Acta Agronómica
ISSN: 0120-2812
actaagronomica@palmira.unal.edu.co
Universidad Nacional de Colombia
Colombia

González Ulibarry, Paco; García Elizalde, Pedro; Gastó Corderch, Juan; De Kartzow Garcia, Alejandro; Obando-Ulloa, Javier Mauricio
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Acta Agronómica, vol. 66, núm. 1, 2017, pp. 109-114
Universidad Nacional de Colombia
Palmira, Colombia

Acta Agron. (2017) 66 (1) p 109-114 ISSN 0120-2812 | e-ISSN 2323-0118 doi: http://dx.doi.org/10.15446/acag.v66n1.52218

# Evaluation of sustainability and the impact of the agriculture styles of the chilean coastal dry lands

## Evaluación de la sustentabilidad y el impacto de los estilos de agricultura del secano costero chileno

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Rec.: 30.07.2015 Acep.:

## Abstract

Agriculture has been progressing continuously, from the use of free natural resources to the fossil fuels as energy sources. Even though agriculture depends mainly on ecosystem resources and services, its development has been apparently centered only on yield, not considering neither the ecological value of the negative externalities nor the decapitalization of the resources that influence sustainability. Thus, the information on the evaluation of the sustainability on different agriculture styles is scarce or almost null. This investigation evaluates the sustainability in different agriculture styles (intensive horticulture, traditional farm and self-sustaining horticulture) established in Hualqui (Region of Biobío, Chile), through the energy flows present on each style to measure the impact generated on the land. The results revealed that the self-sustaining horticulture style showed a higher sustainability compared to the traditional farm and intensive horticulture style. These results can contribute to the public, policies to reorient the action strategy to encourage the sustainability in the different agriculture styles.

**Keywords:** Emergy, horticulture, emergy index and cultural landscape.

## Resumen

La agricultura ha progresado ininterrumpidamente, pasando de la utilización de recursos naturales gratuitos al uso creciente de recursos fósiles como fuentes energéticas. Si bien la agricultura depende fundamentalmente de los recursos y servicios del ecosistema, su desarrollo se ha centrado sólo en la producción, sin tomar en cuenta el valor ecológico de las externalidades negativas ni la descapitalización de los recursos que inciden en la sustentabilidad, por lo que la información sobre la evaluación de la sustentabilidad de los diferentes estilos de agricultura es poca o casi nula. En la presente investigación se evaluó la sustentabilidad de los estilos de agricultura (horticultor intensivo, tradicional campesino y horticultor auto sostenible) establecidos en la comuna de Hualqui (Región del Biobío, Chile), mediante los flujos de energía presentes en cada estilo, para medir el impacto que generan sobre el paisaje. Los resultados muestran que el estilo de agricultura horticultor auto sostenible presenta una mayor sustentabilidad en comparación con los estilos tradicional campesino y horticultor intensivo y pueden contribuir a nivel de políticas públicas para reorientar la estrategia de acción y fomentar la sustentabilidad en los distintos estilos de agricultura.

**Palabras clave:** Emergía, horticultor, índice emergético y paisaje cultural.

## Introduction

Since the Green Revolution, agriculture has been progressing continuously, replacing the use of free natural resources with the use of fossil fuel resources as energy sources. This fact has created a meaningful growth on the agriculture production (Hendrickson, Liebig & Sassenrath, 2008; Pretty, 2008). In addition, the increase of the worldwide population accelerated the pressure on natural resources and on landscapes (Dale, Kline, Kaffka, & Langeveld, 2013; Hendrickson *et al.,* 2008; Moonen & Barberi, 2008; Rodrigues, Rodrigues, Buschinelli, & de Barros, 2010; Stoate *et al.,* 2009) and it also generated a progressive degradation of ecosystems, biodiversity loss, landscape neglection, loss of cultivated land, soil erosion, water sources pollution, pesticide pollution, loading capacity problems, nitrogen and phosphorus pollution and ecosystem services loss, among other problems (Alene & Coulibaly, 2009; Burger *et al.,* 2012; Candela, Elorza, Jiménez-Martínez, & Von Igel, 2012; Hendrickson *et al.,* 2008; McKenzie, Cooper, McCann, & Rogers, 2011; Pretty, 2008; Schneider *et al.,* 2011; Stoate *et al.,* 2009).

