Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 125 No. 1 (2024) 103–113

https://doi.org/10.17170/kobra-202403129760 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Sustainable management practices and soil quality in strawberry cultivation in Norte de Santander, Colombia

Ana Francisca González-Pedraza*, Elizabeth González Sarmiento, Leónides Castellanos González

Agronomic Engineering Program, Agricultural Engineering, Faculty of Agricultural Sciences, University of Pamplona, Colombia

Abstract

In Pamplona, Norte de Santander, strawberry (*Fragaria x ananassa* Duch) producers face a dual challenge: ensuring the safety of their products and conserving natural resources. Nine farms belonging to the Association of Rural Women (ASMUR) were assessed, representing approximately 20 % of the total affiliated production units within the association. The level of implementation of Good Agricultural Practices (GAP) was analysed in accordance with the 2020 Resolution of the Colombian Agricultural Institute (ICA), alongside sustainable soil management as per the Food and Agriculture Organization (FAO) guidelines on good practices for the management and sustainable use of soils in rural areas. Field tests and laboratory analyses were carried out to evaluate soil quality. The results revealed that none of the farms meet the requirements for GAP certification, with notable limitations in infrastructure, training, personnel protection, and traceability. On the other hand, the soils exhibited high organic matter content, acidic pH, and low biological activity. To overcome these limitations and achieve GAP certification, it is crucial to develop a specific action plan, provide advisory and training in GAP and sustainable soil management, make investments in key infrastructure, implement soil monitoring, adjust pH with amendments, encourage agroecological practices, promote the use of bio-inputs, and establish partnerships with entities for access to resources and technical-financial support.

Keywords: good agricultural practices, soil health, rural areas

1 Introduction

Agricultural production assumes a pivotal role for both regional and national economy, and for food security. However, the escalating demand for food and the increase in conventional agricultural practices have given rise to substantial concerns regarding environmental impact and human health (Robertson, 2015; FAO, 2017; Friedrich, 2022; Sumberg & Giller, 2022). These concerns are closely linked to the excessive use of chemical inputs and unsustainable practices, ranging from the depletion of biodiversity through monocultures, to soil and water pollution from pesticides and fertilisers. Furthermore, the emission of greenhouse gases makes a significant contribution to climate change (FAO, 2016; Sumberg & Giller, 2022).

In this context, Good Agricultural Practices (GAP) stand out as a fundamental tool to promote sustainable food production by focusing on the sustainable management of natural resources essential for agriculture (FAO, 2012a; b). GAP addresses principles, standards, and technical recommendations aimed at ensuring the safety and health of food and agricultural products, promoting sustainability at all stages of production. The main objectives of these practices are to ensure the safety and quality of products, enhance the management of natural resources and working conditions, and create market opportunities (Global G.A.P., 2016). In rural agriculture, GAP is crucial for sustainable food production, environmental protection, and the quality of life of farmers, contributing to productivity and food security (Velten *et al.*, 2015; Guerrero & González-Pedraza, 2021; Flórez & Ochoa, 2022).

On the other hand, the use of sustainable soil management practices is essential, as soil quality plays a critical role in food production (FAO & GTIS, 2015). These practices can reduce long-term costs, enhance crop productivity, and

---

* Corresponding author: ana.gonzalez2@unipamplona.edu.co

Published online: 4 July 2024 – Received: 1 December 2023 – Accepted: 14 June 2024

mitigate negative environmental impacts such as soil erosion and pollution (Cortés & Acevedo, 2019). Sustainable soil management also bolsters crop resilience to diseases and adverse weather conditions, thereby increasing long-term profitability and economic sustainability (FAO, 2012a, b; Ezeaku, 2015; OECD, 2015; Carvajal & González-Pedraza, 2021; Chaguala, 2022).

Colombia ranks third among Latin American countries in terms of fruit crop area, with strawberries being one of the most prominent. Between 2015 and 2020, the area dedicated to strawberry cultivation in Colombia increased by an impressive 59 %. Within this context, Norte de Santander emerges as the third-largest strawberry-producing department nationally, contributing 6 % to the country's total production. Over the past five years, there has been a notable 38 % increase in strawberry production in this region, further highlighted by one of the highest yields per hectare nationwide. Specifically, within the department, strawberry production in the municipality of Pamplona is a significant agricultural activity of both economic and social importance to the region, ranking as the second-largest municipality in strawberry production for the year 2016 (Ministerio de Agricultura y Desarrollo Rural, 2021).

