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Effect of nitrogen and phosphorus fertilization sources on the potato crop yield (*Solanum tuberosum* L.)

Efecto de fuentes de fertilización nitrogenada y fosforada en el rendimiento del cultivo de papa (*Solanum tuberosum* L.)

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ABSTRACT

Potato (*Solanum tuberosum* L.) is a demanding crop regarding fertilization practices, and its productivity also depends on the variety used, environmental conditions, soil fertility, and crop management. The aim of this study was to investigate the effect of the interaction of nitrogen and phosphorus fertilization sources on potato crop yield. A randomized block design with a 3×3 factorial arrangement, nine treatments, and four repetitions was established. INIA-303 Canchan was the variety evaluated using three nitrogen fertilization sources: ammonium nitrate (AN), ammonium sulfate (AS), and urea. Also, three phosphorus sources were used: monoammonium phosphate (MAP), diammonium phosphate (DAP), and triple superphosphate (TSP). Total yield, commercial yield, tuber number per plant, and tuber weight per plant were studied. INIA-303 Canchan variety showed positive responses to the combinations of nitrogen and phosphorus fertilization according to the soil and climate conditions where the research was carried out. AN+DAP was the combination with the highest total yield, commercial yield, number, and weight of tubers per plant ($P<0.01$).The fertilization mixtures of AN+DAP, AS+MAP, and AN+MAP, applied on the INIA-303 Canchan potato variety, can be recommended to achieve yields between 32.45 t ha^{-1} and 33.98 t ha^{-1}.

Keywords:
Alkaline soils
Essential plant nutrient
Fertilizers
Potato yield
Solanum tuberosum

RESUMEN

La papa (*Solanum tuberosum* L.) es un cultivo exigente con respecto a las prácticas de fertilización, y su productividad también depende de la variedad utilizada, las condiciones ambientales, la fertilidad del suelo y el manejo del cultivo. El objetivo de este estudio fue investigar el efecto de interacción de las fuentes de fertilización nitrogenadas y fosforadas en el rendimiento del cultivo de papa. Se estableció un diseño factorial 3×3 de bloques al azar con, nueve tratamientos y cuatro repeticiones. La variedad evaluada fue INIA-303 Canchan con tres fuentes de fertilización nitrogenada: nitrato de amonio (NA), sulfato de amonio (SA) y urea, y tres fuentes de fósforo: fosfato monoamónico (FMA), fosfato diamónico (FDM) y superfosfato triple (SFT). Las variables estudiadas fueron rendimiento total, rendimiento comercial, número de tubérculos por planta, peso del tubérculo por planta. La variedad INIA-303 Canchan, mostró respuestas positivas a las combinaciones de fuentes de fertilización de nitrógeno y fósforo bajo las condiciones del suelo y el clima donde se realizó la investigación. En la combinación NA+FDM se encontró el mayor rendimiento total, rendimiento comercial, número y peso de tubérculos por planta ($P<0.01$). Las mezclas recomendadas para la fertilización de la variedad de papa Canchan INIA-303, para lograr rendimientos entre 32,45 t ha^{-1} a 33,98 t ha^{-1}, bajo las condiciones del área de estudio son NA+FDM, SA+FMA y NA+FMA.

Palabras clave:
Suelos alcalinos
Nutrientes vegetales esenciales
Fertilizantes
Rendimiento de papa
Solanum tuberosum

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Potato (*Solanum tuberosum* L.) is one of the most important crops in Peru in economic and food terms. The high Andean region has the biggest surface of the crop, with more than 730,000 producers in 317,647 ha approximately. However, at the coastal level, it is managed with improved varieties (Pradel *et al*., 2017). The INIA-303 Canchan INIA variety was produced by the National Institute of Agricultural Innovation (INIA), showing precocity, resistance to *Phytophthora*, and capability of adapting to various agroclimatic conditions (Fonseca, 1996). It is considered one of the most used varieties in potato production in the Andean region and the Peruvian coast (Egusquiza, 2014; Pradel *et al*., 2017).

