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Hilling effect on yield and profitability of native potato cultivars

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Abstract

In potato cropping, the opportunity and the number of hillings are directly related to yield, commercial quality, and production costs. The research was carried out with the aim of establishing the effect of the number of hillings on biometric and agronomic characteristics (plant height, number of stems, number of stolons, total yield, and commercial yield) and the profitability index of native potato cultivars. The factors under study were three native potato cultivars: Huayro, Peruanita, and Tumbay, and two hilling moments. The study was conducted under a completely randomized block design with a 3x2 factorial arrangement, and four repetitions. The cultivar interaction by the number of hillings carried out was highly significant for total yield and commercial yield. In the three cultivars, when carrying out one or two hillings, the favorable effect was found in higher total and commercial yields. Concerning the Huayro cultivar, the highest total (kg/ha) and commercial yields (kg/ha) were found when it was hilled on two occasions ($p < 0.001$). With zero hilling, total yield losses of 86.02 %, 3.67 %, and 47.89 % were observed in the cultivars Huayro, Peruanita, and Tumbay, respectively. In the economic analysis, the Tumbay cultivar recorded the highest rate of return with a single hilling. For the cultivars Huayro and Tumbay, a second hilling was economically unjustified.

Keywords: crop yield, culture techniques, hilling, potatoes, productivity

Efecto del aporque en el rendimiento y la rentabilidad en cultivares nativos de papa

Resumen

En el cultivo de papa, la oportunidad y el número de aporques tienen relación directa con el rendimiento, la calidad comercial y los costos de producción. El objetivo de esta investigación fue determinar el efecto del número de aporques en las características biométricas y agronómicas (altura de planta, número de tallos, número de estolones, rendimiento total, rendimiento comercial) y el índice de rentabilidad de tres cultivares nativos de papa: Huayro, Peruanita y Tumbay. Los factores estudiados fueron las tres variedades de papa y dos momentos de aporque; el diseño fue de bloques completos al azar con arreglo factorial 3×2 en cuatro repeticiones. La interacción cultivar por número de aporques fue altamente significativa para las variables rendimiento total y rendimiento comercial. En los tres cultivares, al realizar uno o dos aporques se constató el efecto favorable en mayores rendimientos total y comercial. El cultivar Huayro obtuvo los mayores rendimientos total (kg/ha) y comercial (kg/ha) cuando fue aporcado en dos oportunidades ($p < 0{,}001$). Con el aporque cero se observaron pérdidas en el rendimiento total de 86,02 %, 3,67 % y 47,89 % en los cultivares Huayro, Peruanita y Tumbay, respectivamente. En el análisis económico, el cultivar Tumbay, con un solo aporque, obtuvo el mayor índice de rentabilidad; un segundo aporque en los cultivares Huayro y Tumbay no se justifica económicamente.

Palabras clave: aporque, papas, productividad, rendimiento de cultivos, técnicas de cultivo

Introduction

In the current context of climate change, resource degradation, scarcity of energy sources, and a growing world population, there is no other alternative but to intensify agricultural production (Gómez-Calderón et al., 2018). This process must be, however, sustainable in economic, environmental, social, and institutional terms (Toledo, 2016).

Under this sustainable development approach, cultivation practices will require cultivars adapted to different agroclimatic conditions, technological alternatives that contribute to the efficient use of resources, and production methods that incorporate effective practices –like conservation agriculture– to improve biological processes in the soil with minimal mechanical alteration and facilitate the retention of crop residues and other plant-origin materials in the soil (Aliaga et al., 2017; Cadena et al., 2012; García et al., 2018; Nyawade; et al., 2019).

Intensive tillage is a growing problem and constitutes a threat to the sustainability of potato cultivation throughout the world (Cadena et al., 2012; Villalobos-Arraya et al., 2009). Consequently, technological alternatives that allow acceptable productivity with the lowest possible cost, such as, e.g., reducing the number of hillings in potato crops, will be necessary (Caycho-Ronco et al., 2009).