Sustainability is defined as the development that allows satisfying current needs without compromising future generation capacity to satisfy their own needs, and allows observe the impact of economic growth on natural resources (Pretty, 2008). However, agriculture development has been mainly focused mainly on production and cost reduction, without considering the ecologic value of negative externalities or disinvestments of the resources that affect emergy (Ghaley & Porter, 2013; Rydberg & Haden, 2006).

Etymologically, emergy derivates from the expression "energy memory", referring to the method used to evaluate with an integral method the flow and concentration of matter and energy on the systems studied, based on the energetic principles of the biological systems, the general system and ecological system theory (Campbell & Garmestani, 2012), for which, a transformator is defined to compare all the energy types in terms of solar energy or transformativity (expressed in solar joules) to account the natural resources and the economy activity (Zhang, Song & Chen, 2012).

Furthermore, agriculture styles are understood as the way the producer organizes his property, considering the organization of the space, the agriculture production and, production and technology factors according to a pre-established goal through the association of the economic, technological and ecosystemic aspects (Vélez & Gastó, 2002). These styles are defined according to the cultural landscape, which considers territory, natural resources, customs, land use, and management (Gastó, Vera, Vieli, & Montalba, 2009).

Actually, there are very few studies that evaluate the sustainability of each agriculture style. Therefore, the aim of this research is to analyze the sustainability and impact of these agriculture styles on the cultural landscape of Hualqui (Region of Biobío, Chile).

## Material and methods

The cases evaluated in this research, were selected by a technical visit to 20 farms of Hualqui (Region of Biobío, Chile; 36° 58' latitude S – 72° 56' longitude W), which presents a short dry-summer weather (Gastó, Cosio, & Panario, 1993). The farms selected were San Sebastián (intensive horticulture), Ranguel (traditional farmer) and Talcamávida (self-sustainable horticulture) because they showed a well-defined and clear agriculture style, according to the parameters described by Velez & Gastó (2002).

The farm data selected was collected by semi-structured interviews to each farmer. The data related to the inputs and agriculture production was collected on a first interview, while a second interview was performed to make a complete characterization of the farms and to check the data obtained in the first interview.

### Description of agriculture styles in the Hualqui commune

The intensive horticulture farm has a 1.12 ha area. It is used for the production of lettuce, zucchini, tomato, and bean, destined to the local market and keeping the surplus to self-consumption. The farmer is the owner of the farm but because of the limited surface to work, he complements his income with other commercial activities, but his lifestyle corresponds to the one of a classic farmer. The farm shows a good condition, with a leaning to degradation because of the large use of supplies and the deterioration of the techno-structures related to the production.

The traditional style farm has a 7.98 ha area. This farm is mostly dedicated to the production of tomato, lettuce, broad bean, potato, wheat, oat, wine grapes, wine, and liquor, either for sale or self-consumption. The farmer owns the land and he has completed middle school education. Most of his work is based on experience and local tradition. This farm presents a poor condition leaning to degradation because of the reiteration of the wheat production (previous purpose of the farm) and also because of the abandonment of techno-structural elements.

The self-sustainable horticulture farm has a 0.85 ha area and it is mainly flat. The land is rented and is focused on forestry, honey and merken production. This farm presents a good condition with a sign of development because of the land management that is complemented with the production of different crops in harmony with the ecosystem.

### Emergy synthesis

The emergetic synthesis consists on the measurement of the energy present on a system considering the input and output of the energy flows in a determined time lapse. The flow of each input is calculated by the following equation:

Ui = Ri + Ni + Fi

Where: Ui: emergy used for each case of study; Ri: local renewable resources (example: rain, wind and sunlight); Ni: local non-renewable resources (example: top soil loss); Fi: purchased resources (raw materials, fuel, etc.).

On the other hand, the output flow (Yi) includes raw materials, services and products. Each input and output flow is expressed by the transformity in equivalent and comparable units, called emergy units (Rydberg & Hadenm, 2006; Zhang, Song, & Chen, 2012).