The availability of primary (N, P, K) and secondary (S, Ca, Mg) nutrients and minor elements (B, Mn, Zn, Fe) are required to obtain the best yield potential. Mineral nutrients extracted by potatoes depend on the substrate conditions, the fertilization practice, and the variety sown (Egusquiza, 2014; Mokrani *et al*., 2018; Morales-Hernández *et al*., 2013; Niquin *et al*., 2018).

Peruvian coastal soils are deficient in nitrogen and phosphorus; therefore, the supply of macronutrients is essential. The required amounts of nitrogen, phosphorus, potassium (NPK) are 120 to 180 kg N, 60 to 100 kg of P_2O_5, and 0 to 80 kg of K_2O for potato crops (Egusquiza, 2014).

Nitrogen is the nutrient that most affects the yield and quality of tubers (Alva, 2004; Mokrani, 2018; Oliver, 2017). High doses of N promote foliage growth, but delay the initiation of tuberization and reduce yield and quality by decreasing the percentage of dry matter in the tubers (Alva, 2004; Suárez *et al*., 2006). The potato crop can absorb N in the form of nitrate (NO_3^-) and ammonia (NH_4^+), which depend on the age of the plant and the pH of the soil. However, as the availability of nitrate increases, the plant has higher growth rates (Pumisacho and Sherwood, 2002).

Phosphorus is an essential macronutrient in respiration and photosynthesis plant processes. It is part of nucleoproteins, lipids, and phospholipids. It acts on the roots development and meristematic tissues (Salisbury and Ross, 2000; Pumisacho and Sherwood, 2002; Bernal and Espinosa, 2003). Regarding potassium, a crop with high yields can absorb more than 340 kg ha^{-1} of K_2O (MINAGRI, 2011). In potato cultivation, K is needed for the transport of sugars from leaves to the tubers (Becerra-Sanabria *et al*., 2007).

The national average potato yield was 13.72 t ha^{-1} in 2011, being Lima (23.90 t ha^{-1}) and Arequipa (32.77 t ha^{-1}), the departments that contributed the most (MINAGRI, 2012). By 2016, Peru was ranked as the 14th country in potato production worldwide; however, its productivity level (14.78 t ha^{-1}) is 26% lower than the world average. The regions of Arequipa, Ica, and Lima achieved the best average yields with 33.5, 32.2, and 22.7 t ha^{-1}, respectively (MINAGRI, 2017). However, it was not enough since the national average yield has not increased significantly over the last 20 years. On the Peruvian coast, the increase in potato productivity is due to the improved varieties, good quality seed, and high levels of fertilization. However, the soil salinization levels can negatively affect the high dependence on mineral fertilizers (Marchese, 2015). Therefore, the present study was conducted to evaluate the effect of nitrogen and phosphorus fertilization sources and their interaction on the potato cultivation yield under the soil and climate of Peruvian coast conditions.

MATERIALS AND METHODS

The investigation was carried out at the Lagunas farm, in the town of Vinto Bajo, district and province of Barranca in the department of Lima, located at 49 masl, with geographical coordinates, latitude 10°45'1" and longitude 77°45'1". The soil was sandy loam texture, with slightly alkaline pH (7.53), high amount of $CaCO_3$ (5.25%), low organic matter (0.75%), low phosphorus concentration (6.2 ppm), average potassium content (101 ppm), and 1.31 dS m^{-1} of electrical conductivity (qualified as very slightly saline). According to MINAGRI (2011), the acceptable pH for potato production ranges from 5 to 7.

The maximum temperature occurred during the seedling emergence and the minimum temperature in the flowering stage (Figure 1). Low temperatures promoted the tuberization phase, reaching values of 16.7 °C. The medium temperature during crop development fluctuated between 10.75 °C and 20.05 °C. The temperature between sowing and germination should range between 18-24 °C and 15-22 °C during the growing period. An optimal temperature during the potato tuber bulking phase is 14-18 °C because lower than 10 °C and upper than 30 °C could inhibit the tuber development (Kim and Lee, 2019; MINAGRI, 2012).