The practice of hilling consists of accumulating soil to form a ridge at the base of the stem of each plant (Sulca, 2016), creating furrows that allow irrigation work and facilitate the evacuation of excess rainwater (Condori-Mamani et al., 2017; Egúsquiza, 2014; Sulca, 2016; Toledo, 2016).

In the high Andean areas, hilling is also used to control early weeds (Reategui et al., 2019), and according to Aliaga et al. (2017), it is generally done manually on two occasions. However, in some producing areas of Bolivia, traditionally, a single hilling is carried out 60 days after sowing (das). Regarding the timing and number of hillings, Egúsquiza (2014) states that this work must be carried out before the start of tuber formation, although the characteristics of the cultivar and the climatic conditions must be considered. In cultivars with a short vegetative period, hilling anticipates late production potatoes. Generally, in mountain areas, this practice is carried out when the plants reach 25 cm of height (Aliaga et al., 2017; Sulca, 2016).

Given that not only the number of hillings but also the moment in which they are carried out is decisive in yields (Aliaga et al., 2017; Chala, 2016; Egúsquiza, 2014), it is advisable to handle the tuberization curves to favor higher productivity (López et al., 1980; Sulca, 2016). Egúsquiza (2014) and Reategui et al. (2019) specified in days that the first hilling must be made between 50 and 60 das, and the second hilling between 75 and 93 das.

In potato crops cultivated at the sea level, a single hilling is recommended. On the other hand, in irrigation and rainfed highland potato production systems, two hillings are recommended when the physical characteristics of the soil do not favor the conservation of the shape and height of the ridges, which can affect the commercial quality of potato tubers (López et al., 1980; Sulca, 2016; Toledo, 2016).

There is a consensus that hilling does not affect yield, but it serves to prevent plants from falling over, forming and maintaining furrow lines, and preventing tubers from being uncovered and greening or being affected by frost. Besides, a well-done hilling can reduce economic losses due to the damage of pests, such as the potato late blight *Phytophthora infestans* (Mont.) de Bary (Oomycota: Peronosporales: Peronosporaceae), the potato tuber moth *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), and the Andean potato weevil (*Premnotrypes* spp.) (Canqui & Morales, 2009; Inostroza, 2009; Montaldo, 1984; Sandoval, 1989). In this regard, Sulca (2016) indicates that the higher the number of hillings, the lower the damage to the tubers due to larvae.

Based on this analysis, the current research sought to evaluate the number of hillings necessary to achieve high productivity and yield in native potato cultivars in the study area.

Materials and methods

The research was carried out in the location of Huaccoto (Talavera district, Apurímac department, Andahuaylas province), located at 3,794 m a.s.l., at the geographic coordinates 73°28'42.7" W and 13°43'42.4" S. The agroclimatic conditions were favorable for potato cultivation during the experimental phase, with an average temperature of 8.7 °C, accumulated precipitation of 647 mm, and relative humidity of 77.1 % (Sulca, 2016). The soil characteristics where the experiment was carried out are the following: strongly acidic pH (4.72), low organic matter (0.82 %), and medium phosphorus (8.3 ppm), and potassium (173 ppm) contents.

Fifteen tons per hectare of chicken manure were applied as background fertilizer and also a dose of 150-250-150 kg/ha of NPK as complementary fertilizer. The doses indicated above were used because potato crops respond favorably to the application of organic fertilizers (chicken manure, compost) in combination with chemical fertilizers (García et al., 2011; Luna et al., 2016). Fifty percent of the nitrogen was applied during sowing, and the remaining 50 % was administered in the first hilling, approximately 70 days after sowing (Reategui et al., 2019; Sulca, 2016) to facilitate the availability of soluble nutrients from the soil and meet the minimum requirements of the crop.

