All phosphorus fertilized variants showed significantly higher tuber yield compare to control. There were observed significant differences between phosphorus fertilized variants, as well. There were formed four different groups which were statistically confirmed at $p \leq 0.05$. The highest three years mean tuber yield was obtained from application of 90 kg ha^{-1} P_2O_5, by 395.2 quintals ha^{-1}, with a raise of 69.8 quintals ha^{-1} (or 21.5%) compare to control; 40.8 quintals ha^{-1} (or 11.5%) compare to variant 2; 23.6 quintals ha^{-1} (or 6.4%) compare to variant 3, and 14.7 quintals ha^{-1} (or 3.9%) compare to variant 5. There was observed a difference in yield of 8.9 quintals ha^{-1} (or 2.4%) between variants 5 (120 kg ha^{-1} P_2O_5) and 3 (60 kg ha^{-1} P_2O_5) (Table 3, Figure 3), but this difference was not significant at $p \leq 0.05$. These results were similar to that reported by Allison *et al.* (2001), Essah (2009), Hopkins and Ellsworth (2003), etc.

Table 3. Effects of different phosphorus rates on yield (quintals ha^{-1}) of Agria potato cultivar (different uppercase letters indicate significant differences between variants, different lowercase letters indicate significant differences between years for the same variant, and *italic* uppercase letters indicate significant differences between variant's three years means at $p \leq 0.05$).

№	Phosphorus rates (P_2O_5 active matter)	Yield (quintals ha^{-1}) 2011	2012	2013	Mean
1	0 kg ha^{-1} P_2O_5 (control)	342.3 ^{Da}	299.6 ^{Ec}	334.2 ^{Eb}	**325.4 ^{D}**
2	30 kg ha^{-1} P_2O_5	385.2 ^{Ca}	322.2 ^{Dc}	355.8 ^{Db}	**354.4 ^{C}**
3	60 kg ha^{-1} P_2O_5	400.5 ^{Ba}	336.5 ^{Cc}	377.9 ^{Cb}	**371.6 ^{B}**
4	90 kg ha^{-1} P_2O_5	419.5 ^{Aa}	366.2 ^{Ac}	400.0 ^{Ab}	**395.2 ^{A}**
5	120 kg ha^{-1} P_2O_5	400.1 ^{Ba}	350.3 ^{Bb}	391.2 ^{Ba}	**380.5 ^{B}**

Effect of phosphorus rates [$(NH_4)_2HPO_4$ doses] on dry matter content (DMC - %), starch content (SC - %), cellulose content (CC - %), and ash content (AC - %)

Dry matter content (DMC - %) is a very important character especially for potatoes used in the alimentary industry. Potato chips market prefers high dry matter content, which confers robustness and crispness to the slices, and low reducing sugar content, to avoid dark browned chips. Obtained results showed that dry matter content (%) was affected by the application of phosphorus fertilizer. In variants with phosphorus rate over 60 kg ha^{-1} P_2O_5, there was observed a significantly higher DMC (%) than control, but there were not observed significant differences between control and variant 2 (30 kg ha^{-1} P_2O_5), and between variants V3 and V4, as well. The highest dry matter content (%) was observed for V4 (90 kg ha^{-1} P_2O_5) with a three years mean of 19.11%, while the lowest DMC was observed for control (0 kg ha^{-1} P_2O_5) and variant 2 (60 kg ha^{-1} P_2O_5), with a three years mean of 18.14% and 18.4%, respectively (Table 4). There was observed a significant difference for DMC (%) between V4 and V5, by 0.28%, which means that phosphorus fertilization affects dry matter content up to a specific phosphorus rate, and over that rate, the effects on DMC are not significant (Table 4).

