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*Research Article*

# Agricultural eco-efficiency and water footprint- A case study of fifteen crops in the Chupaca province of Peru

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## Abstract

The water footprint is an indicator of the impact of water use from its formation to its final destination. Agricultural eco-efficiency measures the efficient use of resources or materials available for crop production. Water's economic productivity analyses a product's efficient value as per its water supply and commercial value. The present research aimed to determine and relate the water footprint, economic productivity of water and agricultural eco-efficiency of 15 crops in the province of Chupaca - Peru. Georeferencing material was used for the delimitation of agricultural species, CROPWAT 8.0, CLIMWAT8.0, ArcGis 10.5 software, mathematical equations for the water footprint, agricultural eco-efficiency (Data Envelopment Analysis (DEA)) and economic productivity of water. The Total water footprint (TWF) of the fifteen crops was 1718237.01 $m^3$/ton, likewise the BlueWF > GreenWF > GreyWF. In their economic outputs, gross value of production (GVP) > agricultural production (Ag-p) > economic rent agricultural (ERA) was verified. In environmental costs, water consumption that meets the needs of crops (Wc-Ag) > consumption of phytosanitary products (C-fly) > fertilizer consumption (C-fe) was determined. The average Agricultural eco-efficiency (Ag-Eec) and Economic water productivity (Ewp) were 89.8% and 0.046 PEN/$m^3$ respectively. Statistical analysis between Ewp and Ag-Eec was rho = 0.18, t-test = 0.66 < 2.16 (α = 0.05; bilateral), and the correlation indicated that both activities are independent. The environmental costs and economic outputs of agricultural eco-efficiency did not influence the economic value of water.

**Keywords**: Economic outputs, Economic value of water, Environmental costs, Water footprint

## INTRODUCTION

Peru is the third-largest export market for agricultural products in South America and ranks eighth globally in terms of surface water availability (MINCETUR, 2023; OECD, 2021). Peru occupies the 157th position among countries in terms of soil usage solely for agricultural production, covering an area of 236,087 $km^2$ (Knoema, 2021). Furthemore, approximately 80% of its water resource are exclusively utilized for agriculture (Aquino, 2017). Junín and its Chupaca province are one of the many regions that cooperate and guarantee food security and greater agricultural development of the inter-andean valley of Peru (Verástegui, 2019). This is the main economic activity in which thousands of peasant families are dedicated to maintaining the inhabitants' quality of life (Rojas, 2016). Currently, Chupaca has fifteen large productions of crops (Tamayo, 2017) and to guarantee a good food harvest, farmers make excessive use of water (irrigation channels) and different materials (Benavides *et al.*, 2018; Palomares *et al.*, 2021).

Wang and Ye (2017) mentioned that some inputs and outputs can describe the result of agricultural production as good, efficient and productive (Moutinho *et al.*, 2018). One of them is through economic outputs and environmental costs (Georgopoulou *et al.*, 2016; Pang *et al.*, 2016), currently called Agricultural Eco-efficiency (van Grinsven *et al.*, 2019). Agricultural eco-efficiency mentions that environmental costs, such as water consumption of phytosanitary products and fertilizers, should not exceed or cause physiological and environmental damage to the crops (Rybaczewska *and* Gierulski, 2018; van Grinsven *et al.*, 2019). If there are such impacts, agricultural production, its efficiency, and the quality of its products will not be usable or demanded by different markets and food institutions (Georgopoulou *et al.*, 2016). While the economic outputs should hold significant value since they results from the arduous work and costs incurred during the agricultural production cycle (Wang and Ye, 2017). This means that the gross value of the production should yield positive economic returns for farmers, which, thanks to high agricultural productivity, should be higher and distinct from previous years (van Grinsven *et al.*, 2019; Wang and Ye, 2017). Additionally, their economic rent should have a good economic value based on the distance from where the crops are harvested and transported to the sales market (Rybaczewska and Gierulski, 2018).

For several years, farmers in Chupaca province, Peru, did not have a record of correctly using water and various materials for agricultural production (Verástegui, 2019). They only determined how to establish and sell their products with a standardized price to different markets in Peru (Tamayo, 2017; Verástegui, 2019). Water is such an important resource for agriculture that I conceptualize the water footprint (Masud *et al.*, 2018). This is currently being studied through an economic and hydrological approach since it establishes a direct relationship between water consumption and the consumer element (Altobelli *et al.*, 2018). The water footprint is the volume of water used directly or indirectly in all stages of the agricultural production chain (Kahramanoğlu *et al.*, 2019). According to Hoekstra *et al.* (2011), three water indicators help determine the impact of water consumption by crops (Garrido *et al.*, 2019).