Factors assessed

Cultivars

Uncertified seed tubers of three native cultivars from locally produced fields, whose weight fluctuated between 60 g and 80 g, were used (Sulca, 2016). The selected cultivars are traditionally sown in the high Andean zone of Peru from 3,000 to 3,800 m a.s.l. (Egúsquiza, 2014), and are the following: Cultivar (cv.) Huayro (*Solanum x chaucha*) with ploidy 2n = 3x = 36 is cultivated from 3,300 m a.s.l. reaching yields of 25-30 t/ha; cv. Peruanita (*Solanum goniocalyx*) with ploidy 2n = 2x = 24 is sown from 3,300 m a.s.l., and has an intermediate vegetative period, and cv. Tumbay or "qillu runtus" (*Solanum goniocalix*), of ploidy 2n = 2x = 24, is cultivated from 3,000 m a.s.l. with an intermediate vegetative period (Centro Internacional de la Papa & Federación Departamental de Comunidades Campesinas, 2006).

Number of hillings

Three modalities were assessed: without hilling (A0), with one hilling (A1), and with two hillings (A2). The modality without hilling (A0) was considered as the control for subsequent comparisons. The adequate moment to carry out the first and second hillings was established according to the size of the plant (ideal moment) and the characteristics of the cultivars (Egúsquiza, 2014). The first hilling was carried out when plants were approximately 30 cm high (70 days), while the second hilling was carried out 100 days after sowing, on 40 cm high plants (Sulca, 2016). Both tasks were carried out manually, using a tool known locally as *lampa*. The first hilling facilitated the elimination of early weeds and improved the physical conditions for cultivation (Reategui et al., 2019). The second hilling was carried out to favor the greater development of the tubers and prevent the stolons from reaching the surface and becoming new stems (Egúsquiza, 2014).

The experiment was carried out on dryland with accumulated precipitation of 647 mm, and average relative humidity of 72.7 % between November and May, favorable conditions for the incidence of pests. For the control of the Andean potato weevil (*Premnotrypes* spp.), foliar area insects (*Epitrix* spp.), and nematodes (*Globodera pallida*), three applications of cypermethrin, oxamyl, and carbendazim were made, respectively, until before the first hilling. To control foliar diseases (*Phytophthora infestans, Alternaria solani*), four applications with a mixture of cymoxanil and mancozeb were necessary.

Experimental design

The experimental plot was a completely randomized block design installed considering the slope, the fertility gradient, and the variations in the physical quality of the soil (Cadena et al., 2012), and in a 3C × 3A factorial arrangement with nine treatments and four repetitions in an area of 806.4 m^2 (table 1). Seventy-two plants were sown in each experimental unit.

Table 1. Factors assessed and code for treatments

Factors assessed		Code for treatments		
Cultivars (C)	**Number of hillings (A)**			
C1 = Huayro C2 = Peruanita C3 = Tumbay	A0 = Zero hilling A1 = 1 hilling A2 = 2 hillings	C1A0 = T1	C2A0 = T4	C3A0 = T7
		C1A1 = T2	C2A1 = T5	C3A1 = T8
		C1A2 = T3	C2A2 = T6	C3A2 = T9

Source: Elaborated by the authors

The evaluation of the biometric and agronomic variables in the three native cultivars was carried out between 120-150 das, adapting the evaluations to the behavior and the vegetative period of the genetic material used (Condori-Mamani et al., 2017; Marmolejo & Ruiz, 2018).

Evaluation variables

Plant height

The evaluation of this variable was carried out between 100-162 das in 10 plants of the central furrow chosen at random from each experimental plot (Huayro at 162 das, Peruanita at 125 das, and Tumbay at 110 das) (Sulca, 2016). The length of the main stem from the neck of the plant to the terminal bud was recorded (Aliaga et al., 2017; Bautista et al., 2018; Jerez et al., 2017; Sánchez & Meza, 2015; Schulz et al., 2019; Sulca, 2016).

Leaf coverage

This variable was evaluated at different times according to the phenology of each cultivar: Huayro at 130 das, Peruanita at 110 das, and Tumbay at 105 das. In the central furrows of each plot, foliar coverage was recorded in 10 plants (Aliaga et al., 2017; Sulca, 2016). A grid with 50 squares (1.0 m × 0.5 m) was used. The number of squares in which more than 50 % of the observed green area was assessed to find the percentage of vegetation coverage; then, using a simple mathematical procedure, this value was divided by the total number of grids, and the result was multiplied by 100 (Sulca, 2016).

