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Humic Acids and Potassium from Organic Sources on the Yield and Economic Profitability of Paprika Cultivation in an Arid Zone

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Abstract

The preference for healthy food requires reorienting agricultural activity towards the use of organic inputs to guarantee the safety of products without risking their profitability; this aspect is decisive in arid zones with soils deficient in organic matter and potassium. The objectives were: to determine the best interaction between levels of humic acids and potassium from organic sources in the total and classified yield of paprika fruits (Capsicum annuum L.) "papri queen"; as well as to establish the best economic profitability of the crop. The research was carried out in an arid zone soil of the Majes Irrigation, Arequipa, Peru. The treatments were two levels of humic acids: 218 kg ha^{-1}(A1); 436 kg ha^{-1}(A2) and three levels of potassium: 1.0 l ha^{-1} (K1); 2.0 l ha^{-1} (K2); 3.0 l ha^{-1} (K3); This resulted in six treatments, with three replications each, arranged in a randomized complete block experimental design. The best total fruit yield was obtained by the A2K2 treatment (7980 kg ha^{-1}) of which, 90 % were first quality fruit and 10 % second quality. The highest yield index was 134 % for treatment A2K2; this treatment also favored fruit weight and length.

Key words: *Capsicum annuum*, organic fertilizer, organic matter, soils.

INTRODUCTION

The international trend for the consumption of healthy food requires producers to reorient their activities by adopting sustainable production systems prioritizing the use of technologies that respect safety parameters (Abreu et al., 2018; Soto, 2020). The increase in quality and yield with the rational

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use of productive resources constitute determining aspects to meet market demands (Tafur, 2009). In this context, the use of organic inputs to replace conventional ones is a priority in the research of sustainable agricultural systems (Soto, 2020). Agricultural systems must guarantee the provision of quality food to consumers which will be the backing for accessing international and national markets that economically recognize this type of food (Reyes *et al*., 2017).

The cultivation of paprika (Capsicum annuum L.) is of great economic importance worldwide, it is a species marketed for fresh and dried consumption. It contains nutritional properties, being a source of phenolic compounds and antioxidants such as vitamin C (El-Mogy et al., 2019). In Peru, paprika cultivation extends mainly in arid areas because they offer appropriate climatic conditions for its development (García-Montero et al; 2020). It has the advantage of being produced throughout the year, which allows supplying the international market continuously, being a crop of social and economic importance; however, soils contain deficient levels of organic matter and nutrients including potassium, which plays a key role in the formation of fruits (El-Mogy *et al*., 2019).

Currently, most producers located in arid zones use high levels of chemical fertilizers to compensate for nutritional deficiencies in the paprika crop with the risk of contaminating the fruit; therefore, it is necessary to validate the impact of the use of organic fertilizers and their response on yield in order to contribute to the innovation of technologies to improve productivity in arid zones through sustainable management alternatives (Soto, 2020). The application of organic fertilizers has attributes to improve the chemical, physical and biological properties of the soil and generally the costs of its use are significantly lower compared to chemical fertilizers (Rai *et al*., 2014).

In arid areas, the low availability of organic matter to supply paprika fields is one of the main drawbacks, and it is very difficult for farmers to obtain it; therefore, the use of humic acids is an alternative (Galantini and Suñer, 2008). Likewise, potassium from organic sources is one of the nutrients demanded in important quantities by the paprika plant as it intervenes in the carbohydrate transport processes very determinant during the growth and development stage of the fruit (Abreu et al., 2018). The effects of using humic acids showed improvements in yield and quality of paprika fruits (Karakurt et al., 2009; Aminifard et al., 2012). The application of humic acids combined with other fertilizers is an alternative to supplement bell pepper nutrition (Trevisan *et al.*, 2010).

