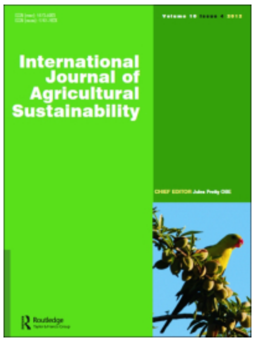

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Categorizing the sustainability of vegetable production in Chile: a farming typology approach

Francisco Benitez-Altuna[a], Jacques Trienekens[a] and Daniel Gaitán-Cremaschi[b]

[a]Business Management and Organisation Group, Department of Social Science, Wageningen University and Research, Wageningen, The Netherlands; [b]Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Barcelona, Spain

ABSTRACT

Sustainable practices are seen as one of the solutions to redress the negative impact of agriculture's growing intensification. Despite efforts by many governments, the adoption rate of sustainable practices amongst farmers is still low. One of the causes is policymakers' insufficient knowledge of farming-system diversity. In order to account for such diversity, this paper proposes classifying farming systems, including new elements such as the sustainability level of agricultural practices and market channel traits, in combination with socio-economic and farm characteristics. We apply a farming typology approach, using vegetable production in Chile as our case study. We developed the typology using multivariate analysis techniques including principal component analysis (PCA) and hierarchical clustering (CA). We collected data using surveys (n = 352) in the central region of Chile. The results reveal five farming-system types: (1) Large dual farming, (2) ecological farming, (3) traditional farming, (4) conventional small-scale farming, and (5) conventional medium-scale farming. The five farming system types provide insights on the different agricultural practices used and their different starting points in terms of their transition towards more sustainable agriculture practices. We also propose possible policies based on these farming-system types that can be useful for policymakers to promote sustainable practices.

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Sustainable agriculture; farm typology; transition pathways; market channel; emerging economies

1. Introduction

World-wide economic growth and the ever-growing demand for food in the last decades have led to agriculture's industrialization, characterized by monoculture production and the extensive use of synthetic agricultural inputs (Perkins & Jamison, 2008). As a result of this industrialization, environmental degradation (e.g. biodiversity loss and soil erosion) and the growing impact of climate change are now challenges society has to cope with (Blazy et al., 2009). This has incited governments, farmers and academics to explore alternative agricultural practices that redress the consequences of conventional agriculture (Knowler & Bradshaw, 2007). We refer to these alternative agricultural practices as sustainable agricultural practices (SAPs). SAPs imply that 'agriculture will have to be carried out to make the best use of available natural resources and inputs, and regenerate conditions for future production' (Leeuwis, 2004, p. 5) e.g. use of traditional seeds, organic fertilizers, preventive practices without chemicals to control pest and diseases, organic herbicides and crop rotation.

In the last decade, governments have implemented numerous projects to foment SAP adoption. However, the transition to these practices

CONTACT Francisco Benitez-Altuna fjbenitez@ucanr.edu, benitez.franco23@gmail.com Berkeley Food Institute, University of California Agriculture and Natural Resources, Berkeley, California, USA

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has been slow (Eyhorn et al., 2019). The limited effect of these projects in rural areas is largely due to policy-makers' and researchers' standardized views of farming systems (Ganpat & Bekele, 2002). Policy-makers often classify farming systems into only two categories: small and large-scale; thus, overlooking the diversity within these categories, and assuming similar characteristics such as homogeneous capabilities, circumstances and resources (Ganpat & Bekele, 2002; Fernández et al., 2019). The standardized view on farming systems leads to inflexible strategies, following one-size-fits-all paths that do not consider the farmers' particular aspirations and resources (Dumont et al., 2020). Moreover, the transition to SAPs is a gradual and unique process for each farming system. It depends on the specific characteristics of both farmers and their farms (e.g. crop, size land and irrigation) as well as the context in which production takes place (Daloğlu et al., 2014; Teixeira et al., 2018). Thus, to design better strategies to stimulate SAP adoption, identifying the diversity of farming systems is essential.

The use of farming typology has been widely used to investigate the diversity of farming systems (Righi et al., 2011). Farming typology groups farming systems by considering economic, political, social, ecological and climatic factors (Dumont et al., 2020), and by similar constraints and opportunities (Ganpat & Bekele, 2002). Most existing farming typology studies differ in their focus. For example, more traditional studies focused on socio-economic and farm production indicators (e.g. Andersen et al., 2007), often in relation to policies aiming at increasing production and farm profit. Similarly, with the growing attention for environmental issues, farming typology studies started to focus on sustainability indicators such as soil quality (Tittonell et al., 2005; Sierra et al., 2017), the response to climate change (Nainggolan et al., 2013), technology adoption (Goswami et al., 2014) and agroecological practices (Teixeira et al., 2018). However, most typologies only include a limited number of mono-disciplinary indicators, little research has sought to construct a farming typology that considers socio-economic, production and farm characteristics together with agricultural practices' sustainability levels (Teixeira et al., 2018).

To address this gap, the objective of this research is to construct a farming typology by combining socio-economic elements, production and farm characteristics, including market channel traits, with the sustainability level of agricultural practices. To this end, we conduct an empirical analysis in the vegetable sector in an emerging economy context, in this case, Chile. Beyond the case of vegetable farming systems in Chile, the paper aims to demonstrate the value of mapping the diversity of farming systems and their sustainability levels to better define objectives and target strategies in rural areas to promote wider adoption of SAPs.

The paper is organized as follows: Section 2, presents the case study of vegetable production in Chile; Section 3, explains our data collection process and multivariate analyses; Section 4, provides the results of the farming system typology for the vegetable sector in Chile and; Section 5, explores the pathways towards sustainability and policy implications based on the farming systems types that were identified. This section also discusses methodological limitations and further research. Lastly, Section 6 presents the conclusions of this study.

