Short note [Nota corta]

ENERGY EFFICIENCY OF SMALLHOLDER COMMERCIAL VEGETABLE FARMS IN CUENCA (ECUADOR) †

[EFICIENCIA ENERGÉTICA DE FINCAS DE PEQUEÑOS PRODUCTORES DE HORTALIZAS EN CUENCA (ECUADOR)]

Pedro Zea, Jeimy Chilpe, Diego Sánchez and Eduardo J. Chica*

Facultad de Ciencias Agropecuarias, Universidad de Cuenca, Avenida 12 de octubre y Diego de Tapia, Cuenca, Ecuador. Email: eduardo.chica@ucuenca.edu.ec
**Corresponding author*

SUMMARY

Background. Vegetable crops in Ecuador are produced primarily by smallholders in the Andes. Cuenca is an intermediate city in Southern Ecuador whose demand of fresh vegetables is supplied mostly by small farms located < 60 Km from the city. **Objective.** The objective of this study was to characterize smallholder vegetable farms located on the outskirts of Cuenca using input/output energy balances. **Methodology.** One hundred and four vegetable farms were visited during the first semester of 2016. Farmers were interviewed using a semi-structured questionnaire about the inputs used by them for crop production and the outputs of their crops. **Results.** Most of the farms (83) produced negative energy balances with energy efficiencies ranging from 0.16 to 0.97 whereas farms with positive energy balances had efficiencies ranging from 1.03 to 1.97. The largest energy input in most farms was from organic fertilizers, followed by the planting material and direct energy use for pumping and other farm activities. A positive significant correlation was detected between farm size and energy efficiency. **Implications.** Our results reveal opportunities to improve the functioning of these farming systems and the need to take into account efficiency considerations in the design of technological and policy interventions oriented to improve the sustainability of these systems. **Conclusions.** Most smallholder vegetable farms in periurban Cuenca operate producing negative energy balances. Organic fertilizers and direct energy are the largest energy inputs used in these farms. Potential energy economies of scale were detected both in energy efficient and energy inefficient farms.

Key words. Andes; mountain agriculture; periurban farming; small farms; sustainability

RESUMEN

Antecedentes. Los cultivos de hortalizas en Ecuador son producidos principalmente por pequeños productores en los Andes. Cuenca es una ciudad intermedia ubicada en el sur del Ecuador cuya demanda de vegetales frescos es cubierta principalmente por pequeños productores asentados a < 60 Km de la ciudad. **Objetivo.** El objetivo de este estudio fue caracterizar fincas hortícolas ubicadas alrededor de Cuenca usando balances energéticos. **Metodología.** Ciento cuatro fincas fueron visitadas en 2016 y los productores encargados de ellas entrevistados para levantar información sobre insumos y niveles de producción de sus cultivos. **Resultados.** La mayoría de las fincas (83) presentaron balances energéticos negativos con eficiencias entre 0.16 y 0.97, mientras que las fincas con balances energéticos positivos tuvieron eficiencias entre 1.03 y 1.97. El insumo con mayor contribución de energía fue el fertilizante orgánico, seguido por el material de siembra y energía usada para bombeo y otras actividades de la finca. Se detectó una correlación positiva entre la eficiencia energética y el tamaño de la finca. **Implicaciones.** Nuestros resultados revelan oportunidades para mejorar el funcionamiento de estos sistemas de producción y la necesidad de incluir aspectos de eficiencia en el diseño de intervenciones tecnológicas y de políticas orientadas a mejorar la sostenibilidad de estos sistemas. **Conclusiones.** La mayorías de las fincas hortícolas en el periurbano de Cuenca operan generando balances energéticos negativos. Los fertilizantes orgánicos y la energía directa son los principales ingresos de energía en estos sistemas de producción. Posible economías energéticas de escala fueron detectadas tanto en fincas energéticamente eficientes como no eficientes.

Palabras clave. Andes; agricultura de montaña; agricultura periurbana; pequeños productores; sostenibilidad.

INTRODUCTION

In Ecuador, the national demand for fresh vegetables is met almost entirely by thousands of small farms located in the Andes close to major cities. As in the rest of the Andes, a rapid process of urbanization has been changing the face rural Ecuador (Idrovo, 2016) affecting the ways food crops, such as vegetables, are

† *Submitted August 9, 2019 – Accepted May 11, 2020.*
ISSN: 1870-0462.

produced. Cuenca is a city located at 2600 m.a.s.l. in southern Ecuador. With 450000 people, Cuenca is the third largest city in Ecuador and the second largest in the Ecuadorean Andes. Traditionally, Cuenca has been surrounded by an active agricultural belt made up of many small- and medium-sized farms that provide fresh produce to meet the city demands. Currently, most of these vegetable production systems are concentrated in ~337 ha locked between the city proper and a natural reserve under a constant threat of land use change due to urbanization (GADP San Joaquín, 2015). As in other Andean cities (see Haller, 2014 or Romero and Ordenes, 2004 for examples) increasing urbanization in the Ecuadorian Andes will have a direct impact on the food supply chain by increasing the distances between areas of production and centers of consumption, reclaiming new (often marginally productive) land for agriculture, risking further degradation of natural ecosystems, and transforming social and economic relations between the countryside and the cities.