On the other hand, several studies documented that potassium application favors paprika fruit quality and production (Shehata et al., 2019; Preciado-Rangel et al., 2019, Botella et al., 2017; Golcz et al., 2012; Hernández-Fuentes et al., 2010). A timely and rational provision of nutrients for crops

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requires determining the nutritional requirements as well as knowing the supply of nutrients available in the soil (Grasso and Díaz-Zorita, 2020). In case the soil cannot provide the nutrients for proper growth and development, their incorporation in adequate amounts and forms will be necessary (Escalona and Pire, 2008; Salas, 2002). This is the condition of soils in arid areas, with deficiency of organic matter and nutrients (Mazuela, 2013) that allowed this research to be proposed. The hypothesis proposed was that the incorporation of humic acids and organic potassium can induce an increase in paprika yield, as well as the economic profitability of the crop.

Consequently, the objectives of the research were to determine the best interaction between humic acid and potassium levels from organic sources in the total and classified yield of paprika (Capsicum annuum L.) "papri queen" fruits, as well as to establish the best economic profitability of the crop under soil and climatic conditions of arid zones.

MATERIALS AND METHODS

Site

The research was carried out in arid lands corresponding to the Majes Irrigation, Arequipa, Peru; located at 16º 30' 12" S; 73º 20' 62" W; altitude 1280 m.a.s.l. The mean monthly temperature ranged between 18 and 20.5 oC; with no rainfall. The initial soil analysis was carried out at the Soil, Water and Seed Laboratory of the Experimental Station - INIA - Arequipa, and reported a sandy loam texture with 0.09 % of organic matter (OM); 2.62 ppm of available P and 28.75 available K. The experimental plot offered very limited organic matter (OM) content. The experimental soil offered very limited content of organic matter and available potassium for an adequate development of the paprika crop (Julca-Otiniano et al., 2006; El-Mogy et al., 2019); this soil condition justified the incorporation of humic acids and potassium from organic sources.

Methodology

The experimental soil was prepared by conventional tillage, while planting was done by transplanting paprika "papri queen" seedlings, with a distance of 0.75 m between rows and 0.25 m between plants, with a density of 53191 plants/ha. The treatments evaluated were two levels of humic acids: 218 kg ha^{-1}(A1); 436 kg ha-1(A2) and three levels of potassium from organic sources: 1.0 l $ha-^{1}$ (K1); 2.0 l ha^{-1} (K2); 3.0 l ha-1 (K3); whose interaction resulted in six treatments, with three replications each, totaling 18 experimental units arranged in a randomized complete block experimental

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design. Humi plus 80® (granular formulation) with 80% humic acids was used as a source of humic acids, which was incorporated into the soil before transplanting in 50% of the dose, and the remaining 50% was incorporated 60 days after transplanting. Bioflora® (liquid formulation) with 25% K2O was used as a source of potassium, which was incorporated in four fractions at 60, 90, 120 and 150 days after transplanting, in total doses each time and via the irrigation system. The irrigation system was drip irrigation with a total volume of 8544 m3/ha.

Complementary fertilization was based on 100 kg of urea, 150 kg of monoammonium phosphate and 152 kg of calcium nitrate applied by fertigation. The fruits were harvested manually by bending the insertion of the peduncle with the stalk; fruits of intense red color, wrinkled tip and flaccid consistency were collected (Nuez et al., 1996). Fruit drying was carried out outdoors by spreading the fresh fruit on a black plastic base for a week, turning them every day to achieve uniform drying of the fruit until they reached 12 or 14% humidity (Zapata et al., 1992). The cultivation period was seven months. The following evaluations were made: 1) average plant size (cm); the measurement was recorded from the beginning of the plant stem to the apex of growth, in 10 plants chosen at random for each treatment and 135 days after transplanting seedlings. 2) average fruit weight (g) and length (cm); it was measured on 10 fruits for each treatment at the end of harvest. 3) total and classified fruit yield (kg ha^{-1}); total fruit weight was recorded for each treatment and then classified into first and second grade fruit.