The green water footprint refers to the volume of water consumed during the growing process of the crop; this is especially significant for agricultural products in terms of absolute water evapotranspiration (Kim and Kim, 2019). The blue water footprint indicates water use through the irrigation system, originating from springs of shallow or underground origin (Kahramanoğlu *et al.*, 2019). At the same time, the greywater footprint is a marker of the level of water contamination in a specific procedure (Donoso *et al.*, 2016). In other words, it is the amount of water diluted or combined with agrochemicals, fungicides, or other chemical substances that are applied in growing areas respecting environmental quality standards (Palomares *et al.*, 2021; Rybaczewska and Gierulski, 2018). Water productivity indicates how much economic production is produced per cubic meter of freshwater extracted (Garrido *et al.*, 2019). It measures the efficiency of water use and understands the economic value of water, which is significant and expressed in higher-yield crops and cultivated areas (Ibidhi and Ben, 2019; Novoa *et al.*, 2019; Omran and Negm, 2020).

Given the theoretical and conceptual information mentioned, it was important to determine if the resources, materials and instruments used in crop production are being managed effectively and efficiently by farmers. Therefore, the research aimed to describe/correlate the agricultural eco-efficiency, the total water footprint and the economic productivity of the water of fifteen crops in the province of Chupaca.

## MATERIALS AND METHODS

### Study area and data description

The study area is located in the province of Chupaca in the Junín region. The province has a surface area of 1,153.05 km$^2$ and an altitude of 3,263 m.a.s.l. (Fig. 1). The fifteen crops and their planting times were as follows: *Allium sativum* (garlic 85ha – 179days), *Pisum sativum var. macrocarpon* (edible-podded pea 42ha – 153d), *P. sativum var. saccharatum* (common pea 119ha – 112d), *Hordeum vulgare* (barley 83ha – 137d), *A. cepa* (onion 57ha – 169d), *Vicia faba* (fava bean 75ha – 182d), *Zea mays var. amylacea* (flour-corn 540ha – 177d), *Z. mays var. saccharata* (sweet-corn 596ha – 151d), *Ullucus tuberosus* (ulluco 39ha – 178d), *Solanum tuberosum* (white-potato 287ha – 149d), *S. chaucha* (creole-potato 40ha – 150d), *S. stenotomum* (andean-potato 21ha – 150d), *Chenopodium quinoa* (quinoa 73ha – 190d), *Triticum sp* (wheat 128ha – 173d) and *Daucus carota* (carrot 191ha – 120d). The evaluation of the crops was carried out from October 2020 to March 2021. The delimitation of the crop areas used a Garmin GPS plus Google Earth Pro program, followed by the conversion and delimitation of the crops to shapefile using the ArcGis 10.5 program. Due to the restrictions of the COVID-19 pandemic, field data col-

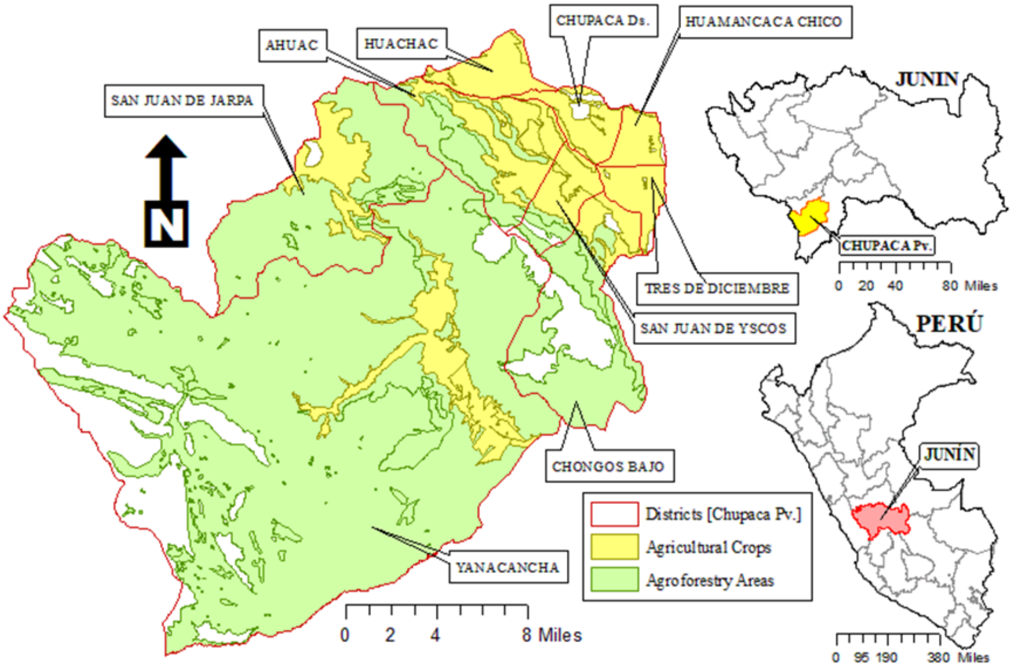

**Fig. 1.** *Map of the location of crops of Chupaca, Peru.* Agroforestry areas only have pasture crops - fodder interacting with livestock