Pamplona enjoys a favourable climate for strawberry cultivation, with average annual temperatures of 12-15°C, relative humidity of 60-75 %, and annual rainfall of 1000–1500 mm (IDEAM, 2014; DANE, 2018). Predominant soils consist of sandy and sandy loam textures, providing good drainage, with pH levels ranging from 5.7 to 6.5 and organic matter exceeding 10 % (IGAC, 2012).

Farmers in Pamplona primarily engage in the cultivation and commercialisation of strawberries for fresh consumption due to demand at both local and national levels. Strawberries grown in this region are renowned for their quality and flavour, making them highly valued in the market. However, one of the challenges affecting strawberry crop production is the presence of various pathogenic agents responsible for diseases that lead to a significant reduction in yields. Also, the high dependency on chemical products and the limited use of biological products represents problematic aspects for cultivation in this area (Castellanos *et al.*, 2019; Mahecha *et al.*, 2019; Cruz *et al.*, 2022). Additionally, the soils where strawberries are cultivated in the area are typically acidic, with high percentages of organic matter (>10 %), high levels of nitrogen, and low levels of phosphorus, along with moderate values of calcium and magnesium (Cruz *et al.*, 2022).

In Pamplona, Norte de Santander, Colombia, fruits and vegetables producer associations are indispensable for the sustenance and development of local agriculture. Notably, the Colombian Horticultural Association (ASOHOFRUCOL) and the Pamplona Agricultural Producers Association (ASPAGRO) stand out, aggregating producers of a wide variety of fruits and vegetables, thus driving improvements in production, marketing, and the training of their members. However, the Association of Rural Women (ASMUR) is distinguished by its exclusive dedication to strawberry cultivation, a crop of significant economic and cultural value to the region. ASMUR focuses not only on promoting strawberry production but also on empowering women in the rural sector, equipping them with tools and knowledge to optimise their agricultural techniques, achieve sustainability, and expand their markets.

The specialisation of ASMUR in strawberries facilitates a more effective approach to the distinctive challenges presented by this crop, including aspects of agronomic management, control of pests and diseases, and practices following harvest. This contributes substantially to the socio-economic development of rural women and their families in Pamplona.

Nevertheless, in the Monteadentro village, there are challenges related to the lack of adoption of GAP and improper soil management, negatively impacting the quality and productivity of crops, as well as the health of people and the environment (Castellanos *et al.*, 2019; Vega *et al.*, 2019; Cruz *et al.*, 2022). As a result, it is relevant to highlight that within the 2020-2023 development plan of the municipality of Pamplona, the importance of certification in good agricultural practices is emphasized (Alcaldía de Pamplona, 2020).

Within this framework, the University of Pamplona, together with its Faculties of Agricultural Sciences and Basic Sciences, has undertaken a commitment to the agricultural sector focused on improving the productive environment. This commitment includes the dissemination of innovative technologies and the refinement of existing ones, based on scientific evidence, which is crucial for the advancement of priority production chains in the competitiveness agenda of Norte de Santander. As part of this effort, the extension project "Strengthening productivity and competitiveness through biological alternatives for cleaner strawberry and pea production, implementing GAP on the farms of agricultural producers in Pamplona" was launched. The main objective of this project was to create a technical and productive training programme, using the Farmer Field School (FFS) methodology, to enhance the implementation of GAP among strawberry producers in Pamplona, with special emphasis on the Monteadentro village due to its significant role in strawberry production, both in terms of cultivated area and productivity. Therefore, this study presents the results of the level of implementation of GAP as well as sustainable soil management for cleaner production on strawberry farms belonging to ASMUR, Norte de Santander.