One way in which small periurban farmers have responded to urban expansion is intensifying their production systems (Haller, 2014). In periurban Cuenca, farmers have evolved from cultivating a wide variety of agronomic and horticultural crops in the 1960s to specializing in a smaller variety of vegetable crops today grown using hybrid traditional/modern-intensive technologies. This evolution and the current performance of these systems has been studied before locally using a variety of social and economic approaches (Alvarado, 2013; Guamán Parra and Tacuri Quizhpi, 2014; Mejía Zambrano, 2014; Sotamba Sanango and Sánchez Dumas, 2013; Tapia Barrera, 2014). However, an extensive characterization of these systems from a physical/technical standpoint is still lacking. Considering the vulnerability of perirurban production systems around Andean cities to urban growth and predicted changes in climate, evaluating the production efficiency of these systems could help identify processes that could be improved in order to keep these systems sustainable. Furthermore, this characterization could be useful to design locally appropriate technologies and to draft policies oriented to improve the sustainability of these agricultural livelihoods in the context of social and climate change in developing intermediate cities. Here, we report an energy efficiency characterization of the most important vegetable production district surrounding Cuenca, an intermediate Andean city in southern Ecuador.

MATERIALS AND METHODS

The study was conducted in San Joaquín, Baños and Sayausí parishes located on the western outskirts of Cuenca (2°53′45″S, 79°03′05″W). The area is located at an average altitude of 2.600 m.a.s.l., the weather is cool with an average annual temperature of 15°C and an average annual precipitation of ~720 mm with monthly precipitations ranging from ~20 mm in the driest month and ~110 mm in the rainiest. The area is characterized by a collection of terraces limited between the Yanuncay and Tomebamba rivers; the predominant soils in the area were Mollisols and Vertisols. Vegetable production in San Joaquín started in the 1960s and has grown to an estimated area of 337 ha in 2015, distributed among hundreds of small- a medium-sized family farms most of which practice polycultures. One hundred and three commercial farms were visited between February and May 2016. The farms ranged from 0.016 to 0.632 ha (mean = 0.122 ha) and were cultivated with an average of 5 simultaneous crops growing in separate plots. A structured interview was presented to the farmer in charge of each farm. The questionnaire was designed to register the amount and frequency of use of all the inputs and all the outputs produced by the farm. In addition, crop diversity and types of technologies used in the farms were also registered. Data was collected for the crops present in the farm at the time of the interview. Most of the interviews lasted between 1 and 2 hours.

For each farm, the amount of inputs used were transformed to its energy equivalents using published coefficients as shown in Table 1. Inputs were aggregated in the following categories: Organic fertilizers, synthetic fertilizers, animal work, human work, lime, seeds and transplants, water, direct energy (pumping, engines, etc.), and agrichemicals (herbicides, fungicides and insecticides). Similarly, the outputs (harvested crops) were transformed to their energy equivalents by multiplying the amount produced by its energy content taken from the USDA National Nutrient Database for Standard Reference (USDA, 2018). Input and output energy equivalents were then used to calculate net energy (NE) and energy efficiency (EE) as in Bojacá et al. (2012). NE was calculated as the difference between the energy equivalence of all the outputs and inputs for each farm (i.e. NE = Energy output – Energy Input), while EE was calculated as the ratio between the energy equivalence of all the outputs and inputs (i.e. EE = Energy output / Energy Input). Farms were considered "energy efficient" when EE ≥ 1, or "energy inefficient" when EE < 1. Correlations between energy indices and farm size and input categories were tested using generalized additive models (Faraway, 2005) in R (R Core Team, 2018).

Table 1. Energy equivalence factors used to transform inputs and outputs levels.