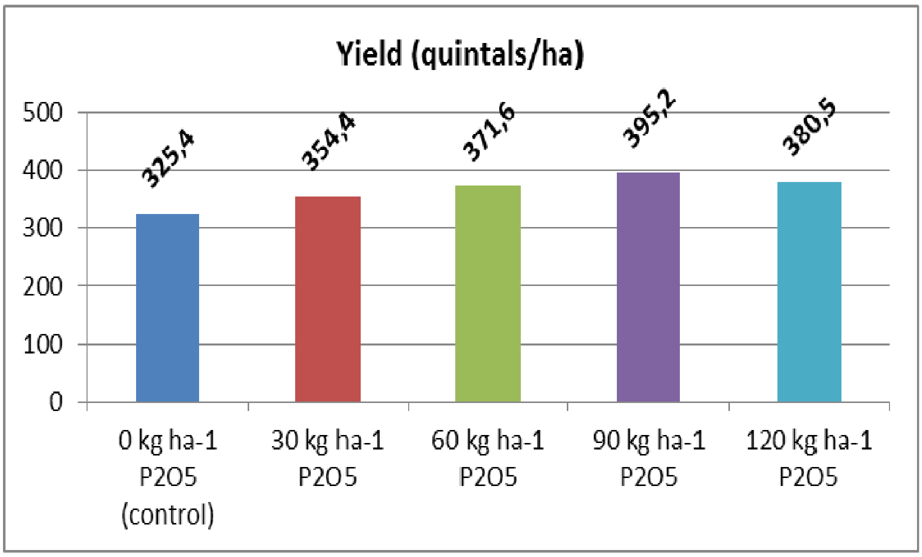

Figure 3. Effect of phosphorus rates on yield (quintals ha^{-1}) (three years mean).

***Starch content* (%).** Starch content (%) of fresh potatoes is correlated with potato density (ISI, 2013). Increase of phosphorus rate up to 90 kg ha^{-1} P_2O_5 was in a right correlation with DMC and starch content (%). The highest starch content (%) was observed for variant 4 (90 kg ha^{-1} P_2O_5) with a three years mean of 14.47%, while the lowest starch content (%) was observed for control (0 kg ha^{-1} P_2O_5) and variant 2 (30 kg ha^{-1} P_2O_5), with a three years mean of 13.84% and 14.11%, respectively. Differences between control and variant 2, as well as between variants V3 and V4, were not significant. There was observed a significant difference for SC (%) between V4 and V5, by 0.24%, as well as for dry matter content, which means that phosphorus fertilization affects starch content up to a specific phosphorus rate, and over that rate, the effects are not significant (Table 4).

Cellulose content (CC - %). Obtained results showed that cellulose content (%) was affected by the application of phosphorus fertilizer. In variants with phosphorus rate over 60 kg ha^{-1} P_2O_5, there was observed a significantly higher CC (%) than control, but there were not observed significant differences between control and variant 2 (30 kg ha^{-1} P_2O_5), and between variants V3, V4, and V5, as well. The highest dry matter content (%) was observed for V5 (120 kg ha^{-1} P_2O_5) with a mean of 0.91%, while the lowest cellulose content was observed for control (0 kg ha^{-1} P_2O_5) and variant 2 (30 kg ha^{-1} P_2O_5), with a three years mean of 0.84% (Table 4).

Ash content (AC - %). Obtained results showed that ash content (%) was affected by the application of phosphorus fertilizer. In variants with phosphorus rate over 60 kg ha^{-1} P_2O_5, there was observed a significantly higher ash content (%) than control, but there were not observed significant differences between control and variant 2 (30 kg ha^{-1} P_2O_5), and between variants V3, V4, and V5, as well. The highest dry matter content (%) was observed for V5

(120 kg ha^{-1} P_2O_5) with a mean of 1.04%, while the lowest ash content was observed for control and variant 2, with a three years mean of 1.0% (Table 4).

Table 4. Effects of different phosphorus rates on on dry matter content (DMC - %), starch content (SC - %), cellulose content (CC - %), and ash content (AC - %) of Agria potato cultivar (different letters indicate significant differences at $p \leq 0.05$).

Phosphorus rates (P_2O_5 active matter)	Dry matter content (DMC - %)	Starch Content (SC - %)	Cellulose content (CC - %)	Ash content (AC - %)
0 kg ha^{-1} P_2O_5 (control)	18.14 [c]	13.81 [c]	0.84 [b]	1.00 [b]
30 kg ha^{-1} P_2O_5	18.40 [c]	14.11 [c]	0.84 [b]	1.00 [b]
60 kg ha^{-1} P_2O_5	19.03 [a]	14.41 [a]	0.89 [a]	1.02 [a]
90 kg ha^{-1} P_2O_5	19.11 [a]	14.47 [a]	0.89 [a]	1.03 [a]
120 kg ha^{-1} P_2O_5	18.83 [b]	14.23 [b]	0.91 [a]	1.04 [a]