### Emergetic Indices

The emergetic indices can be calculated with the emergetic flow equation defined above (Ri, Ni, Fi and Yi), which relates the ratios that indicates a measurement of the efficiency or ecological-environmental state of the cases studied (Chen, Chen, Luo & Lv, 2009). The following indicators were considered in this study:

Solar transformity (Ui/Yi): measures the input and output flow of a process (Cavalett , De Queiroz & Ortega, 2006). A high solar transformity value means that more units of energy input has been used in the process to generate one output unit (Rydberg & Haden, 2006; Zhang *et al.,* 2012).

Emergy yield ratio (EYR): quotient between the total output flows of a process and the flow generated by the paid non-renewables resources (Rydberg & Haden, 2006; Zhang *et al.,* 2012). This index can be equal or higher than 1. If the EYR is higher than 1, it means the paid non-renewable resources are just a fraction of the total resources used in the input flow. When the value is equal to 1, it is a case of extreme artificialization of the productive system and indicates that every resource used in the process is a paid non-renewable resource (Ghaley & Porter, 2013; Zhang *et al.,* 2012).

Environmental loading ratio (ELR): quotient between the flows of non-renewable resources (paid and non-paid) and the flow generated by non-paid renewable resources (Rydberg & Haden, 2006; Zhang *et al.,* 2012). This ratio indicates the loading capacity and decapitalization in the process of production. The higher this index indicates a higher proportion of the energy flow generated by the non-renewable resources than the flow generated by the renewable resources (Ghaley & Porter, 2013; Zhang *et al.,* 2012).

Emergy sustainability index (ESI): quotient resulting between the relation of the emergetic efficiency and the loading capacity. The higher the emergetic yield related to the environmental load, the higher this index will be, indicating greater emergetic sustainability (Ghaley & Porter, 2013; Rydberg & Haden, 2006; Zhang *et al.,* 2012).

## Results and discussion

### Emergy evaluation of agriculture styles

### Intensive horticulture style

The farm with this style of production exhibited an emergy used (U) of 2.59E+16 seJ.year$^{-1}$, the non-paid renewable resources (R) were 4.93E+14 seJ.year$^{-1}$, while the non-paid non-renewable resources (N) and the paid non-renewable resources (F) reached 1.07E+12 and 2.54E+16 seJ.year$^{-1}$, respectively. The total outcome of the farm was 5.30E+14 seJ.year$^{-1}$ (Table 1).

### Traditional style farm

The farmer who practices a traditional style showed an emergy used (U) of 3.16E+16 seJ.year$^{-1}$. On this style, the non-paid renewable resources (R), the non-paid non-renewables resources (N) and the paid non-renewable resources (F) were 2.83E+15; 6.13E+12 and 2.88E+16 seJ.year$^{-1}$, respectively. The total outcome of the farm was 1.08E+13 seJ.year$^{-1}$ (Table 2).

### Self-sustainable horticulture style

The emergy used (U) on this farm was 2.16E+15 seJ.year$^{-1}$. Non-paid renewable resources (R), non-paid non-renewable resources (N) and paid non-renewables resources (F) reached values of 4.07E+14; 8.73E+11 and 175E+15 seJ.year$^{-1}$, respectively. The total outcome of the farm was 1.30E+11 seJ.year$^{-1}$ (Table 3).