Input/output category	Energy equivalence	Reference
Organic fertilizers		
Organic fertilizers	1.32 MJ kg^{-1}	Pérez-Neira et al. (2013)
Synthetic fertilizers		
Urea	67.8 MJ kg^{-1}	Aguilera et al. (2015)
Inorganic N fertilizer	64.4 MJ kg^{-1}	Pérez-Neira and Grollmus-Venegas (2018)
Inorganic P fertilizer	13.2 MJ kg^{-1}	Pérez-Neira and Grollmus-Venegas (2018)
Inorganic K fertilizer	9.5 MJ kg^{-1}	Pérez-Neira and Grollmus-Venegas (2018)
Animal work		
Animal work	44.16 MJ h^{-1} *	Aguilera et al. (2015)
Human work		
Human work	0.58 MJ h^{-1}	Pérez-Neira and Grollmus-Venegas (2018)
Lime		
Lime	1.17 MJ kg^{-1}	Zhang et al. (2012)
Seeds and transplants		
Seeds	2.63 MJ kg^{-1}	Pérez-Neira et al. (2013)
Transplants	0.2 MJ unit^{-1}	Pérez-Neira et al. (2013)
Water		
Water	0.63 MJ m^{-3}	Pérez-Neira et al. (2013)
Direct energy		
Electricity for pumping	12.27 MJ h^{-1}	Pérez-Neira et al. (2013)
Diesel	47.94 MJ L^{-1}	Aguilera et al. (2015)
Agrichemicals		
Tebuconazole	556 MJ kg^{-1} **	Audsley et al. (2009)
Mancozeb	285 MJ kg^{-1} **	Audsley et al. (2009)
Cymoxanil	447 MJ kg^{-1} **	Audsley et al. (2009)
Metaldehyde	153 MJ kg^{-1} **	Audsley et al. (2009)
Chlorpyrifos	329 MJ kg^{-1} **	Audsley et al. (2009)
Cypermethrin	605 MJ kg^{-1} **	Audsley et al. (2009)
Thiocyclam hydrogen oxalate	447 MJ kg^{-1} **	Audsley et al. (2009)
Glyphosate	479 MJ L^{-1} **	Green (1987)
Outputs		
Garlic	6.24 MJ kg^{-1}	USDA, 2018
Zucchini	0.71 MJ kg^{-1}	USDA, 2018
Cabbage white	1.05 MJ kg^{-1}	USDA, 2018
Cabbage purple	1.3 MJ kg^{-1}	USDA, 2018
Napa cabbage	0.67 MJ kg^{-1}	USDA, 2018
Cauliflower	1.05 MJ kg^{-1}	USDA, 2018
Broccoli	1.17 MJ kg^{-1}	USDA, 2018
Lettuce head	0.59 MJ kg^{-1}	USDA, 2018
Lettuce leaf	0.54 MJ kg^{-1}	USDA, 2018
Chives	1.26 MJ kg^{-1}	USDA, 2018
Parsley	1.51 MJ kg^{-1}	USDA, 2018
Cilantro	0.96 MJ kg^{-1}	USDA, 2018
Chard	0.8 MJ kg^{-1}	USDA, 2018
Celery	0.59 MJ kg^{-1}	USDA, 2018
Radish	0.67 MJ kg^{-1}	USDA, 2018
Beet	1.8 MJ kg^{-1}	USDA, 2018
Carrot	1.72 MJ kg^{-1}	USDA, 2018

*Energy equivalence for a team of 2 oxens.
** Values per kilogram of active ingredient

RESULTS AND DISCUSSION

The input/output energy balance analysis of the 104 farms revealed that 83 farms produced negative NE balances ranging from -19,723,81 MJ/farm to -56.88 MJ/farm (mean = -3.892,15 MJ/farm, median = -2,783,59 MJ/farm) whereas 20 farms produced positive energy balances in the range between 147.8

MJ/farm to 19,552.52 MJ/farm (mean = 3,420.61 MJ/farm, median = 1,587.95 MJ/farm). Energy efficiencies in the 103 farms ranged between 0.16 and 1.91 with an average efficiency of 0.65 and a median efficiency of 0.54 (Fig. 1). Overall, these results indicate that roughly only one out of five farms are transforming efficiently inputs into harvests and producing NE gains. While energy efficiency is only one dimension on which the sustainability of a farming system can be evaluated, it provides a quick glimpse of the functioning of a farm operation. However, energy efficiencies can vary widely depending on local factors and the types of crops grown, being horticultural crops normally less energy efficient than arable crops (Pelletier et al., 2011; Smith et al., 2015). In the case of periurban farms in Cuenca, all the farms characterized in this study were dedicated to vegetable crops. The average EE registered in these farms is close to the efficiencies reported for vegetable production systems in other places like Colombia, Spain or Turkey (Alonso and Guzmán, 2010; Bojacá and Schrevens, 2010; Ozkan, Kurklu, and Akcaoz, 2004; Pérez-Neira and Grollmus-Venegas, 2018) and consequently suggest that this low EE could be characteristic of vegetable production systems rather than an indicator of underperforming farms. Moreover, the comparison of EE between this study and reports from other places invites to examine more in depth the characteristics of the farms that had EE≥1 as these values are uncommon for vegetable production systems.