The criterion to classify first quality fruits was to select fruits of intense red color but without spots of another color, whole healthy fruits and free of scalds, spots and wounds; second quality fruits correspond to fruits of red color but that present discolorations observable to the naked eye, as well as spots, burns and scalds (Nuez et al., 1996, Zapata et al., 1992). The total and classified yields correspond to nuts. 4) Analysis of economic profitability; it was calculated based on the control of direct and indirect costs incurred in conducting the experiment for each treatment, which were projected for one hectare of crop.

Statistical analysis

The detection of statistical differences at the treatment level was performed by analysis of variance using SPSS version 21 software; Tukey's significance test ($p < 0.05$) was also developed in order to test for relevant statistical differences between treatments evaluated (Steel and Torrie, 1996)

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RESULTS AND DISCUSSION

Plant size, weight and length of paprika fruits

Table 1 shows the effect of treatments on plant size, weight and length of paprika fruits. The results show acceptable coefficients of variability, giving reliability to the data recorded (Steel and Torrie, 1996). Tukey's significance test ($p<0.05$) showed that the incorporation of treatments had no significant statistical differences in plant size.

Table 1. Plant size, weight and length of paprika "papri queen" fruits by the effect of the application of humic acids and potassium from organic sources in arid zones.

Treatments	Plant size (cm)	Fruit weight (g)	Fruit length (cm)
A1K1	64.0 a	11.0 c	12.8 b
A1K2	66.5 a	12.4 bc	15.5 ab
A1K3	64.2 a	11.3 bc	13.2 b
A2K1	66.8 a	13.5 bc	17.2 a
A2K2	70.6 a	16.6 a	19.0 a
A2K3	68.3 a	14.0 b	17.7 a
CV(%)**	9.85	10.85	11.48

A1K1: 218 kg ha^{-1} humic acids and 1 l ha^{-1} potassium; A1K2: 218 kg ha^{-1} humic acids and 2 l ha^{-1} potassium; A1K3: 218 kg ha^{-1} humic acids and 3 l ha^{-1} potassium; A2K1: 436 kg ha^{-1} humic acids and 1 l ha^{-1} potassium; A2K2: 436 kg ha^{-1} humic acids and y 2 l ha^{-1} potassium; A2K3: 436 kg ha^{-1} humic acids and 3 l ha^{-1} potassium. (*) Equal letters in each column indicate that there are no significant statistical differences between treatments according to Tukey ($p<0.05$). (**) CV: Coefficient of variability.

The incorporation of 436 kg ha^{-1} of humic acids and 2 l ha^{-1} of potassium (A2K2) had the greatest effect on paprika fruit weight and length with significant statistical difference. The trend of the results revealed that doubling the level of acids associated with an intermediate level of potassium (A2K2) improved the weight (16.6 g) and length (19.0 cm) of paprika fruits, while the A1K1 treatment only achieved a weight of 11.0 g and a length of 12.8 cm.

The addition of humic acids provides favorable soil conditions and is also related to the

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availability of organic nitrogen in the soil (Ryabova, 2010), an element closely associated with the development of paprika foliage, increasing the photosynthetic efficiency of the plant in indirect benefit of fruit formation (Veobides-Amador et al., 2018). in addition, humic acids can behave as inducers of phytohormones such as indole acetic acid stimulating the development of paprika fruits (Nardi et al., 2002; Pasqualoto et al., 2009). these are macromolecules that play a determining role in the regulation of nutrient mobility in the soil (Christi et al., 2000). Their inclusion in fertilization plans is supported by generating positive physiological, biochemical and morphological impacts on various crops (Rivera-González et al., 2017).

Paprika fertilization with potassium from organic source at the intermediate level (2 l ha^{-1}) had better response in fruit weight and length. It is documented that potassium participates regulating the movement of opening and closing of stomata (Preciado-Rangel et al., 2019) is an enzymatic activator, improves photosynthesis and participates in the active transport of photoassimilates (Shehata et al., 2019). According to these reports, it can be deduced that the application of potassium was determinant in the increase of weight and length of paprika fruits.