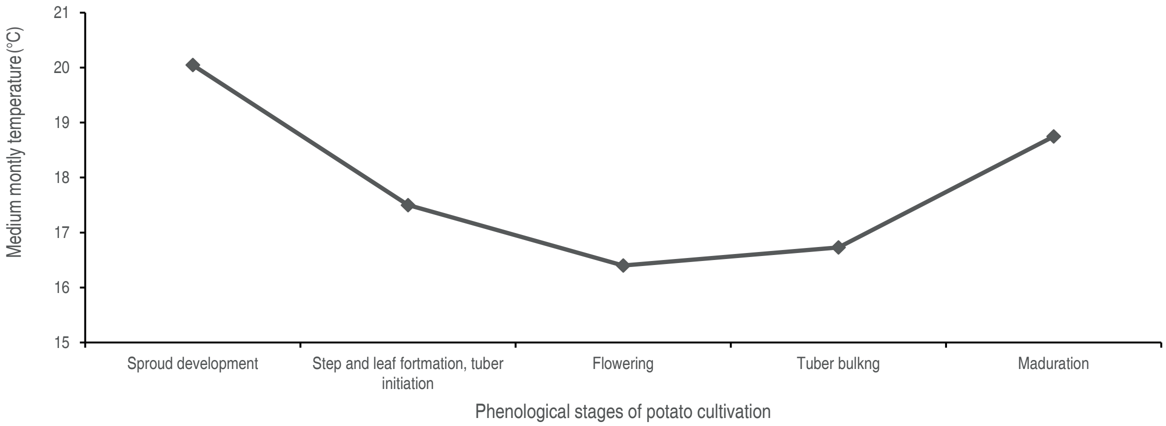

Figure 1. Variation in medium monthly temperature during the experimental phases: Sproud development (30 days after sowing (DAS)); stem and leaf formation and tuber initiation (60 DAS); flowering (75 DAS); tuber bulking (90 DAS); maduration (120 DAS).

The genetic material used for sowing was the improved variety INIA-303 Canchan, widely used in the main potato producing areas of the Peruvian coast since farmers can obtain up to 30 t ha^{-1} in the 120 days (MINAGRI, 2012). A 3×3 factorial randomized block design was established with three nitrogen fertilization sources and three phosphorus fertilization sources as independent factors (nine treatments and four repetitions) (Table 1).

Urea [$CO(NH_2)_2$] with 46% N, Ammonium Nitrate (NO_3NH_4) with 33% N and Ammonium Sulfate $SO_4(NH_4)_2$ with 21% N and 24% S were used as nitrogen fertilization sources. Diammonium Phosphate [$(NH_4)_2HPO_4$] with 18% of N and 46% of P_2O_5, Triple superphosphate $(H_2PO_4)_2$ with 46% P_2O_5, and Monoammonium Phosphate ($NH_4H_2PO_4$) with 11% N and 52% P_2O_5 were used as phosphorus sources (Reetz, 2016).

Table 1. Factors under study.

F1: Nitrogen Sources	F2: Phosphorus Sources	F1×F2 Treatments		
N1: Urea	P1: Diammonium phosphate (DAP)	1: N1P1	4: N2P1	7: N3P1
N2: Ammonium nitrate (AN)	P2: Triple superphosphate (TSP)	2: N1P2	5: N2P2	8: N3P2
N3: Ammonium sulfate (AS)	P3: Monoammonium phosphate (MAP)	3: N1P3	6: N2P3	9: N3P3

The treatments were composed of the combinations of the factors under study (Table 1). The NPK fertilizer formula for all treatments was 276, 166, and 250 kg of N, P_2O_5, and K_2O, respectively. The potato crop usually requires large amounts of K (MINAGRI, 2011).

Fertilization was carried out manually and fractionally. In the sowing period, 60% of P and 36% of N was applied. 46 days after sowing (DAS), the second fertilization was performed, which corresponds to 36% N and 40% P. On 66 DAS, 28% N was added. N was applied fractionally on two stages, according to Egusquiza (2014), 50% N+PK during the sowing period and then at the first hilling period other 50% N.

Tuber number per plant (TNPP), total weight tuber per plant (TWPP), Total (TY), and Commercial (CY) yield were evaluated as the dependent variables (Table 2).