2. Case study: vegetable production in Chile

Emerging economies such as Chile have developed dualistic agricultural sectors. Fast economic growth has generated an agricultural structure wherein small farming systems coexist alongside large-scale farming systems (Kostov & Lingard, 2003). In Chile, the combination of neoliberal agrarian policies and a green revolution perspective has focused on increasing productivity over the short term with the intensive use of inputs, with a focus on large scale farming systems (Montalba et al., 2017). This has caused problems such as environmental deterioration (Montalba et al., 2017), human health decline (Muñoz-Quezada et al., 2016), the loss of ecological diversity due to monoculture production and the exclusion of smallholders (Sarandon & Marasas, 2017). Therefore, different governmental institutions as well as multiple Chilean grassroots organizations have sought to develop and promote SAPs (ODEPA, 2011).

Vegetable production is one of the main agricultural activities in Chile. In 2019, vegetable production covered 77,000 hectares and encompassed 34,000 farmers distributed all over the country. The sector primarily includes small-scale farming systems (less than 5 hectares), and a smaller number of large-scale farming systems (exceeding 300 hectares).

Vegetable farming systems are characterized by many differences due to socio-economic factors, available resources and managerial strategies and skills, making it a heterogeneous sector (ODEPA, 2020). The largest vegetable production area is located in Chile's central area, specifically in the regions of Valparaiso, Metropolitana, O'Higgins and Maule. These regions dedicate approximately 54,000 hectares to vegetable production and produce around 70% of the country's vegetables (ODEPA, 2020).

3. Methods

3.1. Data collection

To construct the farming typology, we collected data via face-to-face surveys with vegetable growers in Chile. The survey included questions related to social, production, farm attributes and factors affecting the adoption of SAPs (see Subsection 3.2. 'variable selection for the farming typology'). We applied random sampling. A total of 352 farmers participated in the survey. The survey was implemented from October 2018 to April 2019 in the regions with major concentration of vegetable growers, i.e. Valparaiso, Metropolitana, O'Higgins and Maule (Figure 1).

3.2. Variable selection for the farming typology

We selected variables based on literature review of previous farming typology studies representing social, production and farm attributes of farming systems (Tittonell et al., 2010; Álvarez et al., 2018), and on literature analysing the factors affecting the adoption of SAPs (Baumgart-Getz et al., 2012; Tey et al., 2017). We used 25 variables (Table 1) divided into four categories: (1) agricultural practices, measured by a farm-level sustainability index (explained in Section 3.2); (2) socio-economic characteristics, including variables related to capital, social features and knowledge (e.g. age, sex, education, experience) (Tittonell et al., 2010; Righi et al., 2011); (3) farm characteristics, including variables related to infrastructure, scale of the farm, area allocated to vegetables and organic certification (Pacini et al., 2014; Goswami et al., 2014); and (4) market channel characteristics, encompassing variables related to the

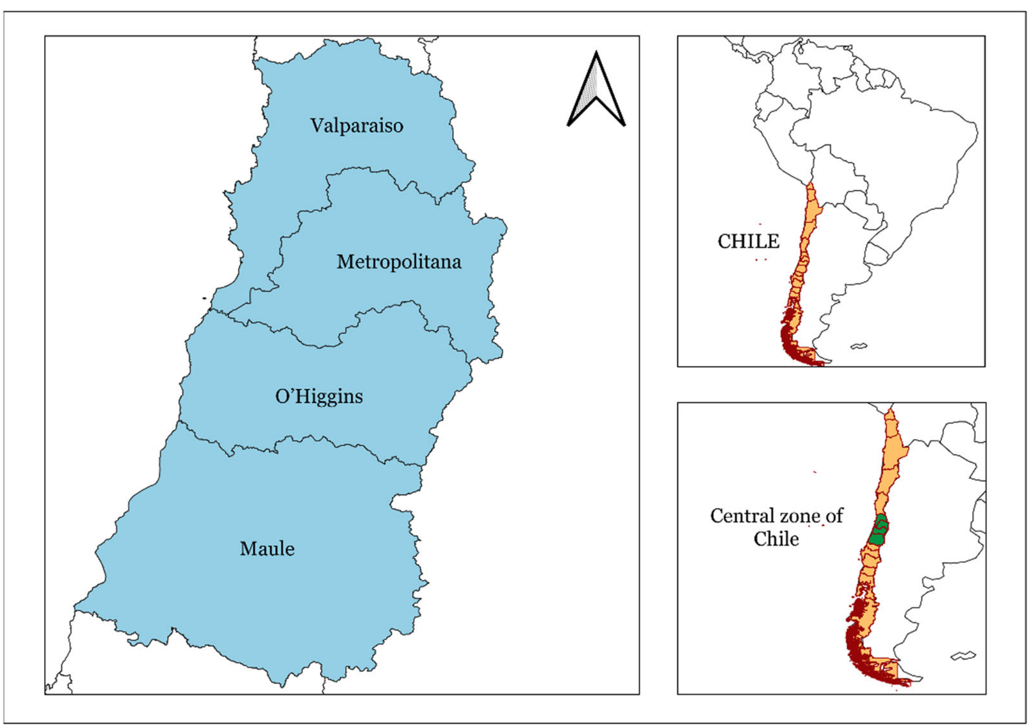

Figure 1. Research area.

proximity to the main market, types of buyers and types of agreements (Guarín et al., 2020).