**Table 1**. Emergetic analysis of intensive horticulture style

| Input Category | Units | Inputs | Emergy per unit | Emergy | Emergy % |
|---|---|---|---|---|---|
| Local renewable (R) | | | | | |
| Sunlight | J.year-1 | 2,72E+13 | 1 | 2,72E+13 | 0,11 |
| Wind | J.year-1 | 3,31E+10 | 2,45E+03 | 8,12E+13 | 0,31 |
| Rain | J.year-1 | 1,24E+10 | 3,10E+04 | 3,85E+14 | 1,49 |
| **Total Local renewable (R)** | | | | 4,93E+14 | 1,91 |
| Local non-renewable (N) | | | | | |
| Top soil loss | J.year-1 | 5,57E+06 | 1,92E+05 | 1,07+12 | 0,00 |
| Total Local non-renewable (N) | | | | 4,91E+15 | 0,00 |
| Diesel | J.year-1 | 3,66E+09 | 1,11E+05 | 4,06E+14 | 1,57 |
| Biomass Forest | g.year-1 | 2,55E+06 | 6,72E+04 | 2,42E+11 | 0,00 |
| Seed | g.year-1 | 7,04E+03 | 1,20E+09 | 8,45E+12 | 0,03 |
| Nitrogen | g.year-1 | 1,20E+05 | 4,05E+10 | 4,86E+15 | 18,77 |
| Phosphorus | g.year-1 | 2,00E+05 | 3,70E+10 | 7,40E+15 | 28,58 |
| Potassium | g.year-1 | 2,40E+05 | 1,85E+09 | 4,44E+14 | 1,72 |
| Micronutrients | g.year-1 | 1,00E+04 | 2,00E+10 | 2,00E+14 | 0,77 |
| Pasturas | g.year-1 | 1,82E+06 | 8,60E+08 | 1,56E+15 | 6,03 |
| Direct work | JH.yr-1 | 1,50E+02 | 1,24E+06 | 1,86E+08 | 0,00 |
| Labour | JH.yr-1 | 5,00E+01 | 1,03E+06 | 5,15E+07 | 0,00 |
| Machine | g.year-1 | 1,09E+05 | 1,12E+10 | 1,22E+15 | 4,70 |
| Services | $.yr-1 | 1,40E+06 | 6,62E+09 | 9,30E+15 | 35,91 |
| Total purchased (F) | | | | 2,54E+16 | 98,09 |
| Total Emergy use (U) | | | | 2,56E+16 | |
| OUTPUTS (Y) | | | | | |
| Tomato | g.year-1 | 1,20E+07 | 2,70E+04 | 3,24E+11 | |
| Cabbage | g.year-1 | 3,32E+06 | 2,70E+04 | 8,95E+10 | |
| Lettuce | g.year-1 | 1,96E+10 | 2,70E+04 | 5,29E+14 | |
| Zucchini | g.year-1 | 2,10E+06 | 2,70E+04 | 5,67E+10 | |
| Rayo Beans | g.year-1 | 2,70E+06 | 2,70E+04 | 7,29E+10 | |
| Leek | g.year-1 | 1,71E+06 | 2,70E+04 | 4,62E+10 | |
| Chard | g.year-1 | 8,50E+06 | 2,70E+04 | 2,30E+11 | |
| Total outputs (Y) | | | | 5,30E+14 | |