The data obtained for the treatments applied were analyzed, assuming normality and significance of variance by Shapiro-Wilk and Fisher tests (P<0.05),

Table 2. Variables under study and evaluation procedure.

Variables under study	Procedure
Tuber number per plant (TNPP)	Five plants were randomly selected from the central rows of each experimental unit. The number of tubers per plant was then averaged.
Tuber weight per plant (TWPP)	Five plants were chosen at random from the central rows of each experimental unit. The tubers were weighed per plant and expressed in kg per plant.
Total yield (TY) and commercial yield (CY)	Ten linear meters were harvested for each experimental unit, and the yield was expressed in t ha^{-1}. Commercial categories was taken into consideration and expressed in t ha^{-1}.

respectively. Once these assumptions were verified, data were subjected to a two-way ANOVA. Mean values were compared using the Duncan test (P<0.05). All analyses were performed by the statistical software Infostat (Di Rienzo *et al*., 2011).

RESULTS AND DISCUSSION

Nitrogen sources, phosphorus sources, and their respective interaction were highly significant (P<0.01) for total yield and tuber weight per plant; whereas, for commercial yield and the number per plant, the nitrogen sources, phosphorus sources, and their respective interaction were significant at P<0.05. The interaction of the fertilization sources also presented an effect on the variables. Therefore, there was no influence of an uncontrolled factor variation in the experiment (Table 3).

Table 3. Values of F, significance, and coefficients of variation (CV) for total yield Commercial yield, Tuber number per plant, Tuber weigh per plant, by nitrogen and phosphorus fertilization sources.

Sources of variation	TY	CY	TNPP	TWPP
Nitrogen Sources (N)	40.419**	31.374**	3.034*	0.052**
Phosphorus sources (P)	15.919**	12.928**	2.621*	0.023**
N×P	6.598**	5.674*	2.384*	0.036**
Error	0.665	1.711	0.755	0.002
CV (%)	2.62	4.81	8.44	4.13

*P<0.05; **P<0.01
TY: Total Yield; CY: Commercial Yield; TNPP: Tuber number per plant; TWPP: Tuber weigh per plant; CV: Coefficient of variation.

The highest total yield (TY) was found with the N2P1 (AN+DAP) treatment and was higher than the combinations N3P3 (AS+MAP) and N2P3 (AN+MAP) by 3.03% and 4.71%, respectively. For the nitrogen fertilization sources, it could be most recommended the AN and for phosphorus sources, the DAP and MAP according to the soil and climate conditions of the study (Figure 2).

Yields of the urea combinations with DAP, MAP, and TSP were lower compared to the two combinations described above. It could be due to urea does not respond in alkaline or slightly alkaline soils (Cépeda, 2010). The AN has a better response in coastal conditions because the plant develops better when nitrates are available (Pumisacho and Sherwood, 2002), while AS improves the assimilation of P because its acidifying effect reduces soil pH.

According to (MINAGRI, 2011), in strongly alkaline soils, the availability of minor elements is low, which can affect crop yield. Urea is recommended for acidic and neutral soils because, in limestone soils, significant nitrogen losses can occur due to volatilization (Cépeda, 2010). The acidity index of urea, AN, and AS (-84, -63, and -110, respectively) is a favorable factor for temporarily buffering soil pH. Excessive acidification can affect the availability of