2 Materials and methods

2.1 Research design

A qualitative research approach was employed in the field, complemented by quantitative data, to assess the implementation of GAP and soil quality on strawberry farms owned by the Association of Rural Women of the Pamplona Province (ASMUR) in the Monteadentro village, municipality of Pamplona, Norte de Santander. Monteadentro is one of the largest strawberry producers in the municipality of Pamplona, and ASMUR is the only organisation exclusively committed to supporting the empowerment of women involved in strawberry production in the area. The focus was on identifying physical, chemical, and biological indicators to develop a management plan that enhances GAP and promotes sustainability in soil utilisation.

2.2 Population

The population was defined by the Association of Rural Women of the Pamplona Province (ASMUR), comprising 40 affiliated women, each of whom owns a farm. This association was created in 2021 as a strategy to obtain governmental resources for the improvement of strawberry production. This allowed them to be beneficiaries of a project titled "Enhancement of Strawberry Production in the Municipality of Pamplona," with the aim of elevating the quality of strawberries at every stage, from cultivation to commercialisation.

2.3 Sample

A representative sample of 22.5 %, equivalent to nine out of the 40 ASMUR farms, was taken. These selected farms underwent a diagnostic assessment to evaluate the implementation of GAP. Additionally, soil profiles were described in the field, and laboratory analyses were conducted to identify soil management practices.

2.4 Farm locations and management

The selected farms are situated at altitudes ranging from 2619 to 2839 m asl, with slopes varying between 23 % and 59 %. These farms have sizes ranging from 2 to 6 ha and are primarily dedicated to strawberry cultivation, with secondary crops including peas (*Pisum sativum* L.), native potatoes (*Solanum betaceum* Cav.), and black potatoes (*Solanum tuberosum* L.).

Strawberry cultivation in the Monteadentro village is managed conventionally, starting with soil preparation through mechanical tillage to decompact and homogenise its texture, thus creating an optimal seedbed. This process includes the construction of cultivation beds and drainage systems. Irrigation is performed via sprinkler systems, adjusted visually by the farmers according to the crop's water needs, and certified varieties suited to local conditions such as 'Ventana', 'Sabrina', 'Albión', and 'Festival' are used.

A key practice is mulching with black plastic, which promotes soil solarisation to effectively control pests, diseases, and weeds, preparing the ground for a planting density of about 54,500 plants per hectare after a month of sealing. Fertilisation combines chemical formulas and poultry manure, without frequent soil analysis. Phytosanitary management includes pesticides against a wide range of pests and pathogens.

Weed control is achieved with herbicides and manual weeding, complementing cultural practices such as pruning to maintain the vitality of the crop and encourage the growth of new inflorescences. The first harvests occur approximately five months after planting, with collection every two days and post-harvest processes that ensure the fruit's quality. It is important to note that, in these small-scale farms, family labour predominates, resorting to external workers only for specific tasks such as sowing and harvesting.

2.5 Assessment of the implementation level of GAP

The implementation of GAP was evaluated on nine farms using a survey established in Resolution 082394 of 2020 by the Colombian Agricultural Institute (ICA, 2020), which defines 57 requirements. These are divided into seven fundamental requirements, 37 major requirements requiring an 85 % compliance rate, and 13 minor requirements with a minimum compliance of 60 %. Eight components were examined, including areas and facilities, equipment, utensils and tools, environmental aspects, propagation material, crop nutrition, crop protection, personnel, and traceability and traceability of the production process of the products obtained.

2.6 Diagnosis of sustainable soil management on strawberry farms

To assess sustainable soil management, indicators of soil quality and health were employed following the Good Practices Guide for the Management and Sustainable Use of Soils in Rural Areas (FAO & MADS, 2018). A mini-profile pit measuring 60 cm x 60 cm x 60 cm was opened in each farm, and the first two soil horizons were described. Physical indicators such as texture, surface compaction, structural stability, and odour were evaluated, along with chemical indicators including organic matter, pH, and electrical conductivity. Biological indicators such as the presence of earthworms, roots, and other factors were also observed. These indicators were rated on a scale of 0 to 9, where 0-3 indicates poor-quality soils, 4-6 signifies soils of moderate quality, and 7-9 denotes good-quality soils.