lection was conducted 15 hours (three days x 5 hours) per week, starting from sowing to post-harvest. Tools such as a tape measure, flexometer, 50 kg balance, tensiometer, current meter, and lysimeters were used. The water footprint was determined using the manual "The Water Footprint Assessment Manual" (Hoekstra and Mekonnen, 2011; Hoekstra *et al.*, 2011), the CROPWAT 8.0 and CLIMWAT 8.0 software, as well as "Fertilizers and their use" (FAO, 1993) and "Crop evapotranspiration. Guidelines for determining crop water requirements" (FAO, 2015). Agricultural eco-efficiency was determined using Data Envelopment Analysis (DEA) (Charnes *et al.*, 1978):

### Agricultural eco-efficiency [Ag-Eec]

The agricultural eco-efficiency of each crop has two dimensions of evaluation "economic outputs and environmental costs". Economic outputs include agricultural production [Ag-p] (Tons: Ton), economic rent agricultural (Kellerman, 1978) [ERA] (The classical theory of von Thume's 1826 / Peruvian soles: PEN) and gross value of production [GVP] (Peruvian soles: PEN). While environmental costs are water consumption that meets the needs of crops [Wc-Ag] (megalitres: ML) (FAO, 2015), fertilizer consumption [C-fe] (tons: Ton) (FAO, 1993) and consumption of phytosanitary products [C-fhy] (tons: Ton) (FAO, 1993).

### Agricultural Eco-efficiency [Ag-Eec] through Data Envelopment Analysis [DEA]

In order to estimate the agricultural eco-efficiency of each cultivated species, the model mentioned by WBCSD (1996) was applied, which implies using the equation designed by Charnes *et al.* (1978) [DEA] interpreted as:

$$[\text{Ag-Eec}]\%_{i=n} = \frac{\text{Economic Outputs}_{i=n}}{\text{Environmental Costs}_{i=n}} * 100 \leq 1 \qquad (1)$$

Where the value 1 indicates that the crop maintains a good added value while generating 100% of its environmental pressures (Kuosmanen and Kortelainen, 2005).

### Total water footprint [TWF] of agricultural crops

The total water footprint is the sum total of the green, blue and grey water footprint (Hoekstra *et al.*, 2011).

$$\text{TWF}_{i=n} = \text{GreenWF} + \text{BlueWF} + \text{GreyWF} \qquad (2)$$

Where TWF: total water footprint ($m^3$/ton); GreenWF ($m^3$/ton): green water footprint; BlueWF ($m^3$/ton): blue water footprint; GreyWF ($m^3$/ton): grey water footprint.

### Economic water productivity [Ewp]

Water consumption is based on the economic value of each agricultural product in the sales markets (Araya *et al.*, 2011).

$$\text{Ewp}_{i=n} = \frac{P_{i=n}}{\text{TWF}_{i=n}} \qquad (3)$$

Where Ewp: Economic water productivity (PEN/$m^3$); P: single sale price of the agricultural crop valued in the market (PEN/ton); TWF: total water footprint of the agricultural crop ($m^3$/ton). The analysis for each crop is represented i (i = 1, 2, 3…, n).