3.3. Measuring the sustainability levels of agricultural practices: a farm-level index

The use of SAPs involves substituting synthetic resources produced out-farm (i.e. fertilizers, insecticides, herbicides) for on-farm resources to achieve sustainable use of natural resources (Taylor et al., 1993). Some examples of practices based on on-farm resources are integrated pest management, crop rotation, green manure and cover crop (Taylor et al., 1993; Kleijn et al., 2019). In order to quantitively analyse sustainability levels of agricultural practices, literature has developed multiple indexes to measure farm sustainability (see for example Astier et al., 2011; Rigby et al., 2001). However, most indexes focus on specific production stages and specific practices. In this paper we use the index proposed by Rigby et al. (2001). The index allows assessing the sustainability level of agricultural practices in farming systems in five different stages, including: seed sourcing, soil fertility, pest control, weed control and crop management. Moreover, it allows to exclude/include components (e.g. use of technology, type of irrigation systems) or to modify the weighting of the components. Therefore, the index is able to capture the complexity of the sustainability level of a farm. Further, the index supports detailed comparative assessment of large samples. Rigby et al. (2001) calculate an index for each production stage, based on the effect of different agricultural practices according to the following sustainability dimensions: minimization of off-farm inputs, minimisation of non-renewable inputs, maximization of natural biological process and promotion of local biodiversity. In the index, the scores in these dimensions for each agricultural practice range between −1 and –3 points according to the following scheme: −1 indicates that the agricultural practice used in a given production stage has a negative impact on the specific sustainability dimension; 0 indicates no significant impact; and 3 a strong positive impact. The sum of the scores in each sustainability dimensions for each agricultural practice provides the sustainability index for that production stage (see 'Total' column in Table 2). In order to adapt the five indexes of each production stage to the local Chilean context, we multiplied the scores on the practices by the percentage of farm area on which the agricultural practice was applied. For instance, if a farmer in 'weed control' uses chemical herbicides on 80% of the field, the sustainability score for weed control would result from multiplying −4 (score associated with the use of chemical herbicides as in Table 2) by 80%, resulting in a final score of −3.2. The total production stage index for a farming system will result from adding the scores of each agricultural practice. The total index can be interpreted in a general way. Scores below 0 indicate that the agricultural practices have a negative impact in terms of sustainability, while scores above 0 indicate a positive impact. Scores equal to 0 indicate no significant impact.

3.4. Farming typology construction

3.4.1. Multivariate analysis

We used the 25 variables (Table 1) to develop our farming typology. We applied a two-step process to analyse these variables. The first step consisted of a principal component analysis (PCA), and the second step comprised a cluster analysis (CA) based on the PCA output.

We conducted the PCA to reduce the number of variables amongst the principal components (PCs). The PCA technique is a dynamic process where some variables are eliminated until the final number of PCs is determined. Each PC represents a set of variables that are not correlated within the PC or with another set of variables in a different PC. The PCA requires standardized variables (Nainggolan et al., 2013) and complete datasets (Dray & Josse, 2015). Therefore, we removed the dummy and nominal variables with less than 5 categories (gender, INDAP, tenure, crop-variety, greenhouse, certification, irrigation, buyer-type and agree-type) and eliminated observations with missing values. We based our multivariate analysis on 342 complete observations. In addition, we transformed some variables using logarithm 10 (support links, number of technical visits and hectares dedicated to vegetable production) to achieve symmetrical distributions and we used winsorization[1] to reduce potential outliers. We determined the final number of PCs according to three criteria: (1) Kaiser's criterion, which suggests selecting all PCs with an eigenvalue higher than 1 (Hervé, 2016); (2) the number of PCs selected have to explain a minimum of 60% of the variance (Hair et al., 2013); and (3) the interpretability of PCs (Kuivanen et al., 2016).

Subsequently, we performed the CA, using the PCs as our input. The CA technique allows researchers to

Table 1. Variables description.

Category	Variable	Description	Type of variable
Agricultural practices	Seed	Type of seeds	numerical index
	Soil	Type of fertilizers	numerical index
	Pest	Type of pesticides	numerical index
	Weed	Type of herbicides	numerical index
	Crop	Type of crop management	numerical index
Socio-economic characteristics	Age	Head of household's age	ratio/years
	Experience	Head of household's years of experience in vegetable production	ratio/years
	Education	Highest educational level	ordinal/7 categories
	Gender	Head of household's gender	dummy/ female-male
	INDAP	Household is beneficiary of INDAP*	dummy/yes-no
	Links	Number of people they can reach out to in case of an urgent problem on the farm	ratio/# of people
	Tech. visits	How many technical visits did you receive in the last year?	ratio/# of visits
	Tenure	Land owner	dummy/own-rent
	Assets	Number of assets: tractor, truck, pick-up, car and motorcycle	interval/# of assets
	Income-farm	Income from the farm	interval/percentage
	Income-total	Total monthly household income	ordinal/8 categories
Farm characteristics	Vegi-size (ha.)	Size of the land used for vegetable production	ratio/hectares
	Crop-variety	Farming systems with only vegetable crops or with vegetable & other crops	dummy/yes-no
	Greenhouse	Use of greenhouses	dummy/yes-no
	Certification	Participatory certification, third-party certification, certification in process, no organic certification	nominal/3 categories
	Irrigation	Type of irrigation: furrows, drip and others	nominal/3 categories
Market channel characteristics	Distance	Distance to market	ratio/kilometres
	Buyer-type	Type of buyer: retailer, wholesaler, intermediary and high-standards (supermarkets, agroindustry and restaurants)	nominal/4 categories
	Agree-type	Type of arrangement with buyer: spot, verbal and written	nominal/3 categories

*The National Institute for Agricultural Development (INDAP) within the Chilean Ministry of Agriculture provides assistance to family farmers (INDAP, 2020).

cluster variables according to their dissimilarity. We used a hierarchical agglomerative cluster and Ward's computation method based on the work proposed by Álvarez et al. (2014). The results of the cluster analysis are presented visually as a dendrogram. The dendrogram represents the hierarchical relationship (dissimilarity) between observations within and between clusters (Álvarez et al., 2014). The dendrogram does not provide an ideal number of clusters. The definition of clusters is subjective and depends on researchers' interpretations and the dendrogram's overall appearance. Following Álvarez et al. (2014), we let the number of clusters be between 3 and 7, with the final number determined by the practical interpretability of each cluster.

3.4.2. Cluster characterization

We analysed the resulting clusters for characterisation. This analysis consisted of testing whether the variables (Table 1) have importance in the clusters' characterisation, including the variables that were eliminated through the PCA. We separated the variables into two groups: continuous and categorical variables. For the continuous variables, we used the non-parametric Kruskal–Wallis (or also called 'one-way ANOVA on ranks') test and the Dunn test. A *p*-value less than 0.05 in the Kruskal–Wallis test implies a significant relationship between a variable and one or more clusters. We conducted the Dunn test to identify in which cluster each variable had individual importance. For the categorical variables, we used Pearson's Chi-squared and Fischer tests. These tests compare the clusters' distribution with respect to the distribution of categorical variables. A *p*-value less than 0.05 in the Pearson's Chi-square and Fisher tests indicates that the distribution of the cluster is related to the categorical variable to which it is compared.