Analyzing the contribution of each input category to the total energy demand for each farms, the largest energy input came from the use of organic fertilizers, followed by direct energy (fuel and electricity) and seeds and transplants (Fig. 2). Energy inputs from organic fertilizers accounted for 13.24% to 88.41% of the total energy inputs of the farms (mean = 50.34%), while energy inputs from direct energy ranged between 4.11% and 39.94% (mean = 17.71%), and energy inputs from seeds and transplants ranged between 0.31% and 30.78% (mean = 11.64%). Together, these three categories accounted for 59.99% to 96.89% of the total energy demand for each farm (mean = 80.25%). The large contribution of energy from organic fertilizers is derived from the characteristic high level of use of this input in the district. Over the years, most of the farms around Cuenca have increased their use of organic fertilizers (primarily chicken manure) and reduced the use of synthetic fertilizers. In spite of their increased reliance on organic fertilizers, most of these farms remain “conventional” as they supplement their crops with smaller amounts of synthetic fertilizers and depend of synthetic molecules for pest, disease and weeds control. Although not a large contributor to the farm energy balance, the reported use of synthetic agrichemicals revealed a weak point on the sustainability of the farms. Most farmers reported using synthetic agrichemicals without technical assistance which often resulted in unnecessary applications or selection of inadequate products for pest control. Furthermore, their reliance on only a few molecules for their pest and disease control needs risks the development of resistance in pest and pathogens. Most farmers reported having losses in the past due to recurrent pest and disease problems.

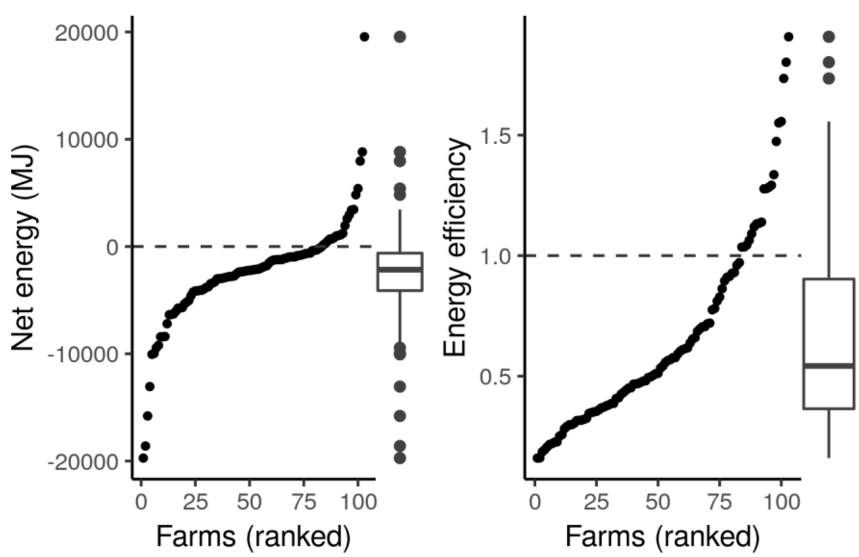

Figure 1. Distribution of the NE production and input/output energy efficiency of the smallholder vegetable farms characterized in the study. Each dot represents one farm. Dashed line at NE=0 or EE = 1 drawn for reference.