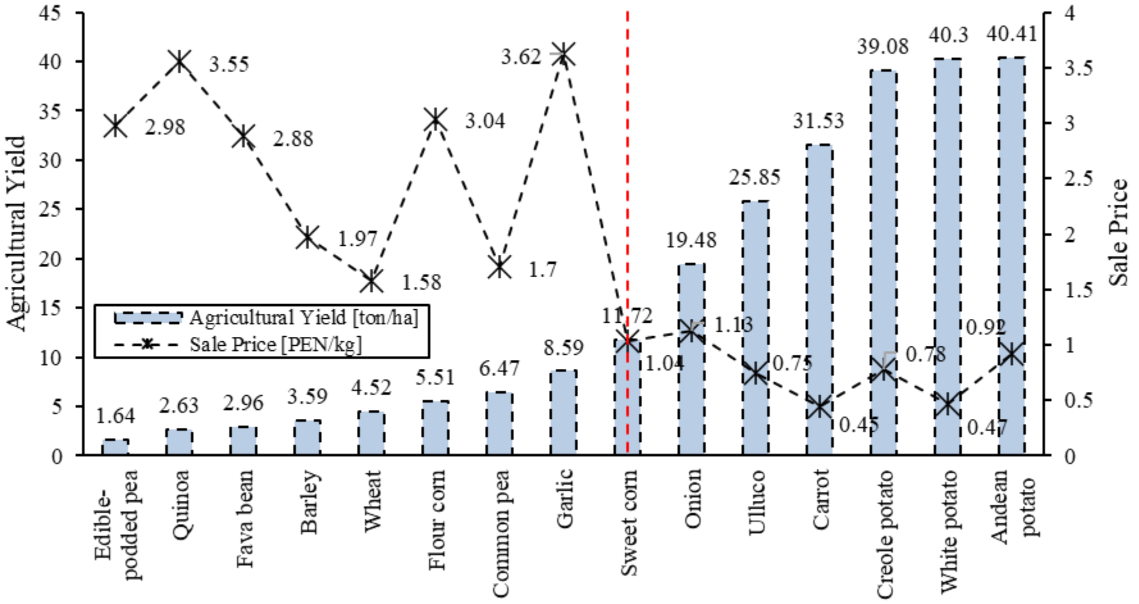

**Fig. 2.** *Analysis of agricultural yield and economic value; Sale Price [PEN/kg]:* $\bar{X}$ *: 1,79, Med: 1,58, SD: 1,14, Min: 0.45, Max: 3,62. Agricultural Yield [ton/ha]:* $\bar{X}$ *: 16,28, Med: 8,59, SD: 15,078, Min: 1,64, Max: 40,41*

### Test analysis and relationship hypothesis

To analyze the indicators of the water footprint and agricultural eco-efficiency, correlation analysis and statistical hypotheses using Karl Pearson (rho) and William Sealy Gosset (t-student) were employed:

$$\mathrm{rho}_{x/y} = \frac{\sum_{i=1}^{n}[x_i-\bar{x}][y_i-\bar{y}]}{\sqrt{\sum_{i=1}^{n}[x_i-\bar{x}]^2} * \sqrt{\sum_{i=1}^{n}[y_i-\bar{y}]^2}} \qquad (4)$$

$$\text{t-student}_{x/y} = \frac{\mathrm{rho}_{x/y} * \sqrt{N-2}}{\sqrt{1-\mathrm{rho}^2_{x/y}}}, \therefore \mathrm{df} = N-2 \qquad (5)$$

Where rho (x/y): correlation between the value and the estimated indicators of the TWF, Ag-Eec and Ewp. T-student (x/y): statistical hypothesis of the correlation analysis between the values and the estimated indicators with a bilateral significance level of α = 0.05↕.

## RESULTS AND DISCUSSION

### Analysis of the yield and sale price of the 15 crops

Crops registered different economic values for each cultivated species. In 2021, Chupaca qualified the *Allium sativum* and *C. quinoa* species with high economic values of 3.62 PEN/kg and 3.55 PEN/kg, respectively (Tamayo, 2017). The species with the lowest economic value were those that have high agricultural yields, such as *U. tuberosus* 0.75 PEN/kg, *S. tuberosum* 0.47 PEN/kg, *S. chaucha* 0.78 PEN/kg, *S. stenotomum* 0.92 PEN/kg and *D. carota* 0.45 PEN/kg (Benavides *et al.*, 2018) (Figure 2).

The tubers of the genus *S.* were the species with the highest yield, exceeding 39 ton/ha. While the *P. sativum var. macrocarpon* pea and *C. quinoa* had lower agricultural yield, their economic values were higher than those with the highest yield. There was a difference in the sale prices in of *Z. mays var. amylacea* and *Z. mays var. saccharata*. The selling cost of *Z. mays var. amylacea* was higher than that of sweet corn by 2 PEN/kg [3.04 PEN/kg ↔ 1.04 PEN/kg]. According to the sales report of the province of Chupaca, the *Z. mays var. amylacea* species undergoes an extra process before being sold to the market (time to dry naturally) (Verástegui, 2019). This means that the lower-yielding species (subjected to an extra process before being sold) will have more value-added economically than other higher-yielding species.

### Analysis of the total water footprint of fifteen crops

The greywater footprint is precisely about water contamination with chemical elements that accelerate plant development and prevent insects, pests and diseases from damaging crops, guaranteeing the quality of the crops and their high agricultural yield (Hoekstra and Mekonnen, 2011). The *Hordeum vulgare*, *Z. mays var. amylacea* and *Triticum sp* species had a greater greywater footprint due to the excessive consumption of phytosanitary products and fertilizers. In contrast, *A. sativum* and *S. stenotomum* species had fewer grey water footprints (Figure 3).