Phosphorus rate (kg ha^{-1} P_2O_5) showed to have a very strong correlation with plant height (r = 0.93), potato tuber yield (r = 0.89) and cellulose content (r = 0.94), a strong correlation with dry matter content (r = 0.79) and starch content (r = 0.72), and a poor correlation with stem number per plant (r = 0.58). Potato tuber yield showed to have a very strong correlation with plant height, dry matter content (r = 0.94), and starch content (r = 0.93), and a strong correlation with cellulose content (r = 0.83), and so on (Table 5).

Table 5. Correlation between phosphorus rate and different indicators **(**yield, plant height, stem number, dry matter content, starch content and cellulose content)

Indicators	P_2O_5 rate	PH (cm)	S№	Yield	DMC (%)	SC (%)	CC (%)
P_2O_5 rate (kg ha^{-1} P_2O_5)	1						
Plant height (PH - cm)	0.93	1					
Stem number per plant (S№)	0.58	0.51	1				
Yield (quintals ha^{-1})	0.89	0.92	0.79	1			
Dry matter content (%)	0.79	0.93	0.66	0.94	1		
Starch content (%)	0.72	0.84	0.79	0.93	0.97	1	
Cellulose content (%)	0.94	0.97	0.39	0.83	0.85	0.74	1

CONCLUSIONS

The observed data showed that phosphorus fertilizer rate significantly affected the yield, dry matter content and starch content of Agria potato cultivar, grown under Peja agro-climatic conditions. There were observed significant differences between variants (different phosphorus rates) for potato tuber yield (quintals ha^{-1}), dry matter content (%), starch content (%) and other yield quality indicators of potato cultivar Agria, grown under Peja agro-climatic conditions. The highest potato tuber yield was obtained using 90 kg ha^{-1} P_2O_5, with a three years mean of 395.2 quintals ha^{-1}, followed by variant 5 (120 kg ha^{-1} P_2O_5) variant 3 (60 kg ha^{-1} P_2O_5), by 380.5 and 371.6 quintals ha^{-1}. The highest quality tubers (high dry matter content and starch content) were achieved also using 90 kg ha^{-1} P_2O_5, with a three years mean of 19.11% and 14.47%, respectively. Recommended phosphorus rate for Agria potato cultivar in the studied region is 60-90 kg ha^{-1} active matter P_2O_5, or 130.4-195.7 kg per hectare diammonium phosphate [$(NH_4)_2HPO_4$].

References

Allison J. H., Flower, J. H., Allen, E. J. (2001) Effects of soil- and foliar- applied phosphorus fertilizers on the potato (*Solanum tuberosum*) crop. *J agri sci. Vol.*137 (4): pp. 379-395.

AOAC (Association of Official Analytical Chemists) (1990) Official methods of analysis of the Association of Official Analytical Chemists, 15th Edition, Washington DC, USA: pp. 101-152.

Davis, J. D, Davidson, R. D., Essah, S. Y. C. (2009) Fertilizing Potatoes. Colorado State University Extention. http://www.ext.colostate.edu/pubs/crops/00541.html.

Essah, S. Y. C. (2009) Optimizing inputs for maximum potato production. 40 p. http://www.colostate.edu/Depts/SLVRC/CROPWATER/srmac10/essahSRMAC10.pdf.

Grewal, J. S., Trehan, S. P. (1993) Phosphorus and potassium nutrition of potato. *Advances in Horticulture*, Vol. 7: pp 261-298.Hopkins, B. G., Ellsworth, J. (2003) Phosphorus Nutrition in Potato Production. Idaho Potato Conference, January 22-23, 2003: pp.75-85. http://www.extension.uidaho.edu/nutrient/pdf/Potato/Phosphorus%20 Nutrietion%20i n%20Potato%20Production.pdf.

Hopkins, B. G. (1995) Application of Phosphorus, Lime, and Zinc, and Soil Temperature Effects on Sorghum Zinc Nutrition. *In:* Zinc Nutrition of Sorghum in Kansas. PhD Dissertation, Kansas State University, Manhattan: pp. 80-108.