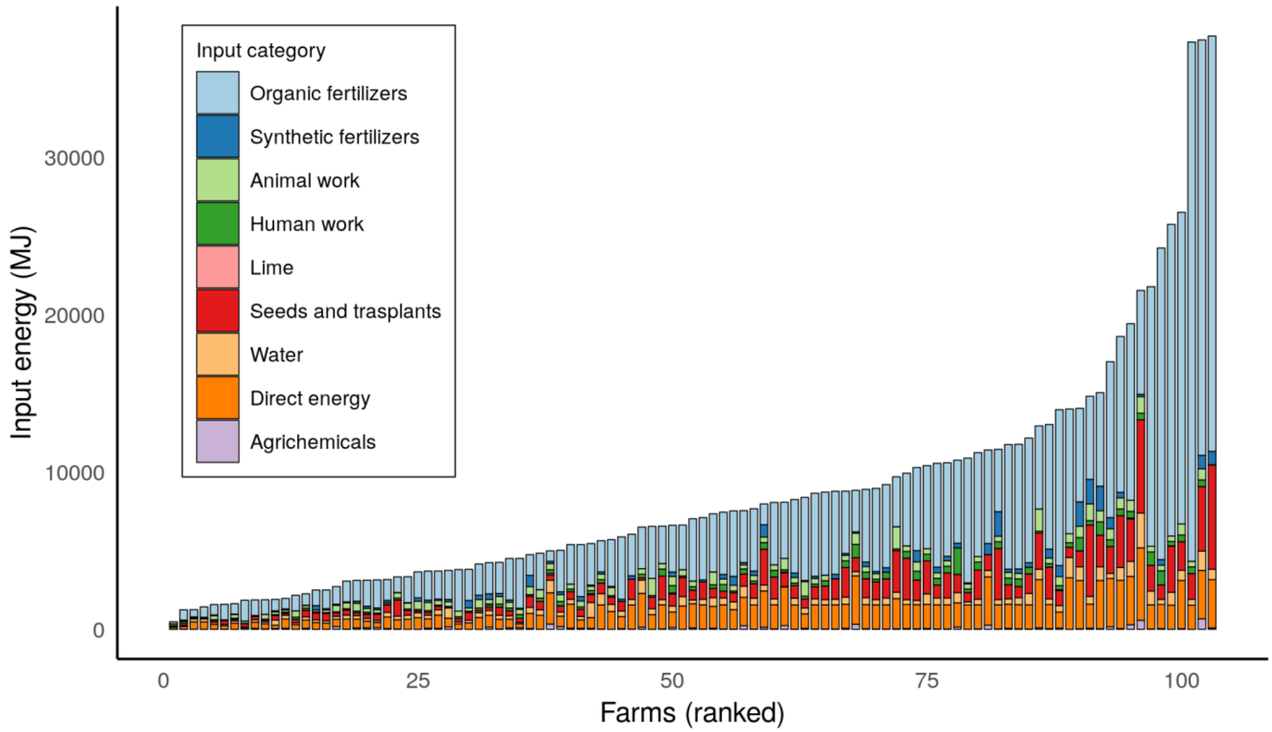

Figure 2. Total energy inputs per farm distributed among input categories. Each bar represents one farm.

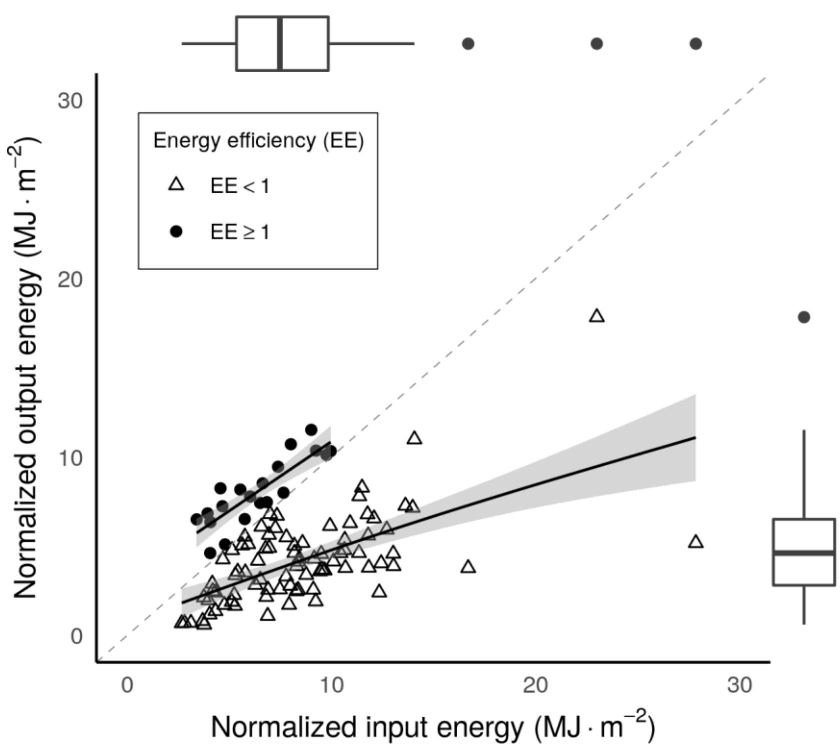

Figure 3. Relationship between normalized energy inputs and outputs. Each symbol represents one farm. Black curves represent fitted generalized additive models for farms with EE≥1 and farms with EE<1. Shaded area represents the 95% confidence interval of each model. The dotted diagonal line a theoretical EE = 1 where input energy intensity equals output energy productivity.