The species that efficiently took advantage of the water supply through the irrigation canals were the species *Z. mays var. amylacea, Z. mays var. saccharata* and *P. sativum var. macrocarpon*. The agricultural species with a high green water footprint were *Z. mays var. amylacea, Z. mays var. saccharata* and *Triticum sp*. It

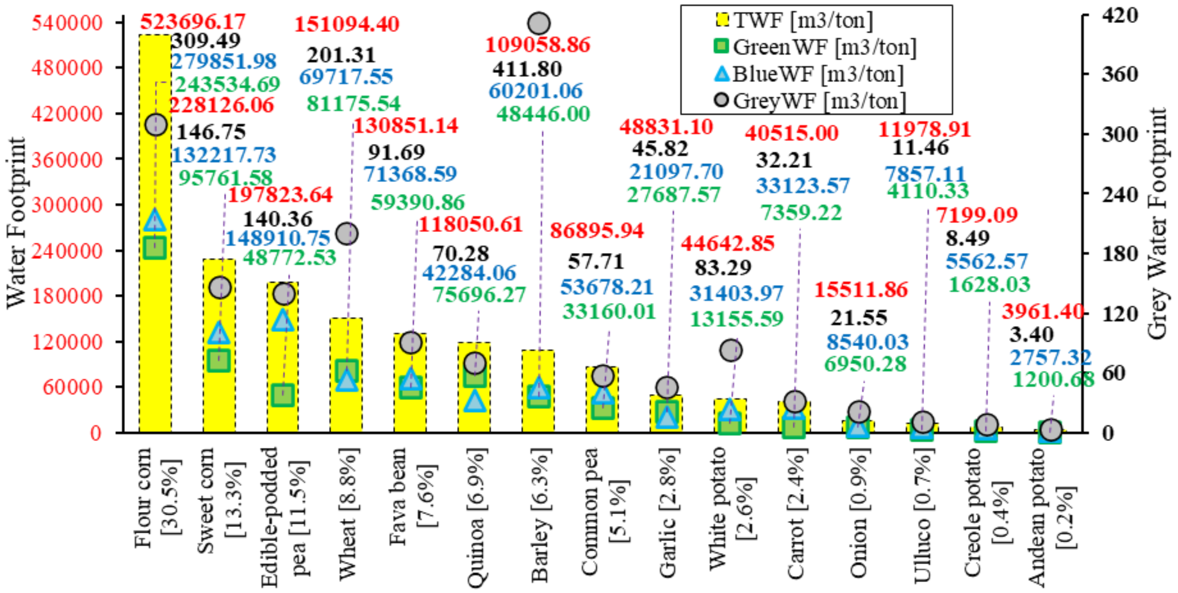

**Fig. 3.** *Water footprint. Note. The red values are results of the total water footprint; blue letters blue water footprint; green letters green water footprint and black letters grey water footprint. %: percentage of water footprint of each species:GreenWF: X̄: 49868.61, Med: 33160.02, Min: 1200.68, Max: 243 534.69, Σ: 748029.2. BlueWF: X̄: 64571.48, Med: 42284.06, Min: 2757.32, Max: 279851.98, Σ: 968572.21. GreyWF: X̄: 109.04, Med: 70.28, Min: 3.4, Max: 411.8, Σ: 1635.6. TWF: X̄: 114549.13, Med: 86895.94, Min: 3961.4, Max: 523696.17, Σ: 1718237.01*

could be said that the farmers of Chupaca ensured that these species could consume water through the rains. At the same time, the rest of the species cultivated by the farmers of Chupaca did not use the water efficiently through the irrigation canals or the rainfall between October and March. The study of the total water footprint of the 15 agricultural crops in the province of Chupaca established that the species *Zea mays var. amylacea, Z. mays var. saccharata* and *P. sativum var. macrocarpon* had higher water consumption through irrigation channels, precipitation, and water combined by chemical elements. Meanwhile the agricultural species *A. sativum*, *S. chaucha* and *S. stenotomum* did not have high water footprint values, water use can be scarce or deficient.

## Analysis of environmental costs and economic outputs of 15 crops

The species that reached the highest production during the month of October and March were *S. tuberosum, Z. mays var. saccharata* and D. *carota*. The species that turned out to have lower production were *Vicia faba*, *C. quinoa* and *P. sativum var. macrocarpon*. Economic rent reached higher incomes with the species *S. tuberosum, Z. mays var. amylacea* and *Z. mays var. saccharata*. This occurred because the transportation and planting of these crops were very close to local markets. Likewise, transporting these crops was voluminous (avoiding empty spaces in the trucks), as Palomares *et al.* (2021) mentioned.

The *Vicia faba* species was one of the crops where its income had economic losses towards agricultural income (-63.93PEN). This value caused monetary losses to farmers exclusively dedicated to planting, harvesting, and selling said species (some merchants transport the fava bean with other products, so their agricultural income did not cause major economic damage). The species *P. sativum var. macrocarpon* and *P. sativum var. saccharatum* also add to the little economic benefit in agricultural income because their values were not as high as the rest of the crops. The gross value of the production reached its maximum economic value with the *Z. mays var. amylacea, Z. mays var. saccharata* and *S. tuberosum* as they are precisely the species with the largest agricultural extension as well as their high value demanded in local markets. While the species with the lowest gross economic value were barley, *Vicia faba* and *P. sativum var. macrocarpon*. All the crops had a high gross production value (*Z. mays var. amylacea, Z. mays var. saccharata* and *S. tuberosum* had the greatest economic contribution to the agricultural sector). Although the agricultural income of the fava bean species was negative, its GVP was also positive. The *P. sativum var. macrocarpon* species was the only one to had a low GVP. Palomares *et al.*, (2021) stated that GVP can be influenced by crop yield. When comparing this statement with the *P. sativum var. macrocarpon* species, it clearly had a low yield and the GVP was also be low (Table 1).