**Table 2.** Emergetic analysis of traditional agriculture style

| Input Category | Units | Inputs | Emergy per unit | Emergy | Emergy % |
|---|---|---|---|---|---|
| Local renewable (R) | | | | | |
| Sunlight | J.year-1 | 1,56E+14 | 1 | 1,56E+14 | 0,49 |
| Wind | J.year-1 | 1,90E+11 | 2,45E+03 | 4,66E+14 | 1,47 |
| Rain | J.year-1 | 7,12E+10 | 3,10E+04 | 2,21E+15 | 6,98 |
| Biomass Forest | g.year-1 | 1,28E+07 | 6,72E+04 | 8,57E+11 | 0,00 |
| Local renewable (R) | | | | 2,83E+15 | 8,95 |
| Local Non-renewable (N) | | | | | |
| Top soil loss | J.year-1 | 3,19E+11 | 1,92E+05 | 6,13E+12 | 0,02 |
| Total Non-renewable (N) | | | | 2,82E+16 | 0,02 |
| Purchased | | | | | |
| Diesel | J.year-1 | 2,07E+09 | 1,11E+05 | 2,29E+14 | 0,73 |
| Seeds | g.year-1 | 3,79E+05 | 1,20E+09 | 4,55E+14 | 1,44 |
| Nitrogen | g.year-1 | 3,00E+05 | 4,05E+10 | 1,22E+16 | 38,42 |
| Phosphorus | g.year-1 | 3,00E+05 | 3,70E+10 | 1,11E+16 | 35,10 |
| Potassium | g.year-1 | 3,00E+05 | 1,85E+09 | 5,55E+14 | 1,76 |
| Labour | JH.yr-1 | 6,00E+01 | 1,24E+06 | 7,44E+07 | 0,00 |
| Machinery | g.year-1 | 6,10E+03 | 1,12E+10 | 6,83E+13 | 0,22 |
| Services | $.yr-1 | 6,38E+05 | 6,62E+09 | 4,23E+15 | 13,37 |
| Total Purchesed (F) | | | | 2,88E+16 | 91,03 |
| Total Emergy used (U) | | | | 3,16E+16 | |
| OUTPUTS (Y) | | | | | |
| Tomatoes | g.year-1 | 1,20E+06 | 2,70E+04 | 3,24E+10 | |
| Lettuce | g.year-1 | 2,40E+06 | 2,70E+04 | 6,48E+10 | |
| Bean | g.year-1 | 1,13E+06 | 2,70E+04 | 3,04E+10 | |
| Potato | g.year-1 | 1,24E+07 | 2,70E+04 | 3,35E+11 | |
| Wheat | g.year-1 | 3,60E+03 | 2,88E+09 | 1,04E+13 | |
| Oat | g.year-1 | 6,50E+05 | 4,05E+09 | 2,63E+15 | |
| Clover | g.year-1 | 1,45E+07 | 2,88E+09 | 4,17E+16 | |
| Wine | g.year-1 | 8,10E+06 | 1,18E+09 | 9,58E+15 | |
| Liquor | g.year-1 | 6,75E+05 | 1,18E+09 | 7,99E+14 | |
| Total outputs (Y) | | | | 1,08E+13 | |

**Table 3.** Emergetic analysis of self-sustainable horticulture style

| Input Category | Units | Inputs | Emergy per unit | Emergy | Emergy % |
|---|---|---|---|---|---|
| Local renewable (R) | | | | | |
| Sunlight | $J.year^{-1}$ | 2,22E+13 | 1 | 2,22E+13 | 1,03 |
| Wind | $J.year^{-1}$ | 2,71E+10 | 2,45E+03 | 6,63E+13 | 3,07 |
| Rain | $J.year^{-1}$ | 1,01E+10 | 3,10E+04 | 3,14E+14 | 14,54 |
| Seeds | $g.year^{-1}$ | 4,96E+01 | 7,86E+04 | 3,90E+06 | 0,00 |
| Manure | $g.year^{-1}$ | 2,10E+04 | 2,13E+08 | 4,47E+12 | 0,21 |
| Biomass Forest | $g.year^{-1}$ | 3,60E+06 | 6,72E+04 | 2,42E+11 | 0,01 |
| Total Local Renewable (R) | | | | 4,07E+14 | 18,86 |
| Local Non-renewable (N) | | | | | |
| Top soil loss | J/yr | 1,92E+05 | 1,92E+05 | 8,73E+11 | 0,04 |
| Total Local Non-renewable (N) | | | | 4,01E+15 | 0,04 |
| Purchased (F) | | | | | |
| Diesel | $J.year^{-1}$ | 1,36E+09 | 1,11E+05 | 1,51E+14 | 6,97 |
| Seeds | $g.year^{-1}$ | 1,87E+03 | 1,20E+09 | 2,25E+12 | 0,10 |
| Nitrogen | $g.year^{-1}$ | 5,50E+03 | 4,05E+10 | 2,23E+14 | 10,31 |
| Phosphorus | $g.year^{-1}$ | 3,00E+03 | 3,70E+10 | 1,11E+14 | 5,14 |
| Potassium | $g.year^{-1}$ | 3,00E+03 | 1,85E+09 | 5,55E+12 | 0,26 |
| Direct work | $JH.yr^{-1}$ | 3,40E+01 | 1,24E+06 | 4,22E+07 | 0,00 |
| Labour | $JH.yr^{-1}$ | 1,20E+01 | 1,03E+06 | 1,24E+07 | 0,00 |
| Machinery | $g.year^{-1}$ | 3,90E+03 | 1,12E+10 | 4,37E+13 | 2,02 |
| Services | $\$.yr^{-1}$ | 1,84E+05 | 6,62E+09 | 1,22E+15 | 56,30 |
| Total Purchased (F) | | | | 1,75E+15 | 81,10 |
| Total Emergy used (U) | | | | 2,16E+15 | |
| OUTPUTS (Y) | | | | | |
| Rayo Beans | $g.year^{-1}$ | 8,00E+05 | 2,70E+04 | 2,16E+10 | |
| Zucchini | $g.year^{-1}$ | 1,25E+02 | 2,70E+04 | 3,38E+06 | |
| Tomatoes | $g.year^{-1}$ | 3,50E+06 | 2,70E+04 | 9,45E+10 | |
| Honey | $g.year^{-1}$ | 5,00E+05 | 2,70E+04 | 1,35E+10 | |
| Pollen | $g.year^{-1}$ | 3,00E+03 | 3,00E+03 | 9,00E+06 | |
| Royal jelly | $g.year^{-1}$ | 1,71E+06 | 1,00E+01 | 1,71E+07 | |
| Merken | $g.year^{-1}$ | 1,00E+01 | 2,70E+04 | 2,70E+05 | |
| Total Output (Y) | | | | 1,30E+11 | |