4. Results

4.1. Descriptive statistics

The sample's main characteristics are presented in Table 3. The agricultural practices are represented by the five indexes for each production stage (i.e. seed, soil, pest, weed and crop). Results showed that only the average scores of the pest and weed

Table 2. Scoring sustainability of agricultural practices.

Production stage	Sustainability dimensions: Minimises off-farm inputs	Minimises non-renewable inputs	Maximises natural biological processes	Promotes local biodiversity	Total
Seed sourcing					
1 Conventional seed					0
2 Organic seed		1			1
3 Reused	1				1
4 Traditional	1				1
Soil fertility					
1 Conventional synthetic	−1	−1	−1		−3
2 Organic fertilizer purchased		1	1		2
3 Prepared organic fertilizer	2	2	1	3	8
Pest/disease control					
1 Chemical pesticides	−1	−1	−3	−3	−8
2 Organic pesticide purchased		1	1		2
3 Prepared organic pesticide	1	1	1	1	4
4 Preventive practices without chemicals	2	2	2	2	8
Weed control					
1 Chemical herbicides	−1	−1	−1	−1	−4
2 Organic herbicides purchased		1	1		2
3 Mechanic control	1	0.5	1	0.5	3
4 Preventive practices without chemicals	1	1	1	1	4
Crop management					
1 Crop rotation	0.5	0.5	1		2
2 Intercropping	1	1	1	1	4
3 Crop rotation + intercropping	1.5	1.5	2	1	6

Source: Based on Rigby et al. (2001).

indexes were negative (−3.30 and −0.19, respectively), suggesting that the agricultural practices used in these production processes are unsustainable. In terms of socio-economic characteristics, the average age amongst the sample was 52, with 29 years of agricultural experience on average. The mean education level amongst surveyed farmers was between uncompleted and completed high school. Of the total sample, only 21% were women, and most of the respondents (70%) were beneficiaries of the National Institute for Agricultural Development (INDAP). On average, farmers had 4 people that they could reach out to in case of problems on the farm. Farmers received an average of 9 technical assistance visits within the last year, including from both government and private institutions. A small majority of the farmers (56%) owned their farmland. Farmers scored an average of 1.87 in terms of asset ownership, including tractors, trucks, pick-ups, cars and motorcycles. On average, the total monthly income of the households surveyed was 560,000 Chilean pesos (±700 USD). The mean percentage of income stemming from farming activities was 80%.

As regards farm characteristics, the average size of land exploited was 10 hectares. However, there was significant variability between study participants, ranging from farming systems with 100 m^2 to others with 600 hectares. Only 30% of the farming systems produced crops other than vegetables. Almost half of the farmers surveyed (49%) used greenhouses to produce vegetables. These greenhouses had an average size of 7504 m^2. Only 6% of the farmers surveyed had an organic certification and 5% had a certification stating that the farming system was in the process of transitioning to SAPs. The remaining 89% did not have any organic certification. In terms of irrigation systems, most farming systems used drip systems (46%) or irrigation by furrows (45%).

Regarding market channel characteristics, the average distance between farming systems and the closest market was 23.45 km. Farmers' principal market channels were intermediaries (40%), wholesalers (25%), retailers (22%), and supermarkets, agroindustry and restaurants (8%). Most of the transactions in the vegetable sector did not include any previous

Table 3. Descriptive statistics, variables prior to modifications (logarithm 10 and winsorizing).

Category	Variable	Min	Mean	Max
Agricultural practices	Seed	0.00	0.20	1.00
	Soil	−3.00	0.30	8.00
	Pest	−8.00	−3.30	8.00
	Weed	−4.00	−0.19	4.00
	Crop	0.00	2.58	6.00
Socio-economic characteristics	Age (years)	24.00	52.68	91.00
	Experience (years)	1.00	29.07	78.00
	Education	1.00	4.56	7.00
	Gender (women)	0.00	0.21	1.00
	INDAP	0.00	0.70	1.00
	Links	0.00	4.12	80.00
	Tech. visits	0.00	3.98	90.00
	Tenure (owners)	0.00	0.56	1.00
	Assets (units)	0.00	1.87	5.00
	Income-farm (%)	0.00	79.56	100.00
	Income-total (category)	1.00	2.95	8.00
Farm characteristics	Vegi-size (ha.)	0.01	10.23	600.00
	Crop-variety	0.00	0.30	1.00
	Greenhouse	0.00	0.49	1.00
	Certification			
	- *Participatory*	0.00	0.04	1.00
	- *Third-party*	0.00	0.02	1.00
	- *Transition*	0.00	0.05	1.00
	- *No certification*	0.00	0.89	1.00
	Irrigation			
	- *Drip*	0.00	0.46	1.00
	- *Furrows*	0.00	0.45	1.00
	- *Others*	0.00	0.08	1.00
Market channel characteristics	Distance (km)	0.00	23.45	250.00
	Buyer-type			
	- *Retailer*	0.00	0.22	1.00
	- *Wholesaler*	0.00	0.25	1.00
	- *Intermediary*	0.00	0.40	1.00
	- *High-standards*	0.00	0.08	1.00
	Agree-type			
	- *Spot*	0.00	0.53	1.00
	- *Verbal*	0.00	0.38	1.00
	- *Written*	0.00	0.07	1.00

agreement with buyers (53%); however, some farmers had verbal agreements (38%), and a small percentage had written agreements (8%).

4.2. Multivariate analysis and defining the number of farming types (clusters)

We obtained three PCs from the PCA. These PCs explained 67% of total data variation: PC1 explained 30%, PC2 22% and PC3 15%. The three PCs comprised 7 variables, i.e. assets, vegi-size (hectares), education, age, income-total, income-farm and distance to market. Figure 2 illustrates the correlation between the variables and the PCs. In the figure, the vector length of each variable represents the strength of the relationship with each PC. PC1 strongly and positively correlated with assets and vegi-size; PC2 strongly and positively correlated with education and age; and PC3 strongly and positively correlated with total income, income from the farm, and distance to market.