The species *Z. mays var. amylacea, Z. mays var. saccharata,* D. *carota* and *S. tuberosum* had the highest water consumption, exceeding 1,000,000 megaliters (sum: irrigation and precipitation). The species that

**Table 1.** Analysis of environmental costs and economic outputs

| Crops | Ag-p[ton] | ERA[PEN] | GVP[PEN] | Wc-Ag[ML] | C-fe[ton] | C-fhy[ton] |
|---|---|---|---|---|---|---|
| *Allium sativum* | 752145.03 | 6264.66 | 2722764.99 | 204109.65 | 390.15 | 6217.75 |
| *Pisum sativum var. macrocarpon* | 69998.56 | 349.64 | 208595.70 | 135169.44 | 123.06 | 1404.06 |
| *Pisum sativum var. saccharatum* | 826923.86 | 820.49 | 1405770.56 | 350220.57 | 401.03 | 7587.44 |
| *Hordeum vulgare* | 314116.52 | 3836.37 | 618809.55 | 284579.61 | 1555.42 | 1238.36 |
| *Allium cepa* | 1103206.5 | 2243.49 | 1246623.35 | 184927.38 | 423.51 | 2477.79 |
| *Vicia faba* | 207407.25 | -63.93 | 597332.88 | 230567.25 | 273.75 | 4037.25 |
| *Zea mays var. amylacea* | 3048483.6 | 18008.5 | 9267390.14 | 1797886.8 | 1787.4 | 23608.8 |
| *Zea mays var. saccharata* | 7012196.28 | 8712.57 | 7292684.13 | 1861695.4 | 1716.48 | 7593.04 |
| *Ullucus tuberosus* | 1005283.5 | 2652.89 | 753962.63 | 239453.37 | 306.54 | 847.86 |
| *Solanum tuberosum* | 11546767.68 | 30932.05 | 5426980.81 | 1285754.26 | 3375.12 | 6245.12 |
| *Solanum chaucha* | 1565450.16 | 3007.38 | 1221051.12 | 212894 | 333.6 | 817.2 |
| *Solanum stenotomum* | 851855.21 | 1378.58 | 783706.80 | 88513.11 | 137.97 | 410.97 |
| *Chenopodium quinoa* | 201213.55 | 3522.86 | 714308.10 | 162741.82 | 186.88 | 1719.88 |
| *Triticum sp* | 624192 | 6533.51 | 986223.36 | 265336.32 | 917.76 | 4412.16 |
| *Daucus carota* | 5967875.22 | 7419.57 | 2685543.85 | 1322604.33 | 1025.67 | 10250.97 |
| Max | 11546767.68 | 30932.05 | 9267390.14 | 1861695.4 | 3375.12 | 23608.8 |
| Min | 69998.55 | -63.93 | 208595.69 | 88513.11 | 123.06 | 410.97 |
| Med | 851855.21 | 3522.86 | 1221051.12 | 239453.37 | 401.03 | 4037.25 |
| $\overline{X}$ | 2339807.66 | 6374.57 | 2395449.86 | 575096.88 | 863.62 | 5257.91 |
| Σ | 35097114.91 | 95618.64 | 35931747.96 | 8626453.31 | 12954.34 | 78868.65 |

Fertilizers (urea, ammonium nitrate, lime nitrate, NPK fertilizers, ammonium phosphate among others); phytosanitary (insecticides, fungicides, acaricides, insect repellents, herbicides, biostimulants and regulators, nutrients, adjuvants, among others); the total water consumption (Wc-Ag) is the sum between the irrigation system and precipitation.

does not consume too much water was *S. stenotomum*. *S. tuberosum*, *Z. mays var. amylacea* and *Z. mays var. saccharata* were the species with the highest fertilizer consumption during agricultural production for accelerated growth. While the species *C. quinoa*, *S. stenotomum* and *P. sativum var. macrocarpon* were of lower consumption of fertilizers. The problem of pests and diseases was one of the sanitary inspection problems that control the local sales market, so farmers opted to apply high concentrations of phytosanitary products (to improve the quality of said species) (Palomares *et al.*, 2021). The species with the highest consumption of phytosanitary products were *Z. mays var. amylacea*, D. *carota* and *Z. mays var. saccharata*, while there were only two species of the genus *S.* and U. *tuberosus* that consume few phytosanitary products.