IPNI (International Plant Nutrition Institute). (2012) "Nutrient Source Specifics: Diammonium Phosphate" (PDF). Retrieved 2012-12-10.

ISI (International Starch Institute). (2013) Determination of Starch in Potatoes, according to EU-direction. Available online at www.starch.dk/isi/methods/starchct.html

Jenkins P. D., Ali, H. (2000) Phosphate supply and progeny tuber numbers in potato crops. *Ann. Appl. Biol. Vol.* 136: pp. 41-46.

Jenkins, P. D., Ali, H. (1999) Growth of potato cultivars in response to applications of phosphate fertilizer. *Ann. Appl. Biol.* 135: pp. 431-438.

Khiari L., Parent, L. E., Trembley, N. (2001) The phosphorus Compositional Nutrient Diagnosis range for potato. *Agronomy Journal* Vol. 93: pp. 815-819.

Loneragan, J. F., Grove, Y. S., Robson, A. D., Snowball, K. (1979) Phosphorus toxicity as a factor in zinc-phosphorus interaction in plants. Soil Science Society of America Journal 43: pp. 966-972.

Loneragan, J. K., Grunes, D. L., Welch, R. M., Aduayi, E. A., Tengah, A., Lazar, V. A., Cary, E. E. (1982) Phosphorus accumulation and toxicity in leaves in relation to zinc supply. Soil Science Society of America Journal 46: pp. 345-352.

Lu, Z. G., Grewal, H. S., Graham, R. D. (1998) Dry matter production and uptake of zinc and phosphorus in two oilseed rape genotypes under differential rates of zinc and phosphorus supply. Journal of Plant Nutrition 21: pp. 25-38.

Marschner, H. (1995) Mineral Nutrition of Higher Plants. Accademic Press inc., San Diego, California, 889 p: pp. 123-147.

McKetta, J., John, J., ed. (1990). Encyclopedia of Chemical Processing and Design (Chemical Processing and Design Encyclopedia). New York: Marcel Dekker, Inc. 515 p: pp. 469-490.

Paar, A. (2013) Determination of Starch Polarimetric Method (MCP 200/300/500). Available at www.mep.net.au/foodlab/FL_24/FL24_MCP_Starch.pdf.

Papakroni, H. (2001) Used Programs on computer - (2) Excel. Teaching Student's Book, 275 p: pp. 165-175.

Rowe, R. C. (1993) *Potato Health Management.* The American Phytopathological Society, Minnesota, USA, 178 p.

Snedecor, G. W., Cochran, W. G. (1980) One way classification-Analysis of Variance – The random effect model- Two way Classification (Eds) In Statistical Methods. Iowa State Univ. Press, Iowa USA: pp. 215-273.

Singh, H., Narda, N. K., Chawla, J. K. (2004) Efficiency of phosphorus through trickle fertigation of potato (*Solanum tuberosum*). *Indian J. Agric. Sci.* 74: pp. 476-478.

Tindall, T. A., Westermann, D. T., Stark, J. C., Ojala, J. C., Kleinkopf, G. E. (2001) Phosphorus Nutrition of Potatoes. Universityof Idaho, College of Agriculture, Cooperative Extension System Agricultural Experiment Station. Current Information Series No. 903. 4 p. http://eprints.nwisrl.ars.usda.gov/1166/1/802.pdf.

Trehan S. P., Sharma, R. C. (2002) External phosphorus requirements of different potato (*Solanum tuberosum*) cultivars resulting from different internal requirements and uptake efficiencies. Indian J. Agric. Sci. Vol. 73 (2): pp. 54-56.

Tukaki, J. L., R. L. Mahler, R. L. (1990) Evaluation of nutrient solution phosphorus concentration in plantlet tuber production under greenhouse condition. *Journal of Plant Nutrition*, 13(1): pp. 149-168.

Van Wazer, J. R (1958) Phosphorus and its Compounds - Volume I: Chemistry. New York: Interscience Publishers, Inc., 503 p: pp. 123-127

Zhu, Y. G., Smith, S. E., Smith, F. A. (2001) Zinc (Zn)-phosphorus (P) Interactions in Two Cultivars of Spring Wheat (*Triticum aestivum* L.) Differing in P Uptake Efficiency. Annals of Botany 88: pp. 941-945. http://aob.oxfordjournals.org/content/88/5/941. full.pdf.