When the total energy inputs and outputs were normalized based on farm size, an expected positive correlation was found between input and output energy per unit of area (Fig. 3). Nonetheless, the slope of this correlation was different in farms with EE≥1 and farms with EE<1. In both types of farms, higher efficiencies were found at lower levels of normalized input energy indicating that, farms that required greater amounts of energy where not using it as efficiently as less energy intensive farms. Furthermore, at each input level, farms with EE≥1 output energy produced was less variable than in farms with EE<1, suggesting that energy efficient farms might be closer to the limit of the energy production capacity of their current technologies/growing conditions; consequently, these results also reveal a potential for optimization of the technologies/practices used in energy inefficient farms.

Several general additive models were fitted to study the influence of normalized input energy use and farm characteristics on the normalized EE and NE production of the farm. None of the models fitted explained well the variability of EE or NE ($R^2 < 0.39$), however, some significant correlations were detected and explored further (Fig. 4). Farm size was significantly related to both EE and NE, with larger farms being more efficient and productive than smaller farms. In contrast, the relationship between EE and NE with the normalized energy input from organic fertilizers and direct energy was, in general, negative. In the case of organic fertilizers and direct energy, EE decreased more rapidly as the level of use of these two inputs increased in energy efficient farms than in energy inefficient farms. These results suggest that, for the farms in this study, energy economies of scale could be operating. In general, farm sizes in our study area were extremely small with half of the farms under 0.1 ha and none larger than 0.63 ha; however, this farm size distribution is common for periurban agriculture (Bellwood-Howard et al., 2015; Pérez-Neira and Grollmus-Venegas, 2018). Like EE itself, the relationship between farm size and EE has also been reported to be dependent on the production system and local conditions (Pelletier et al., 2011) but is normally mediated by the type of technology used in production and the way it is applied. In the farms of this study, negative general correlations between energy from organic fertilizers and direct energy sources suggest that these inputs are being used beyond optimal levels. As revealed by the qualitative analysis of the interviews with the farmers, rates of use of most inputs is set by custom or empirically and not necessarily estimated based on the actual crops needs. This excessive use of inputs not only affects the physical sustainability of the farms by reducing energy efficiency but also reduces economic profits which, as reported by most farmers were normally slim.