Number of stems

In the three cultivars, the evaluation was carried out at 162 das. The number of main stems per plant –extracted from a lateral furrow in each plot– originated in each tuber-seed was counted (Jerez et al., 2017; Sulca, 2016).

Number of stolons

This parameter was evaluated at 110 das in cv. Huayro, while in Peruanita and Tumbay it was carried out at 100 das. The number of main stolons per plant was considered, and the data were recorded in two groups with stolons larger than 10 cm and a group with segments smaller than 10 cm (Sulca, 2016).

Yield

Harvest was carried out manually at 203 das (Sulca, 2016). Only the two central furrows per plot were considered to avoid the edge effect (Schulz et al., 2019; Seminario et al., 2017; Zuñiga et al., 2018). The weight of the tubers found in each experimental unit was considered concerning the plant density per hectare to establish the yield (t/ha). Then, this value was converted to weight per hectare based on the total value (Bautista et al., 2018; Sánchez & Meza, 2015). The weight of the selected tubers was considered as the total weight or yield; then, to find the commercial yield, these were classified into Extra first and second categories from 20 g to 500 g (Sánchez & Meza, 2015).

Economic evaluation

Economic analysis

For the three cultivars analyzed, the production cost per hectare was found. Likewise, the gross value of the production was estimated. From this value, data to find the net profit, and the profitability index was generated (Sulca, 2016). Before the analysis of variance, the Kolmogorov-Smirnov normality test ($p > 0.05$) and Levene's homogeneity of variances test were performed to verify that the variances of the dependent variables were close to equality (Rubio-Hurtado & Berlanga-Silvente, 2012). Afterward, each variable was subjected to an analysis of variance. The comparison of means was performed using Duncan's multiple range comparison test (95 % reliability) (Rojas & Seminario, 2014). All the analyses were carried out with the statistical software InfoStat (Di Rienzo et al., 2013).

Results and discussion

Analysis of variance

The highly significant effects ($p \leq 0.001$) of the factors cultivar, the number of hillings, and the cultivar × hilling interaction were found for total and commercial yields in the three native cultivars. In general, when making two hillings, cultivars Huayro, Peruanita, and Tumbay showed the highest yields with 34.6 t/ha, 28.2 t/ha, and 28.1 t/ha, respectively. However, no difference was recorded when comparing the results obtained with one or zero hillings (figure 1).