Total and graded yield of paprika fruits

The results of the total and classified yield of paprika "papri queen" fruits shown in Table 2 correspond to dry fruits and demonstrate that the integrated fertilization of 436 kg ha^{-1} of humic acids and 2 l ha^{-1} of potassium (A2K2) had the best response, with data that offer significant statistical difference ($p<0.05$) with respect to the other treatments according to Tukey's test; the records present coefficients of variability with values considered acceptable for research of this type, giving reliability to the results (Steel and Torrie, 1996).

The trend of the results indicates that the A2K2 treatment achieved a total yield of 7980 kg ha^{-1} of paprika of which 90 % represents first quality fruits (7182 kg ha^{-1}) and 10 % second quality fruits (798 kg ha^{-1}). On the other hand, the A1K1 treatment achieved a total fruit yield of 5002 kg ha^{-1} of which 60 % are first quality fruits (3004 kg ha^{-1}) and 40 % second quality fruits (1998 kg ha^{-1}). Doubling the application of humic acids from 218 to 436 kg ha^{-1} obtained a favorable response in paprika yield. This behavior was also evaluated by Shamsullah (2020) who found that fertilization with 12 l ha^{-1} of humic acids increased paprika yield significantly up to 12.86 t ha^{-1}.

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Table 2. Total and sorted (first and second) yields of paprika paprika "papri queen" fruits by effect of humic acid and organic source potassium application in arid areas.

Treatments	Total yield (kg ha^{-1})	Performance first (kg ha^{-1})	Performance first (kg ha^{-1})
A1K1	5002.0 c	3004.0 d	1998.0 a
A1K2	5944.0 bc	4458.0 c	1486.0 bc
A1K3	5568.0 c	3898.0 cd	1670.0 ab
A2K1	6122.0 bc	4896.0 bc	1226.0 cd
A2K2	7980.0 a	7182.0 a	798.0 e
A2K3	6895.0 b	5860.0 b	1035.0 de
CV(%)**	9.71	10.92	14.88

A1K1: 218 kg ha^{-1} humic acids and 1 l ha^{-1} potassium; A1K2: 218 kg ha^{-1} humic acids and 2 l ha^{-1} potassium; A1K3: 218 kg ha^{-1} humic acids and 3 l ha^{-1} potassium; A2K1: 436 kg ha^{-1} humic acids and 1 l ha^{-1} potassium; A2K2: 436 kg ha^{-1} humic acids and 2 l ha^{-1} potassium; A2K3: 436 kg ha^{-1} humic acids and 3 l ha^{-1} potassium. (*) Equal letters in each column indicate that there are no significant statistical differences between treatments according to Tukey ($p<0.05$). (**) CV: Coefficient of variability.

Humic substances present a very complex composition and structure with several beneficial functions among them decreasing the effects of abiotic stress and increasing yields (Veobides-Amador et al., 2018; Huelva et al., 2013); the favorable response of humic acid applications on crops would also be associated to benefits in soil properties (Julca-Otiniano et al., 2006; Celestina et al., 2019) acting as an amendment (Meléndez, 2003) improving especially the cation exchange capacity of soils to facilitate nutrient exchange between soil and plants (Anillo-Correa et al., 2013; Vázquez et al., 2020), these aspects allowed favoring the yield of paprika crop.

In relation to the effect of potassium, the results show that the intermediate level (2 l ha-1) generated the best response in the total yield of paprika fruits. On the other hand, the increase up to 3 l ha-1 does not increase yield, a situation that is explained by the law of diminishing returns (Grasso and Díaz-Zorita, 2020). In this regard, Salas (2002); Botella et al. (2017) state that when the potassium supply is excessive, "luxury consumption" of potassium occurs without improving crop yield. In arid areas, potassium application is of great interest because it induces the plant to overcome water deficiency stress (Constán-Aguilar et al., 2014, Lo Scalzo et al., 2014) by participating in the

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mechanism of regulation of stomata opening and closing to control the water regime and reduce the transpiration rate (Medina-Lara et al., 2008), also favoring the transport of solutes from the leaves to the fruits (El-Mogy et al., 2019) and increasing the yield of paprika fruits.