## Emergy index for the evaluation of each agriculture style

According to Table 4, the intensive horticulture farm showed a higher outcome value (5.30E+14 $J.ha^{-1}.year^{-1}$) and a higher relation of loading capacity (51.48) in comparison to the other agriculture styles. However, the self-sustainable horticulture farm evidenced a higher value of solar transformation (1.67E+04), emergetic yield ratio (1.23) and emergy sustainability index (0.29).

**Table 4.** Emergetic index of the different agriculture styles

| Emergy indices | Parameters | Agriculture style | | |
|---|---|---|---|---|
| | | Intensive Horticulture | Traditional farmer | Self-sustainable horticulture |
| Output (J/ha/yr) | Y | 5,30E+14 | 1,08E+13 | 1,30E+11 |
| Solar transformity (seJ/J) | U/Y | 4,88E+01 | 2,92E+03 | 1,67E+04 |
| Emergy yield ratio (EYR) | U/F | 1,02 | 1,10 | 1,23 |
| Environmental loading ratio (ELR) | (F+N)/R | 51,48 | 10,17 | 4,30 |
| Emergy sustainability index (ESI) | EYR/ELR | 0,02 | 0,11 | 0,29 |

The high values of the environmental loading ratio presented by the different agriculture styles analyzed in this study were caused by the large dependence on paid non-renewable resources in contrast to a relatively small area for production. This behavior also explains the value of the energetic yield relation of each farm. Additionally, the high transformity obtained by the self-sustainable horticulture farmer is coherent with the high relation of emergetic yield, thus with a low efficiency in the use of emergetic flows entering the system (Zhang *et al.,* 2012).

The loading capacity relation, which is relatively low in these cases is evidenced by the different styles of agriculture in the Hualqui commune, indicating a minor dependence of paid non-renewable resources regarding a relatively small surface, which is consistent with the emergetic yield (Campbell & Garmestani, 2012). These values are consistent with the high value of emergy sustainability index, due to a low loading capacity in relation to the emergetic yields observed (Table 4). In general, a high sustainability can be explained by a low intensity in the production process without overcharging the system (Chen *et al.,* 2009).

Even though self-sustainable horticulture farmer has to rent the land, he must minimize the acquisition of paid non-renewable resources, so it can be assumed that his emergetic index result from the environmentalist attitude observed during the interviews.

## Conclusion

The results obtained in this research are consistent with each typology established from field work and calculations, which validates quantitatively initial observations regarding the choice of the properties on fieldwork. This evidences that the self-sustainable horticulture farmer achieves a greater sustainability, due to his emergetic sustainability index. In general, sustainability is consistent with the relation to loading capacity on each agriculture style studied. This is due to the dependence on paid non-renewable resources that every style uses and the linking presented by each farmer with the natural, social and economy environment, which results in the way the farmer interacts with the landscape. The results of this study may contribute to the analysis of sustainability and impact, which may be considered at the level of public policies to reorient the strategy of action and promote sustainability in the different agriculture styles.

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