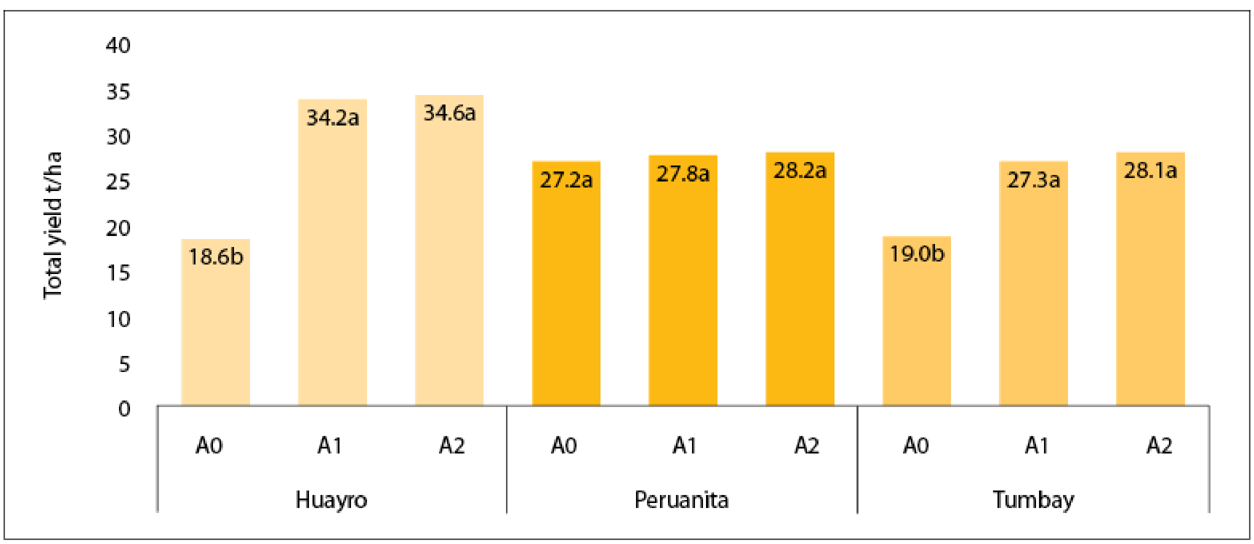

Figure 1. Total yield in t/ha per cultivars. *A0*. Zero hilling; *A1*. One hilling; *A2*. Two hillings.

In cv. Huayro, when one and zero hillings were carried out, total yields decreased by 1.17 % and 86.02 %, respectively, in relation to the effect of two hillings. In cv. Peruanita, two hillings did not generate significant advantages since with one and zero hillings, the yield was reduced only by 1.44 % and 3.67 %, respectively; therefore, as Estrada (2013) and Aliaga et al. (2017) highlighted, a single well-done hilling may be enough. In the case of cv. Tumbay, making two hillings, meant a yield increase of 2.93 % and 47.89 % compared to one and zero hillings, respectively.

In the traditional production systems of the Andahuaylas province, generally, two hillings are carried out and, according to Maldonado et al. (2011), the average yield of the Huayro, Peruanita, and Tumbay cultivars is 15.56 t/ha, 15.02 t/ha, and 22.97 t/ha, respectively. In turn, Seminario et al. (2017) found yields of 18.91 t/ha and 8.06 t/ha in the Tumbay and Peruanita cultivars, respectively. Further, in the Huayro cultivar, Campos (2014) found a yield of 23.86 t/ha with two hillings. In all the cases reviewed in the existing literature, the yields were lower compared to those obtained in the current study.

Thus, the number of hillings depend mainly on the cultivar that is used and if the hilling is carried out at the right time and in the right way, favoring a high tuberization and, consequently, an increase in total yields (Campos, 2014; Chala, 2016; Egúsquiza, 2014; Maldonado et al., 2011. As Egúsquiza (2014) affirmed, hilling is a necessary activity with a positive effect on total crop yield.

It can be inferred that these differences in total yield between the three cultivars are due to the characteristics of the cultivars, climatic conditions, timing, and the number of hillings (Egúsquiza, 2014; Sulca, 2016). Hence, Chala (2016) observed that, with two and three hillings, the total yield of tubers increased by 15.5 % and 24.7 %, respectively, compared to the control, due to the higher volume of loose soil available to form roots, stolons, and tubers.

Regarding the commercial yield, the T3 treatment (Huayro with two hillings) obtained the highest value compared to the Peruanita and Tumbay cultivars ($p < 0.001$). When analyzing the results by cultivars, in Huayro, the commercial yield is reduced to 0.10 % and 129.58 % when one and zero hillings are made, respectively. In the Tumbay cultivar, T9 (with two hillings) produced 14.4 t/ha, while with one and zero hillings, the commercial yield was reduced by 0.70 % and 176.92 %, respectively. In the Peruanita cultivar, as occurred in the Huayro and Tumbay cultivars, with two hillings, a higher yield compared to zero hillings was obtained, and a reduction in commercial yield was observed by 14.16 % and 40.22 % when one and zero hillings were made, respectively (figure 2). As Egúsquiza (2014) indicated, hilling is an essential task to avoid losses in the commercial quality of tubers. Potato plants that are not hilled or have inadequate hilling, lack of a good layer of protective and stabilizing soil, so these are prone to falling over, their tubers are easily infested by pests, and suffer from greening and rotting by sun exposure (Chala, 2016; Egúsquiza, 2014; Montaldo, 1984).