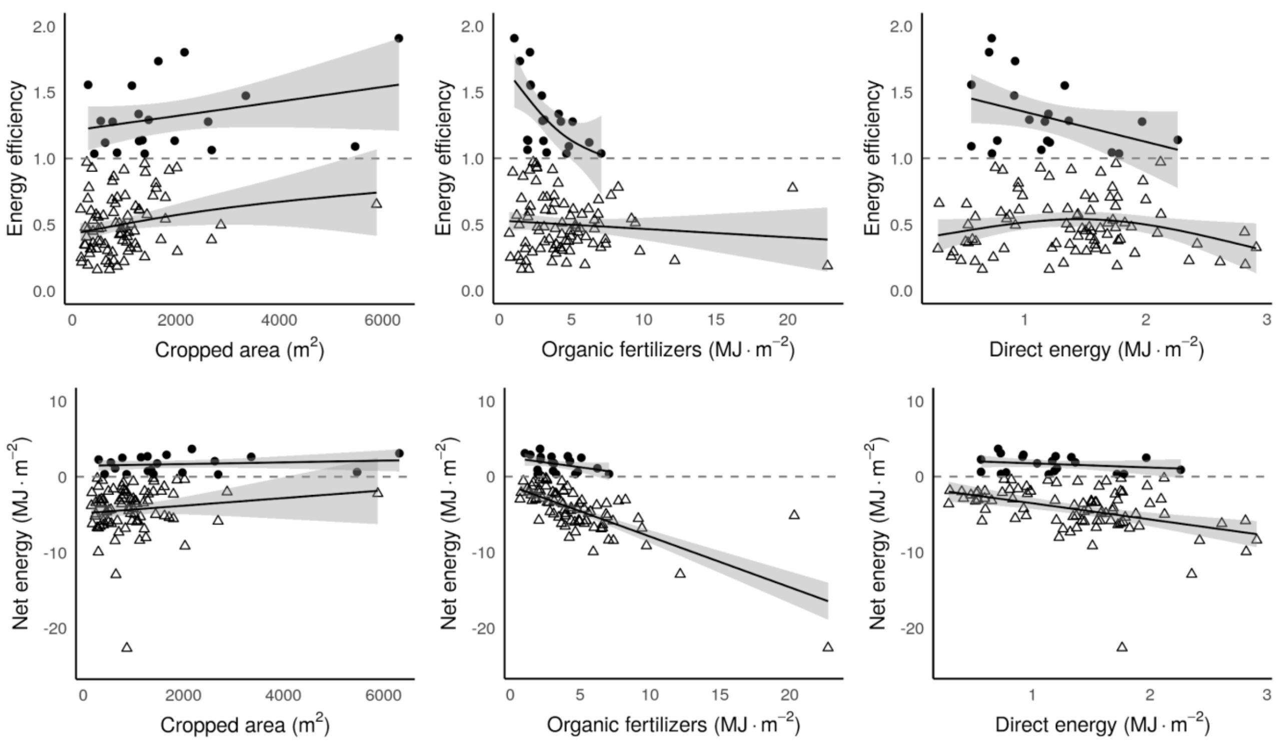

Figure 4. Correlations between farm energy efficiency and net energy with farm size, energy from organic fertilizers and direct energy. Each symbol represents one farm. All energy values are normalized as $MJ{\cdot}m^{-2}$. Black curves represent fitted generalized additive models for farms with EE≥1 (black circles) and farms with EE<1 (white triangles). Shaded area represents the 95% confidence interval of each model.

A more in depth characterization of energy efficient farms could lead to identify key processes that can promoted by technology development and policy design in order to improve the functioning of these traditional periurban production systems in Cuenca and other intermediate Andean cities.

CONCLUSIONS

Most of the vegetable farms characterized produced negative energy balances. Potential energy economies of scale were detected both in energy efficient and energy inefficient farms. Several inputs are probably being used in excessive quantities leading to reduced energy efficiencies and slim profits.

Acknowledgements
We thank Inmaculada Carmona for key exchanges during the preparation of this manuscript.

Funding. This work was funded by internal competitive funds from the University of Cuenca (XIV internal call) through the project 'Evaluación integral de los sistemas de producción hortícola periurbanos de Cuenca y actitud de los productores sobre la adoptabilidad de estrategias de intensificación sustentable'.

Conflict of interest statement. The authors declare that there is no conflict of interest.

Compliance with ethical standards. This article does not contain data from experiments involving either human participants or animal subjects.

Data availability. Data are available with Eduardo J. Chica, eduardo.chica@ucuenca.edu.ec upon reasonable request.

REFERENCES

Aguilera, E., Guzmán Casado, G., Infante Amate, J., Soto Fernández, D., García Ruiz, R., Herrera, A., Villa, I., Torremocha, E., Carranza, G. and González de Molina, M., 2015. Embodied energy in agricultural inputs. Incorporating a historical perspective. [online] Available at: <http://repositori.uji.es/xmlui/handle/10234/141278> [Accessed 8 May 2020].

Alonso, A.M. and Guzmán, G.J., 2010. Comparison of the Efficiency and Use of Energy in Organic and Conventional Farming in Spanish Agricultural Systems. *Journal of Sustainable Agriculture*, 34(3), pp.312–338. https://doi.org/10.1080/10440041003613362

Alvarado, W., 2013. *Evaluación de la sustentabilidad del sistema de producción en la zona baja de la parroquia San Joaquín*. M. Sc. Universidad Politécnica Salesiana. Available at: <http://dspace.ups.edu.ec/handle/123456789/5710> [Accessed 08.05.2020]

Audsley, E., Stacey, K.F., Parsons, D.J. and Williams, A.G., 2009. *Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use.* [pdf] Cranfield University. Available at: <http://dspace.lib.cranfield.ac.uk/handle/1826/3913> [Accessed 8 May 2020].

Bellwood-Howard, I., Häring, V., Karg, H., Roessler, R., Schlesinger, J. and Shakya, M., 2015. *Characteristics of urban and peri-urban agriculture in West Africa: results of an exploratory survey conducted in Tamale (Ghana) and Ouagadougou (Burkina Faso)*. International Water Management Institute (IWMI). Available at: <https://hdl.handle.net/10568/68484> [Accessed 8 May 2020].

Bojacá, C.R. and Schrevens, E., 2010. Energy assessment of peri-urban horticulture and its uncertainty: Case study for Bogota, Colombia. *Energy*, 35(5), pp.2109–2118. https://doi.org/10.1016/j.energy.2010.01.029

Bojacá, C. R., Casilimas, H. A., Gil, R., and Schrevens, E., 2012. Extending the input–output energy balance methodology in agriculture through cluster analysis. *Energy*, 47(1), pp.465-470. https://doi.org/10.1016/j.energy.2012.09.051

Faraway, J.J., 2005. *Extending the linear model with R: generalized linear, mixed effects and nonparametric regression models*. Boca Raton: Chapman and Hall/CRC.