We used the three PCs obtained from the PCA for our cluster analysis. As a result of the latter, we obtained a dendrogram (Figure 3). The dendrogram was cut at a height of 40, resulting in five clusters. We based our decision to leave five clusters on the interpretation of the PCs and their interpretability in the local context (Supplementary materials Figure A shows the boxplots per numerical variables, and Table B features a table summarizing the statistical tests).

4.3 Farming system types (cluster characterisation)

The five farming systems (clusters) we identified were: large dual farming (Type I); ecological farming (Type II); traditional farming (Type III); conventional small-scale farming (Type IV); and conventional medium-scale farming (Type V). We start with discussing the sustainability scores per type. Figure 4 shows the sustainability scores per farming activity for each farming category.

Type I – Large dual farming

Type-I represents 20% (n = 69) of the sample. Farming systems of this type, practice both extensive and intensive vegetable production and possess a large size of cultivated land on average (33 ha.). This type has sustainability scores close to 0, meaning that the agricultural practices used in production have a limited impact on the environment. This type has the highest percentage of third-party certified organic farmers. In addition, this type represents farms with more economic resources, making them versatile producers, explaining why we can find organic, conventional or both conventional and organic production systems.

Farms in this type are market-oriented and lead suppliers for high-standard market channels such as supermarkets, agroindustry and restaurants, and have the highest percentage of written agreements with their buyers (16%). More than half of the farmers own their land (80%) and they have the

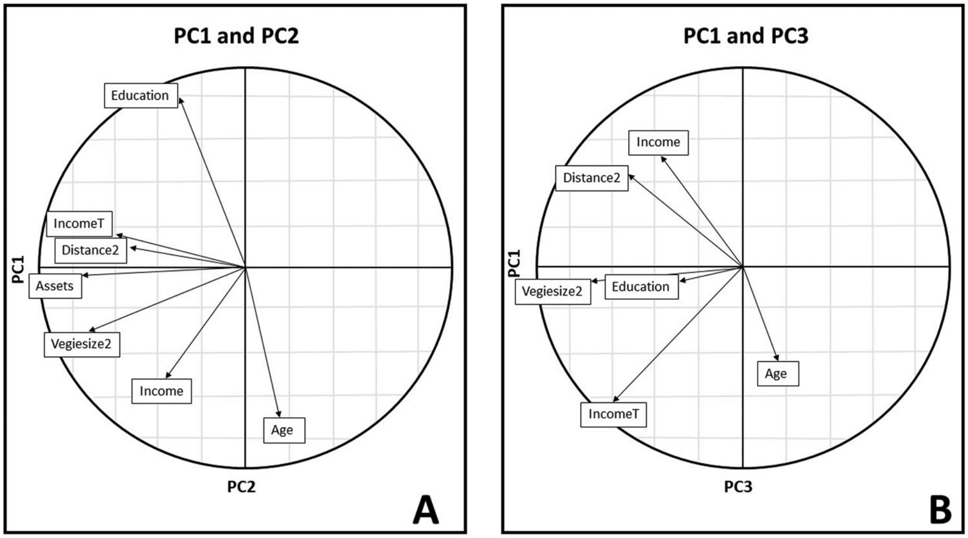

Figure 2. Correlation circles for PCs. In *Chart A Correlation Circle for PC1-PC2,* the variables with longer vectors on the horizontal axis correlate with PC1, and the variables with longer vectors on the vertical axis correlate with PC2. In *Chart B Correlation Circle for PC1-PC3*, the variables with longer vectors on the vertical axis correlate with PC3.

highest number of assets (at least 3) for field work support and transportation, as these farms are most distant from their main market (54 km.). Farmers in this type show the lowest percentage of INDAP beneficiaries (53%) but receive support from private services and have a higher number of technical visits (i.e. at least one visit per month) as well as a larger number of contacts that they can reach out to in case of problems. Farmers in this type have the highest monthly income per household.

Type II – Ecological farming

Type-II represents 17% (n = 57) of the research sample. Most of these farming systems produce vegetables alongside other crops on small pieces of land (1 ha.). Farmers adopt sustainable practices to conserve seeds, produce bio-inputs (i.e. mulch, compost, organic herbicides), rotate and diversify their crops and these farmers reject synthetic inputs. These lead to positive sustainability scores, especially in the practices related

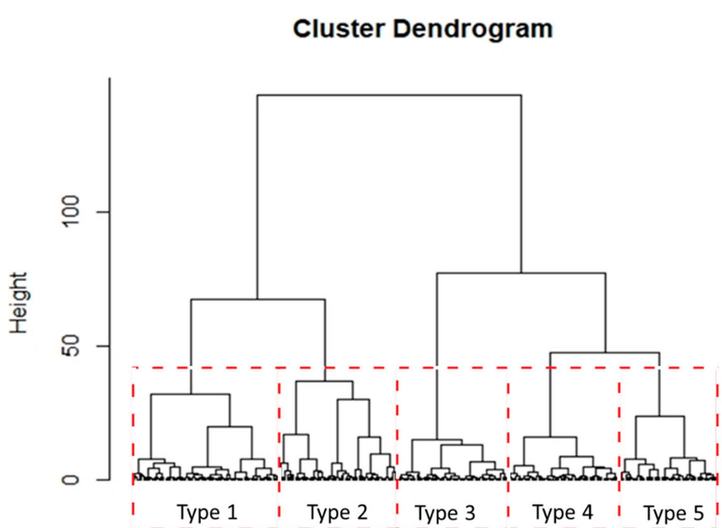

Figure 3. Agglomerative hierarchical cluster dendrogram of the 342 farms, classified into 5 clusters.