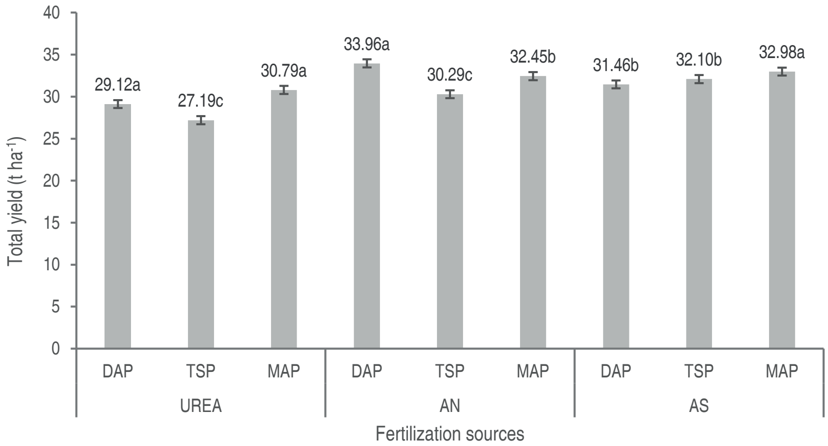

Figure 2. Total yield of INIA-303 Canchan tubers (t ha^{-1}) with the interaction of nitrogen and phosphorus sources. Different letters within the nitrogen source mean a significant difference (*P*>0.05).

nutrients for plant growth, the levels of phytotoxic elements, the microbial activity, and even the physical conditions of the soil (Cépeda, 2010; Presutti *et al.*, 2017). Gutiérrez (2015) stated that the management of nitrogen fertilization, in terms of dose, time, and method of application, influences the yield and quality of the potato tuber. Optimal nitrogen fertilization and irrigation water management are important to improve nitrogen uptake efficiency and minimize N losses (Alva, 2004). The management of these factors is a challenge in the different soils where potatoes are grown, which are generally vulnerable to water leaching and soluble nutrients (Sifuentes *et al.*, 2015). In general, fertilizers with a high content of ammonium nitrogen origin can acidify soils when they are applied repeatedly. Microorganisms in the soil convert the nitrogen from ammonium (NH_4^+) to nitrate (NO_3^-), thus releasing ions H^+, which acidify the soil (Wadas and Dziugiel, 2015).

For commercial yield (CY), the highest value was achieved by AN+DAP, which was statistically similar to the AN+MAP. AN+TSP was the lowest value (26.10 t ha^{-1}) and is different from other treatments. The combination AS+MAP achieved the best value (29.18 t ha^{-1}), but it did not have a statistical significance (Figure 3). The combinations of urea with DAP, TSP, and MAP showed a lower yield, possibly due to the acidity index of the fertilizers used.

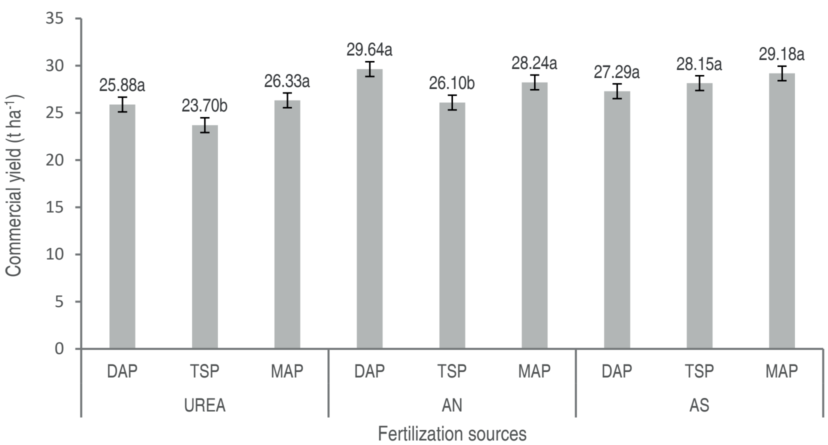

Figure 3. Interaction of nitrogen and phosphorus sources in the commercial yield of INIA-303 Canchan tubers (t ha^{-1}). Different letters within the nitrogen source mean a significant difference (*P*>0.05).

According to MINAGRI (2017), the average yield at the coastal level was 25 t ha^{-1}. Both the total yield and commercial yield were above the national average (14.5 t ha^{-1}). Soil fertility is a quality resulting from the interaction between the physical, chemical, and biological characteristics of the soil, and it consists of the capacity to provide necessary conditions for plant growth and development (Egusquiza, 2014). Soil pH has an indirect influence on chemical processes, nutrient availability, biological processes, and microbial activity (MINAGRI, 2011).