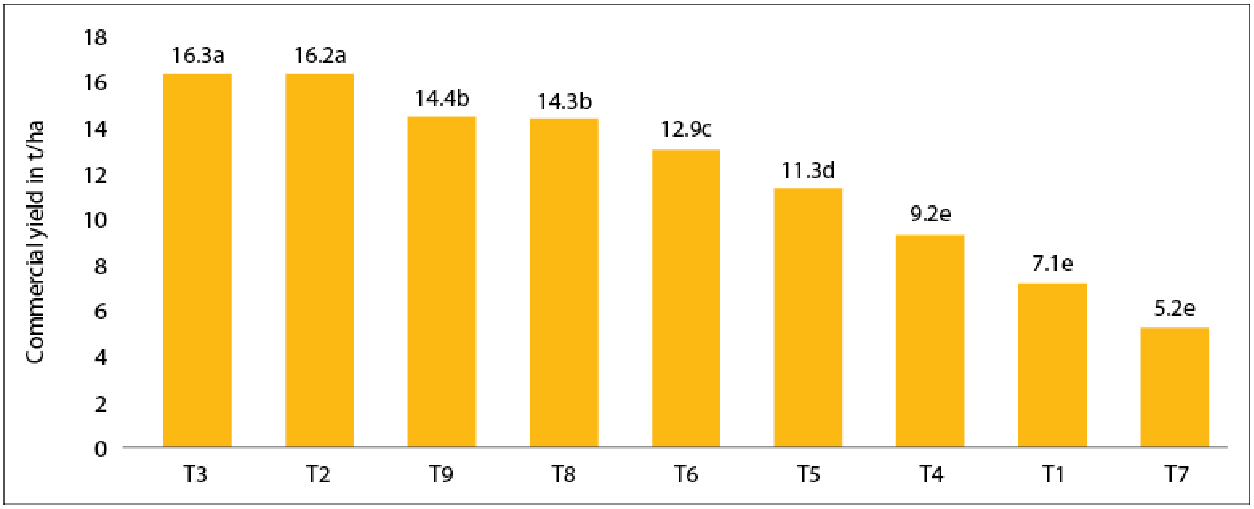

Figure 2. Commercial yield (t/ha) in the interaction cultivar × number of hillings.
Source: Elaborated by the authors

In late cultivars such as cv. Huayro, not making timely hilling can affect the commercial quality by up to 30 %, because the formation of stolons and tubers occurs from 100 das. On the other hand, in the Peruanita and Tumbay cultivars, these losses can reach up to 50 % because the formation of stolons and tubers begins at 60 days; therefore, to avoid loss of commercial quality, hilling must be differentiated according to the cultivar and climatic conditions (Campos, 2014; Egúsquiza, 2014; Maldonado et al., 2011).

Although the interaction cultivar × number of hillings did not have a significant effect on the yield factors (plant height, foliar coverage, number of stems, and number of stolons), in the individual effect of cultivars, the highest values in the average number of hillings were recorded in the Huayro cultivar (50.76, 67.78, 6.33, and 50.75 cm, respectively). For the effect of the number of hillings, when no hilling was carried out (A0), the highest value was found for plant height, number of main stems, and number of stolons per plant. This result may be because hilling work involves the removal of soil layers and, as a consequence, the involuntary cutting of underground stolons and other stolons that can become future stems (Egúsquiza, 2014). Perhaps for this reason, in some high Andean areas, hilling is carried out manually on two occasions, although in some producing regions of Bolivia, a single hilling is traditionally carried out 60 das (Aliaga et al., 2017).

Regarding the number of stems, the mean in the current study was six stems per plant. On the other hand, Rojas and Seminario (2014) reported five stems per plant on average for native cultivars. Nonetheless, this value may vary depending on the cultivar, the physiological state of the tuber-seed at the time of sowing, and the planting density (Silva et al., 2017). In general, the higher the number of stems per plant or per area, the higher the number of tubers and the total yield, although the size of the tubers may decrease (Toledo, 2016).

Economic analysis

By adding hilling practices to the cropping practices in the three cultivars studied, production cost increases. The production costs of the different treatments vary depending on the number of wages required for the first and second hilling. Up to 27 wages may be necessary to carry out a first hilling, while a second hilling requires up to 15 wages (Sulca, 2016).

In the cv. Tumbay with one hilling (T8), the highest profitability index (120.8 %) was recorded due to the higher commercial yield, and the price in the local market (figure 3). A minimum hilling guarantees the quality and productivity of the potato crop, although this work implies an increase in production cost (Egúsquiza, 2014).