### Analysis of Agricultural eco-efficiency [Ag-Eec] and Economic Productivity of Water [Ewp]

*Vicia faba* is the only crop that had an eco-efficiency lower than 0.5, which is 50%. Eight species had a perfect eco-efficiency, while only two species had almost the same eco-efficiency. It was affirmed that half of the crops were eco-efficiently managed in agricultural activities, while the rest needed to be studied to determine if their resources and materials were technically poorly managed in agricultural production. Water is the essential natural resource for the growth and development of agricultural crops, hence its importance in research. Therefore, the total water footprint of each species was determined and then divided by the sale price of each crop, as suggested by Garrido *et al.* (2019). This result showed that "a species or agricultural crop had a high economic value due to water scarcity".

Andean potato had a high hydric economic value of 0.232 PEN/m$^3$, which was totally different from its similar ones (*S. tuberosum* and *S. chaucha*). The lowest water economic value species were *Z. mays var. saccharata* 0.005 PEN/m$^3$ and *Z. mays var. amylacea* 0.006 PEN/m$^3$. The rest of the species, their Ewp, ranged from 0.01 PEN/m$^3$ to 0.108 PEN/m$^3$, showing that there is no exact or fixed value for the economic productivity of water applied to local sales markets.

Many agricultural areas did not have irrigation systems (or sprinkler irrigation) during the evaluation stages. They needed the precipitation stations during October to March to cover the water needs of each species. As mentioned above, many agricultural areas did not have irrigation systems and lacked a record of the water volume, demonstrating some species' economic im-

**Table 2.** Correlation and statistical hypothesis between the indicators of Agricultural Eco-efficiency, Water Footprint and Economic Productivity of Water

| | Green | Blue | Grey | TWF | Ewp | Ag-p | ERA | GVP | Wc-Ag | C-fe | C-fi | Ag-Eec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Green | | 8.35e | 3.05e | 16.16e | 1.74 | 0.03 | 1.14 | 3.26e | 2.33e | 1.06 | 4.48e | 0.3 |
| Blue | 0.92c | | 2.96e | 19.3e | 2.01 | 0.27 | 1.05 | 3.14e | 2.57e | 1.09 | 4.06e | 0.34 |
| Grey | 0.65b | 0.64a | | 3.12e | 1.98 | 0.18 | 0.78 | 1.16 | 1.06 | 1.71 | 1.4 | 0.29 |
| TWF | 0.98c | 0.98c | 0.65b | | 1.94 | 0.16 | 1.11 | 3.32e | 2.53e | 1.1 | 4.46e | 0.33 |
| Ewp | -0.44 | -0.49 | -0.48 | -0.47 | | 1.05 | 1.21 | 1.25 | 1.8 | 1.73 | 1.64 | 0.66 |
| Ag-p | 0.01 | 0.08 | -0.05 | 0.05 | -0.28 | | 5.52e | 3.12e | 3.65e | 5.7e | 1.33 | 1.27 |
| ERA | 0.3 | 0.28 | 0.21 | 0.3 | -0.32 | 0.84c | | 3.82e | 3.39e | 8.18e | 2.21e | 1.45 |
| GVP | 0.67b | 0.66b | 0.31 | 0.68b | -0.33 | 0.65b | 0.73b | | 8.59e | 3.49e | 5.32e | 1.24 |
| Wc-Ag | 0.54a | 0.58a | 0.28 | 0.58a | -0.45 | 0.71c | 0.69b | 0.92c | | 3.85e | 4.31e | 1.13 |
| C-fe | 0.28 | 0.29 | 0.43 | 0.29 | -0.43 | 0.85c | 0.92c | 0.7b | 073b | | 1.79 | 0.76 |
| C-fi | 0.78c | 0.75a | 0.36 | 0.78c | -0.41 | 0.35 | 0.52a | 0.83c | 0.77c | 0.45 | | 0.34 |
| Ag-Eec | 0.08 | 0.1 | -0.08 | 0.09 | 0.18 | 0.33 | 0.37 | 0.33 | 0.3 | 0.21 | 0.1 | |

Bilateral significance level [Karl Pearson (rho) // α = 0.05↕ // $p<0.05^a$, $p<0.01^b$, $p<0.001^c$]. Relationship hypothesis shrinkage t-test [William Sealy Gosset (t-student) N – 2 = 13 → t-student = 2.16e↑ // ≥ Nh → is rejected // ≤ Ah → is accepted].