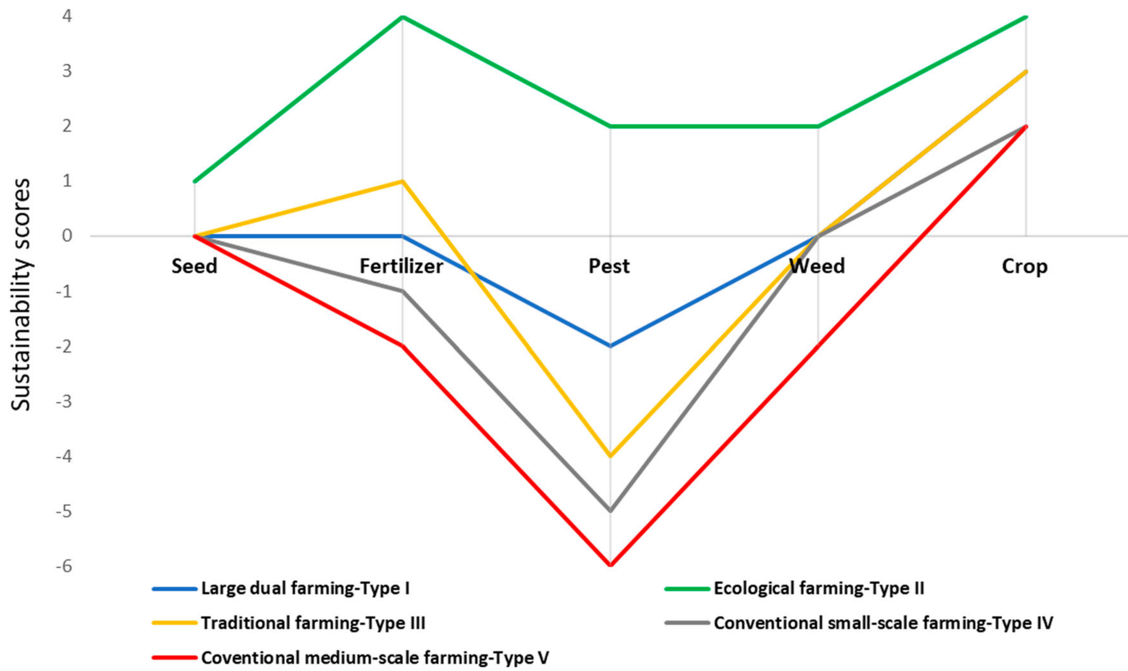

Figure 4. Farming types and sustainability of agricultural practices.

to soil fertility (Figure 4). Type-II represents the farms with the highest number of organic certifications by a participatory guarantee system[2] (PGS) and a higher number of farms with organic certifications in transition. Within this farming type, some farms are not interested in obtaining formal organic certifications and refer to themselves as 'agroecological'.

Their market strategy generally consists of offering a wide variety of products and selling these directly to end consumers in street markets and specialised stores, directly on the farms or through home delivery services. Commonly there are not fixed agreements with buyers (81%). Like Type-I farms, the majority of farmers in this type own their land (65%), but own a low number of assets (max. 1). This type also includes the highest percentage of women (53%). Farmers in this group have diversified sources of income and, therefore, the lowest percentage of income from the farm (35%). Finally, farmers in this category receive the lowest number of technical visits by INDAP (4 per year).

Type III – Traditional farming

Type-III represents 19% (n = 65) of the sample. The majority of these farming systems have small areas of land cultivated (2 ha.). This type is characterized by using a mix of natural inputs and synthetic inputs and on average adopts three traditional agricultural practices: fertilization with animal manure, weeding by hand and crop rotation. Farmers use synthetic inputs to control pests or diseases. The kind of synthetic inputs used depends on the individual farmers' purchasing power and previous experience. Practices used in this type have positive sustainability scores in soil fertility and in crop management practices. However, practices used for pest control have negative sustainability scores.

This type provides the largest percentage of production to intermediaries at farm-gate (62%), with the highest percentage of verbal agreements (62%), and developing long-term relationships with buyers. Less than half of the farmers in this type own their land (46%). Similar to Type-II farmers, most of the farmers in this type own at least 1 asset. This type primarily stands out due to the farmers' average age (64), their experience (41 years on average) and the lowest level of education (basic education completed). The latter is usual because farmers started to work as day labourers at an early age.

Type IV – Conventional small-scale faming

Type-IV represents 19% (n = 65) of the sample. The majority of these farmers cultivate a small amount of land (2 ha.), just like those in Type-III. Commonly, farmers in this type opt to use synthetic inputs which mostly serve to fertilize and control pests. These farmers' purchasing power limits their use of synthetic inputs, and they are likely to weed by hand to reduce production costs. This type has mostly negative sustainability scores, which means that the agricultural practices used negatively impact the environment. The only agricultural practice amongst this type with positive scores is crop management.

Similar to those in Type-III, farmers in this type trade mostly in spot markets, selling their crops primarily to intermediaries (43%), retailers (25%) and wholesalers (23%). Moreover, less than half of the farmers own their land (46%) and has at least one asset, just like Type-II and III farmers. Finally, farmers in this group represent the highest percentage of INDAP beneficiaries (91%) and receive at least ten technical visits per year.

Type V – Conventional medium-scale farming

Type-V represents 25% (n = 86) of the sample. Most of the farmers cultivate a medium-size piece of land (10 ha.). These farming systems adopt a low-cost strategy with higher production volumes and have a significant amount of money invested in the farming system. Thus, this type tries to avoid risks and uncertainties in crop production using the 'best' plants and preparing the soil with the 'best' synthetic fertilizers to ensure high production levels. This type encompasses the lowest number of farming systems with organic certifications. The farms have the lowest sustainability scores, the scores related to soil fertility, pest control and weed control reveal a strong negative impact on the environment.

Amongst this type, we find farmers with the highest percentage of sales to wholesalers (40%). In addition, this type is essentially divided between farmers without agreements and farmers with verbal agreements. Similar to Type-III and IV farmers, most of the farmers in this type do not own the land (52%). Moreover, these farmers own at least two assets and travel an average distance of 28 km. to deliver their products. This type includes the lowest percentage of women (5%). Farmers in this type also earn the highest percentage of income from their farms (97%) and they receive at least ten technical visits per year, just like those in Type-IV.