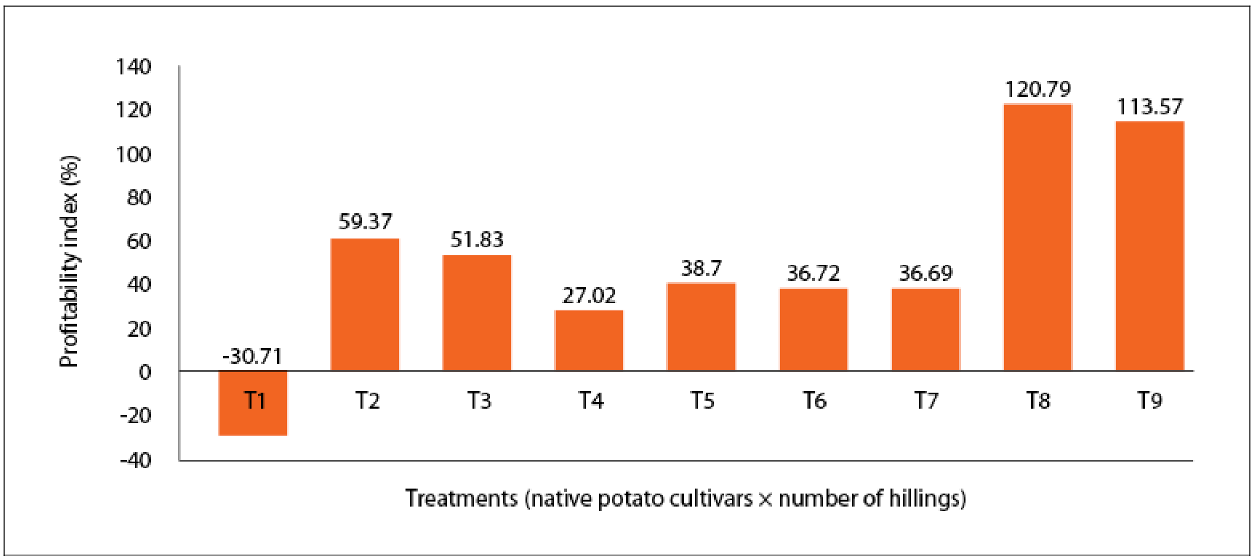

Figure 3. Yield index of native potato cultivars as a function of the number of hillings.
Source: Elaborated by the authors

The cv. Huayro without hilling (T1) obtained a negative profitability index (-30.71 %), possibly because the stolons, not having a considerable layer of soil, became aerial stems and hence, decreased the tuberization rate (Egúsquiza, 2014). However, with a well-done hilling, the profitability index improves significantly by up to 59.37 %. In the case of cv. Peruanita, the highest profitability index was found with a single hilling (T5).

According to the results of the three cultivars, a second hilling is not justified in economic terms. Employing the cv. Única and a single early hilling at 15 das, Estrada (2013) found a 1.3 % net profitability in the irrigation plots of Majes-Arequipa. However, Chala (2016) reported that farmers could obtain more income if they carry out three hillings, although this increases costs compared to hilling twice. Therefore, for economic reasons, a single well-done hilling is sufficient. Carrying out two hillings is only justified when local conditions are of high rainfall, and, as a consequence of frost, some parts of commercial interest (tubers) may be affected by physical and biological agents (Egúsquiza, 2014).

Conclusions

The interaction cultivar × number of hillings influences all the variables measured in the current study ($p < 0.001$). The treatment with the highest yield was cv. Huayro with two hillings ($p < 0.001$). In contrast, the yield of cv. Peruanita, without any hilling, was statistically similar to that of the cultivars in which some hilling was made. In the economic analysis, cv. Tumbay, with a single hilling, yielded the highest profitability index. In the Huayro and Tumbay cultivars, a second hilling is not justified in economic terms.

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Disclaimers

All the authors made significant contributions to the document, agree with its publication, and state that there are no conflicts of interest in this manuscript.

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