GADP San Joaquín, 2015. *Diagnóstico de la Actualización del Plan de Desarrollo y Ordenamiento Territorial 2015*. [pdf] GADP San Joaquín. Available at: <http://gadsanjoaquin.gob.ec/wp-content/uploads/2017/04/PDYOT-San-Joaquin.pdf>. [Accessed 8 May 2020].

Green, M., 1987. Energy in pesticide manufacture, distribution and use. In: Z.R. Helsel ed. 1988. *Energy in world agriculture: Energy in Plant Nutrition And Pest Control*. New York: Elsevier. Ch.7.

Guamán Parra, J.A. and Tacuri Quizhpi, M.P., 2014. *Estudio de la demanda de productos hortícolas en los hogares de la ciudad de Cuenca y su relación con la producción de la parroquia San Joaquín Bajo*. B. Sc. Universidad Politécnica Salesiana. Available at: <https://dspace.ups.edu.ec/handle/123456789/7040> [Accessed 08.05.2020]

Haller, A., 2014. The “sowing of concrete”: Peri-urban smallholder perceptions of rural–urban land change in the Central Peruvian Andes. *Land Use Policy*, 38, pp.239–247. https://doi.org/10.1016/j.landusepol.2013.11.010

Idrovo, J., 2016. *Transformaciones rurales y agrarias en Ecuador*. [pdf] Santiago: Rimisp. Available at: <http://www.rimisp.org/wp-content/files_mf/1466656003179EcuadorESTUDIOTransformacionesRuralesyAgrariasenEcuadorJorgeIdrovo_editado.pdf>. [Accessed 8 May 2020].

Mejía Zambrano, R.V., 2014. *Evaluación del sistema hortícola intensivo en la parroquia San Joaquín Azuay-Ecuador*. M. Sc. Universidad Politécnica Salesiana. Available at: <https://dspace.ups.edu.ec/handle/123456789/6302>. [Accessed 08.05.2020]

Ozkan, B., Kurklu, A. and Akcaoz, H., 2004. An input–output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. *Biomass and Bioenergy*, 26(1), pp.89–95. https://doi.org/10.1016/S0961-9534(03)00080-1

Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A., Kramer, K.J., Murphy, D., Nemecek, T. and Troell, M., 2011. Energy Intensity of Agriculture and Food Systems. *Annual Review of Environment and Resources*, 36(1), pp.223–246. https://doi.org/10.1146/annurev-environ-081710-161014

Pérez-Neira, D. and Grollmus-Venegas, A., 2018. Life-cycle energy assessment and carbon footprint of peri-urban horticulture. A comparative case study of local food systems in Spain. *Landscape and Urban Planning*, 172, pp.60–68. https://doi.org/10.1016/j.landurbplan.2018.01.001

Pérez-Neira, D.P., Montiel, M.S. and Fernández, X.S., 2013. Energy Analysis of Organic Farming in Andalusia (Spain). *Agroecology and Sustainable Food Systems*, 37(2), pp.231–256. https://doi.org/10.1080/10440046.2012.734263

R Core Team, 2018. *R: A Language and Environment for Statistical Computing*. [online] Vienna, Austria: R Foundation for Statistical Computing. Available at: <https://www.R-project.org>.

Romero, H. and Ordenes, F., 2004. Emerging Urbanization in the Southern Andes. *Mountain Research and Development*, 24(3), pp.197–201. https://doi.org/10.1659/0276-4741(2004)024[0197:EUITSA]2.0.CO;2

Smith, L.G., Williams, A.G. and Pearce, B.D., 2015. The energy efficiency of organic agriculture: A review. *Renewable Agriculture and Food Systems*, 30(3), pp.280–301. https://doi.org/10.1017/S1742170513000471

Sotamba Sanango, R.P. and Sánchez Dumas, J.S., 2013. *Estudio de comercialización hortícola en la parroquia San Joaquín Bajo-Cuenca*. B. Sc. Universidad Politécnica Salesiana. Available at: <https://dspace.ups.edu.ec/handle/123456789/5552> [Accessed 08.05.2020]

Tapia Barrera, M.R., 2014. *Prácticas y saberes ancestrales de los agricultores de San Joaquín*. M. Sc. Universidad Politécnica Salesiana. Available at: <https://dspace.ups.edu.ec/handle/123456789/6297> [Accessed 08.05.2020]

USDA, 2018. *USDA national nutrient database for standard reference Legacy Release*. [online] United States Department of Agriculture - Agricultural Research Service. Available at: <http://www.ars.usda.gov/nutrientdata> [Accessed 8 May 2020].

Zhang, J., Palmer, S. and Pimentel, D., 2012. Energy production from corn. *Environment, Development and Sustainability*, 14(2), pp.221–231. https://doi.org/10.1007/s10668-011-9318-4.