5. Discussion

We divide the discussion of our findings into three sections. First, we discuss which variables previous studies have used to categorize farming systems and how these are related with the farming types we identified. Second, we discuss the sustainability policy implications based on the different starting points of the various farming system types in their transition to SAPs. Last, we provide limitations of our study and lines for future research.

5.1. Typology categorization

In terms of our typology's construction, as far as we know, our study is one of the first to combine the sustainability level of agricultural practices with socio-economic, farm and market channel characteristics. A comparison of our findings with previous Chilean farming typology studies confirms that the variables which provide the greatest diversity when categorising farming systems are related to socio-economic and farm characteristics, specifically age, education, assets, income from the farm, total income, and cultivated area (Köbrich et al., 2003; Georges, 2019). However, we also found that distance to market is one of the variables that characterizes farming types. According to Tefera et al. (2004) and Guarín et al. (2020), distance to market is related to farmer's market strategies and the type of buyers (e.g. farmers' market, wholesalers and cooperatives) and has implication for how they use their land. Moreover, our study agrees with earlier observations (Tittonell et al., 2005; Álvarez et al., 2018), indicating that socio-economic and farm characteristics affect the agricultural practices used and the social interactions between farmers. This is in line with Efole et al. (2017) and Álvarez et al. (2018) who stress that the diversity of resource endowments and constraints leads to different livelihood strategies.

In terms of the variables used to measure the sustainability level of agricultural practices, we used similar variables to those found in prior typology studies focused on sustainability aspects, namely, the use of pesticides, the amount of nitrogen released, the preservation of native flora and fauna and the use of manure (Kansiime et al., 2021; Stylianou et al., 2020). However, our study differs from the others by using a farm-level index that aggregates the different sustainability variables (Table 2), making it easier to operationalize the sustainability concept and understand the complex dynamics between sustainability and farming systems.

Regarding the sustainability scores of our typology, our results indicate that these are influenced not only by the type of the agricultural practices used but also by socio-economic and structural farm characteristics. For example, the sustainability level of our Type-I farming system coincides with previous studies which argue that farming types with larger plot sizes, greater economic performance and higher education levels are associated with better sustainability levels (Mutyasira, 2020; Stylianou et al., 2020). This result may be explained by the fact that farming systems with more resources are in a position to make the changes needed to meet sustainability standards. Moreover, our Type-II farming system supports evidence from Masi et al. (2021) and Teixeira et al. (2018) who found that agroecological principles are often implemented by women farmers.

Our results suggest that market channel characteristics are correlated with the sustainability level of agricultural practices. For example, in line with Guarín et al. (2020), we found that farming systems with organic certifications (i.e. Type-I in our typology) are linked to more formal market channels with buyers demanding high production standards. However, in line with Kansiime et al. (2021), we found for our Type-III, IV and V systems, that market-oriented farming types are more likely to make intensive use of pesticides to ensure high production yields. Our results for Type-II also seem to be consistent with Mutyasira (2020) who states that farming types located closer to markets have greater potential for crop diversification and high-value commercialization. Lastly, Bánkuti et al. (2020) and Guarín et al. (2020) found that farming types with formal agreements with agribusiness (e.g. supermarkets, processors and specialized stores) are linked to relatively wealthy farming systems, similar to our results for Type-I and II farming systems.

5.2. Policy implications for sustainability

Type-I farming systems (large dual farming systems) may be framed by a Western worldview, where sustainability is based on technology, management practices and social changes and where economic growth is the primary objective (Kothari et al., 2014). This is why organic farms in Type-I rely on technology (e.g. replacing conventional synthetic inputs with external synthetic inputs authorized for organic production) and focus on product uniformity (cosmetic fresh food quality), with their main market channel being supermarkets willing to pay premium prices. Consequently, one strategy to increase the organic component in this type is raising legal requirements and industry norms (e.g. mandatory standards for minimum soil cover, afforestation, legal limits for pesticide residues, biological pest control, traceability) in order to stimulate sustainable practices. These strategies can be combined with consumer information campaigns and financial support (e.g. tax reductions for organic inputs, organic exports and organic certifications) (Teixeira et al., 2018). As for organic farms in this type, the conventionalisation[3] of these farms has to be prevented by toughening regulations for organic certifications and setting additional conditions such as limitations on large-scale monocultures and requiring the sustainable use of resources (e.g. water) (Darnhofer et al., 2010; Eyhorn et al., 2019).

Type-II (ecological farming) incorporates the only farming systems with a positive impact on the environment. We can attribute this to the holistic approach abiding by agroecological principles related to ancient worldviews, where nature and society live in harmony through a mutually supportive relationship (Carbonnier et al., 2011). Moreover, a large percentage of these farming systems are managed by *neo-rurals,*[4] characterized as professionals with economic activities both in urban and in rural areas (Ratier, 2002), who promote agroecological production systems and alternative marketing networks and who build new relationships between producers and end consumers (Orria & Luise, 2017). A possible way for governments to support these types of farming systems is by sustaining the culture concepts of these farmers by, e.g. the facilitation of participatory spaces, where farmers can trade their products and exchange experiences (Templer et al., 2018), guaranteeing land rights for conservation, and fomenting the participatory guarantee system (Teixeira et al., 2018).

Type-III (traditional farming) represents farming systems with a mix of agricultural practices. This may be explained by the direct relation with territorial heritage and indigenous roots. This finding coincides with work by Gaitán-Cremaschi et al. (2020), who found that some farmers combine traditional and indigenous practices, which reduce the use of pesticides and mono-cropping. Given that these farmers have restricted access to capital and land, governments can create incentives for SAP adoption regularizing land tenure and providing technical assistance to control pests and diseases through agroecological principles (e.g. biocides, plant species selection, natural barriers, traps) (INDAP, 2016), also as a way to save money. Moreover, governments can connect these farmers with the network of farmers in Type-II who have a developed market for organic products and have more experience in agroecological practices.