Economic profitability of paprika cultivation

The trend of the results of the economic profitability analysis shown in Table 3 indicates that the total cost of production of paprika fruits increases as the level of application of treatments increases.

Table 3. Economic profitability analysis of paprika "papri queen" cultivation due to the effect of the application of humic acids and potassium from organic sources in arid zones.

Treatments	CD ($)	CI ($)	CT ($)	Rdto (kg ha^{-1})	PV ($)
A1K1	2771.51	790.77	3562.28	5002	1.20
A1K2	2855.31	805.85	3661.16	5944	1.20
A1K3	2939.11	820.94	3760.04	5568	1.20
A2K1	3136.87	856.54	3993.41	6122	1.20
A2K2	3220.67	871.62	4092.29	7980	1.20
A2K3	3304.47	886.70	4191.17	6895	1.20
Treatments	IT ($)	IN ($)	B/C	RN	IR (%)
A1K1	6002.400	2440.121	1.685	0.6850	68.50
A1K2	7132.800	3471.638	1.948	0.9482	94.82
A1K3	6681.600	2921.555	1.777	0.7770	77.70
A2K1	7346.400	3352.992	1.840	0.8396	83.96
A2K2	9576.000	5483.709	2.340	1.3400	134.00
A2K3	8274.000	4082.827	1.974	0.9741	97.41

CD: direct cost; IC: indirect cost; TC: total cost; TCO: total yield of paprika nuts; PV: selling price per kg of paprika nuts in US dollars; IT: total income (IT: TCO x PV); IN: net income (IN: IT -CT); B/C: benefit-cost ratio (BC: IT/CT); NR: net profitability (NR: NR/CT); IR: economic profitability index (IR: NR x 100); $: US dollars; $: US dollars.

Treatment A2K2 achieved the highest profitability index (134.0%) associated with a better response in paprika fruit yield (7980 kg ha^{-1}), demonstrating a difference of 36.59% in the profitability index compared to treatment A2K3 which offers the second-best yield, as well as a difference of 65.5%

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with respect to A1K1 which achieved the lowest yield. Regarding the difference in the profitability index between A2K2 and A2K3, it is evident that the additional application of 1 l ha^{-1} of potassium from organic sources did not have any favorable economic effect, this behavior is due to the additional cost involved in its application.

Thus, the profitability analysis corresponding to the A2K2 treatment implies that an investment of $ 4092, 29 US dollars was made and a net income of $ 5483,709 US dollars was obtained, representing 134.0 % of the investment; that is, the investment was recovered and a significant net income was achieved by the incorporation of the A2K2 treatment. Obviously, this profitability will be of great interest to the paprika producer in arid areas. Regarding the results; López-Marín et al. (2016) argue that the paprika crop has worldwide transcendence due to its high production, adaptability and competitiveness in the market. It acquires social and economic importance for producers in arid zones where the extension of cultivated land increased significantly due to the appropriate climate, although the soils contain deficient levels of organic matter (Mazuela, 2013). In this context, the economic evaluation of its cultivation turns out to be transcendental, because the fertilization proposals with better responses in crop yield must also be viable from the economic point of view (Leela et al., 2015) for its adoption by paprika producers in arid areas.

CONCLUSIONS

Under arid soil and climatic conditions, the best yield of paprika fruits was achieved as a result of fertilization with 436 kg ha^{-1} of humic acids and 2 l ha-1 of potassium from organic sources (A2K2), achieving a total nut yield of 7980 kg ha-1; of which 90 % (7182 kg ha^{-1}) corresponded to first quality fruits and 10 % (798 kg ha^{-1}) to second quality fruits. The highest profitability index of the paprika crop was 134 % for the A2K2 treatment. This treatment also favored fruit weight (16.6 g) and fruit length (19.0 cm). Consequently, the complementary use of humic acids and potassium from organic sources offers good prospects for the fertilization of paprika crops in arid zones.

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