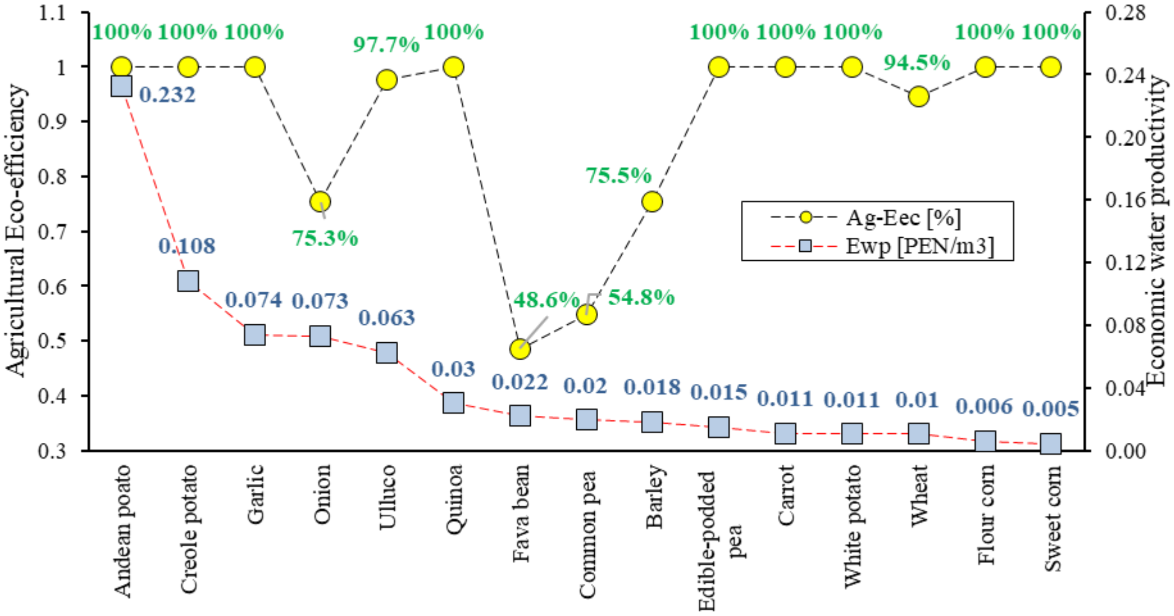

**Fig. 4.** *Analysis of Agricultural Eco-efficiency and Economic Productivity of Water; Ag-Eec: X : 0.898, Med: 1, Min: 0.486, Max: 1. Ewp [PEN/m3]: X: 0.046, Median: 0.02, Min: 0.005, Max: 0.232*

portance.

### Analysis of statistical relationship between the indicators of Agricultural eco-efficiency [Ag-Eec] and Economic water of productivity [Ewp]

The GVP was influenced by the green, blue and total water footprint, and its relationship was very similar and significant (rho = 0.66 to 0.68; t-test = 3.14 to 3.32> 2.16). If the GVP is low or high, the result of each species will be influenced by its yield. This analysis was also similar with the consumption of phytosanitary products (C-fi). It was determined that the greater or lesser consumption of different phytosanitary products it will depend on the irrigation system, precipitation, and the total water footprint (rho = 0.75 to 0.78; t-test = 4.06 to 4.48> 2.16). It is not common for Wc-Ag to be unrelated (rho = 0.54 to 0.36; t-test = 2.33 to 2.57> 2.16) with the green, blue, and total water footprint, except with the grey water footprint. Wc-Ag applied to each agricultural crop will always have a positive or negative effect on water records (Table 2).

Having a record and control of water use for irrigation canals; its economic value is low and will benefit many farmers so that other agricultural crops have more economic value and demand in the markets. It is good to determine which indicators of agricultural eco-efficiency are directly or inversely related to the water footprint and the economic productivity of water. The most important research question is: Is the economic productivity of water statistically related to agricultural eco-efficiency? And the answer is “no". The relational coefficient indicates that it is very low and the correlation hypothesis test affirms that there is no relationship. This means that if a crop or species consumes too many or too few natural resources from Ag-Eec, the result will not be influenced by its volumetric economic value of water, and it will not affect water consumption. Therefore, we ensure that the total of crops evaluated in the field, both their environmental costs and their economic outputs, will not have effects or problems during the payment for water service.

## Conclusion

The commercial value of the "Edible-podded pea, Quinoa, Faba bean, Barley, Wheat, Flour corn, Common pea, Garlic" crops was higher than their yield. The productive yield of the "Onion, Ulluco, carrot, Creole potato, White potato, Andean potato" crops was higher than their price. Sweet corn was the only species that exhibited a balance between commercial value and productive yield. The total water footprint was superior in crops (cereals and legumes) and less total water footprint in tubers. Flour corn was superior in blue and green water footprint, accounting for 30.5% of the total. Barley was the only species to consume more grey-water footprint. Grasses and legumes had the highest total water footprint consumption, while tubers consumed a lower water footprint. Grasses and tubers were species that had high environmental costs and economic outputs. The total Ag-Eec of the fifteen crops was 89%; more than half of the species had perfect agricultural eco-efficiency. The total Ewp of the fifteen species was 0.046 PEN/$m^3$; only the Andean potato species showed excessive water consumption. There was no relationship between Ag-Eec and Ewp. Therefore, environmental costs and economic outputs of agricultural eco-efficiency did not influence the economic value of water, and both are independent of farm production.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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