The highest TNPP and TWPP were found by the AN+DAP (Figure 4 and Figure 5). AN+DAP combination, for the TNPP variable, was higher than AN+MAP and AS+MAP treatments with 4.90% and 15.72%, respectively. AN+DAP was higher than AS+MAP and AN+MAP with 3.03% and 4.71%, respectively for the TWPP variable. The highest TNPP average was 11.85, while the highest TWPP was 1,214 kg per plant. According to Egusquiza (2014) and INIA (2012), the cultivar INIA-303 Canchan has 20 tubers per plant as the average TNPP, while the average TWPP can reach 1 kg per plant.

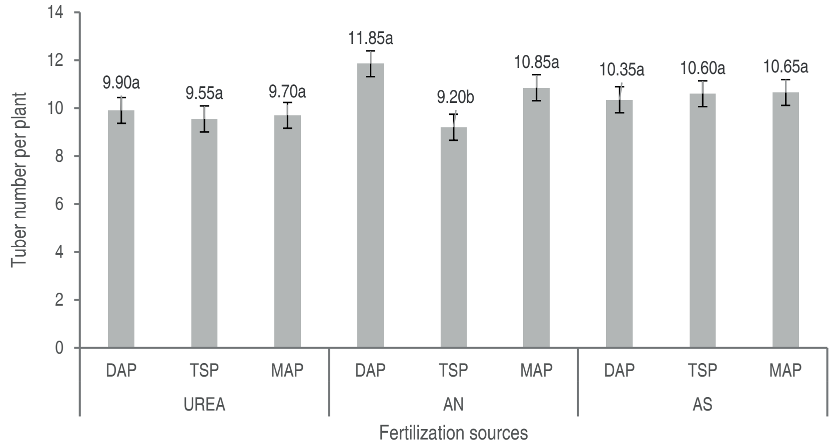

Figure 4. Effect of the combination of nitrogen and phosphorus sources in the variable tuber number per plant yield (TNPP). Different letters within the nitrogen source mean a significant difference (*P*>0.05).

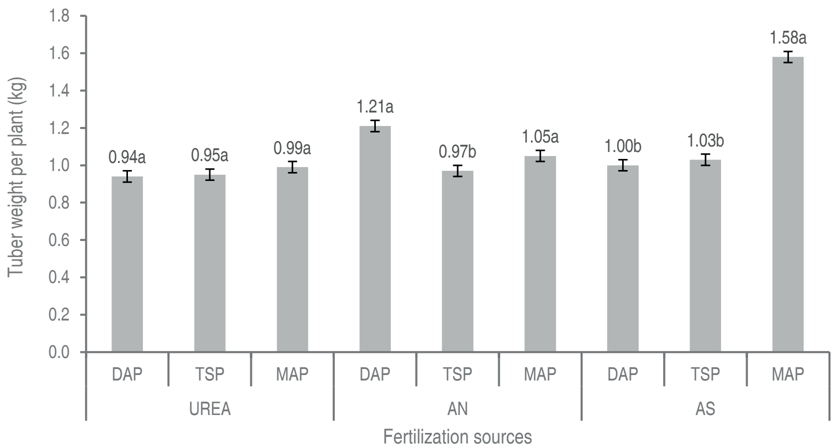

Figure 5. Effect of the combination of nitrogen and phosphorus sources in the tuber weight per plant yield (TWPP). Different letters within the nitrogen source mean a significant difference (*P*>0.05).

CONCLUSIONS

The INIA-303 Canchan cultivar showed positive response to the combinations of nitrogen and phosphorus fertilization sources under the soil and climate conditions of the Peruvian coast. The total and commercial yield, tuber number per plant and tuber weigh per plant were significantly affected by the interaction of nitrogen and phosphorus sources. The highest total yield, commercial yield, number and weight of tubers per plant were found with the combination of ammonium nitrate+diamonic phosphate. The three most recommended mixtures for the fertilization of the INIA-303 Canchan potato variety sown in Peruvian coast, to achieve yields between 32.45 t ha^{-1} and 33.98 t ha^{-1}, are ammonium nitrate+diammonium phosphate, ammonium sulfate+monoammonium phosphate, and ammonium nitrate+monoammonium phosphate.

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