Type-IV (conventional small-scale farming) includes systems that have a negative impact on the environment. For most of the farmers in this category, their primary source of income is their farm, making them risk-averse to changing conventional cash farming practices towards sustainable farming practices (Templer et al., 2018). Like farmers in Type-III, these farmers also have restricted access to capital and land. Hence, drivers to motivate SAP adoption would be regularization of land tenure, financial support such as crop insurance, greening payments or subsidies when adopting SAPs (Teixeira et al., 2018). Moreover, Type-II, III and IV have similar farm sizes and have similar market traits. Moreover, network development can support the exchange of experiences to strengthen cooperative market channels (Rossing et al., 2020).

Type-V (conventional medium-scale farming) represents farming systems with the greatest negative impact on the environment. There are two likely causes for this. First, most farmers in this category do not supply a market channel that requires high-quality safety standards (Gaitán-Cremaschi et al., 2020). Second, similar to Type-IV farming systems, their primary source of income is their farm but with the difference that these farmers occupy larger tracts of land, implying greater investment risks. Moreover, like farmers in Type-III and IV, most of these farmers do not own land. Therefore, most of these farmers are risk-averse and have no incentive to adopt SAPs. One option to induce these farmers to embark on sustainable pathways is by helping to replace conventional synthetic inputs with organic inputs accompanied by financial support (e.g. tax reductions for organic inputs, crop insurance, greening payments and subsidies) (Iyabano et al., 2021).

As shown before, divergence between farming types illustrates that the transition to SAPs cannot be generalized (Loboguerrero et al., 2020), it must be understood as a nonlinear, complex, long-term, multilevel, multiphase and cross-scale process (Lam et al., 2020). Therefore, governments have to define diverse and complementary policies at national and regional level to support farmers during the transition period towards SAPs and to promote focal actions adapted to local needs.

5.3. Limitations and future research

The multivariate analysis methodology (PCA and CA) we applied has limitations for our study. PCAs and CAs are based on clustering the average values of the variables, which makes 'typical' groups prevail over 'atypical' groups (Tittonell et al., 2020). For example, Types-I and II had the highest percentage of farms with third-party organic certifications and with PGS organic certifications. However, this does not mean that Type-III, IV and V categories do not include any farms with organic certifications. Consequently, farms with organic certifications in Types-III, IV and V are 'atypical' and do not align with average values in their groups. Therefore, further research can be focused specifically on the characteristics of 'atypical' farmers. Likewise, we acknowledge that the farm-level index used in this study, based on the work of Rigby et al. (2001), has some limitations. For example, Dale and Polasky (2007) highlighted the limitation of not embracing a broader perspective considering the spatial context of agricultural lands. However, the literature also mentioned advantages of this index; Gómez-Limón and Sanchez-Fernandez (2010) and Waas et al. (2014) argued that this index allows ranking agricultural practices from best to worst, expressing negative and positive effects. Moreover, Bockstaller et al. (2008) stressed the usefulness of this index for interpreting results by aggregation of the indicators in production stages (e.g. seed sourcing, soil fertility pest and disease control). Further research could investigate the possibilities of the index to include spatial and landscape elements.

5. Conclusions

This study aimed to characterize farming systems in the vegetable sector in the context of an emerging economy. The farming types identified in our study add to the literature by stressing the heterogeneity of farming systems and underlining how the sustainability of agricultural practices is interconnected with socio-economic, farm and market channel characteristics. Our study shows that the transition to sustainable agriculture can have different starting points, and, although the transition to sustainable agriculture may imply contradictory pathways, they can coexist and coevolve, even if they are seen as contradictory (Plumecocq et al., 2018).

We do not consider the farming types identified as conclusive or fixed, farming systems evolve continuously and shift from one category to another, and they can overlap. In Chile, the findings presented in this study can be used to fine-tune programmes promoted by INDAP (e.g. sustainable agriculture and land tenure regularisation program) and to thus gradually boost the transition towards sustainable production systems. Practitioners and policymakers can use these farming types as a point of departure to understand farmers' heterogeneity and become aware of the diversity of possible solutions to encourage the adoption of sustainable practices.

Notes

1. In winsorization, 'extreme values are replaced by a less extreme value instead of being discarded as with trimming. Typical usage is that 90% Winsorization sets values to be no more extreme than the 5th and 95th percentiles' (Sullivan et al., 2021, p. 536).
2. The PGS is a certification issued by farmers who organise themselves into organic farmers' associations. These associations have internal control systems to comply with organic regulations and grant the organic certification to their members. The Agricultural-Ranching Service (*Servicio Agricola Ganadero*, SAG), a body within the Chilean Ministry of Agriculture of Chile, audits and registers these associations (SAG, 2020).
3. This implies complying with the organic regulations but not with organic farming principles (Darnhofer et al., 2010).
4. Individuals migrating from urban to rural areas seeking an alternative lifestyle to the capitalist system (Trimano, 2019).

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Notes on contributors

Francisco Benitez-Altuna is a project scientist at Berkeley Food Institute. He obtained his PhD at the Business Management and Organisation Group of Wageningen University & Research. He is focused on addressing policy and economic barriers, motivations, and opportunities towards sustainable food systems in California. His research interests include food value chains, on topics related to coordination, sustainable transitions, innovation and governance.

Jacques Trienekens is professor at the Business Management and Organisation group of Wageningen University. His research interests include (international) food chain and network management and food chain innovation. He has wide project experience in national and international research projects, both as researcher and as manager. He is member of the board of directors of International Food and Agribusiness Management Association (IFAMA).

Daniel Gaitán-Cremaschi is a researcher at Universitat Autònoma de Barcelona. He obtained his PhD at Business Economics Group in Wageningen University (2016). He was awarded the 2021 Daniel Carrasco Fellowship edition in Spain. His research is focused on the analysis of the inter-connected drivers of rural vulnerability in Spain, to develop new countrywide and regional indexes for rural development diagnosis. He is also involved in exploring policy scenarios, together with multiple stakeholders, aimed at reducing rural vulnerability.

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