2.7 Physicochemical analysis of soils

2.7.1 Soil texture

Soil texture was determined following the Bouyoucos method by Gee & Bauder (1986). This method involves shaking a soil sample in a solution containing sodium hexametaphosphate and water as a dispersing agent. After shaking the solution, readings were taken with a hydrometer at 40 seconds and after two hours of settling, considering temperature corrections. The percentages of sand, silt, and clay were calculated using the following formulas:

$$\text{silt} + \text{clay}\,(\%) = \frac{\text{hydrometer reading corrected at 40''}}{\text{weight of dry soil}} \times 100$$

$$\text{clay}\,(\%) = \frac{\text{hydrometer reading corrected at 2 h}}{\text{weight of dry soil}} \times 100$$

% Silt = (percentage of silt + clay) – (percentage of clay)
% Sand = 100 – (percentage of silt + clay).

2.7.2 Soil pH

The methodology of McLean (1982) was followed for soil pH analysis. Ten grams of dry and sieved soil (<2 mm) were taken and mixed with 20 mL of distilled water. After shaking for five minutes and allowing it to settle for ten minutes, the pH was measured directly in the suspension with a previously calibrated glass electrode.

2.7.3 Total soil organic matter

Organic matter was determined using the ignition loss method by Westman *et al.* (2006). Ten grams of dry and sieved soil (<2.00 mm) were weighed. These were placed in a porcelain crucible and dried in an oven at 110° ± 5° C for approximately one hour to remove moisture. Then, the crucible with the sample was subjected to a temperature of 445° ± 10° C in a muffle furnace for six hours. After ignition, the corresponding weight was recorded. The percentage of organic matter (% OM) was calculated using the following:

$$\text{total soil organic matter}\,(\%) = \frac{A - B}{A - C} \times 100$$

Where: A = Weight of the crucible and dry soil before ignition; B = Weight of the crucible and dry soil after ignition; C = Weight of the crucible, rounded to 0.01 g.

2.8 Management plan for improving the implementation of GAP and sustainable soil use

In collaboration with the women project leaders, a participatory management plan was developed to enhance GAP and promote sustainable soil management. This plan was based on the deficiencies identified during the diagnosis and characterisation phase. Recommendations were made in accordance with the guidelines established in Resolution 082394 of 2020 (ICA, 2020) and the Good Practices Guide for the Management and Sustainable Use of Soils in Rural Areas (FAO & MADS, 2018).

2.9 Statistical analysis

Descriptive statistics were employed to analyse soil data, including pH, organic matter, sand, silt, and clay, calculating average values, standard deviation, maximum, and minimum values. To assess compliance with GAP, the data were tabulated, and the percentage of compliance for each component on the farms was determined. Statistical processing was carried out using the SPSS version 25 program for Windows (IBM, 2017).

3 Results

3.1 Level of Implementation of GAP

Fig. 1 illustrates the average overall compliance percentage with GAP across the nine farms under study. Based upon this data, the farms with the highest compliance percentages were El Guásimo, El Pedregal, and La Aguaita. Nevertheless, it is critical to note that no farm reached or exceeded the 85 % compliance threshold, which might be contemplated as an ideal or requisite benchmark for GAP certification. In addition, the ranges of standard deviation indicate a high degree of variability in the adherence to each of the GAP components within the farms.

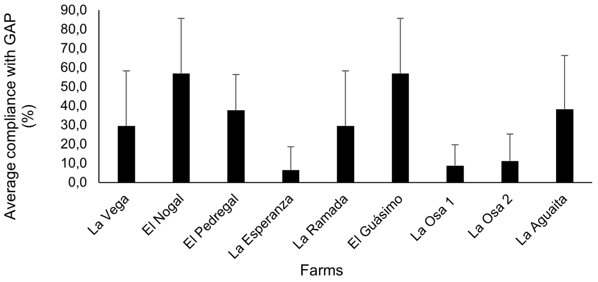

Fig. 1: *Average percentage of overall compliance with GAP requirements according to ICA guidelines in the nine evaluated farms.*

The percentage of compliance with various components assessed on the farms is illustrated in Fig. 2. The results indicate that the environmental component achieved the highest compliance percentages (>50 %), followed by propagation material, crop nutrition, equipment, tools and utensils, and crop protection. In contrast, areas and facilities, and the personnel component show a low compliance percentage, with traceability achieving 0 % compliance.

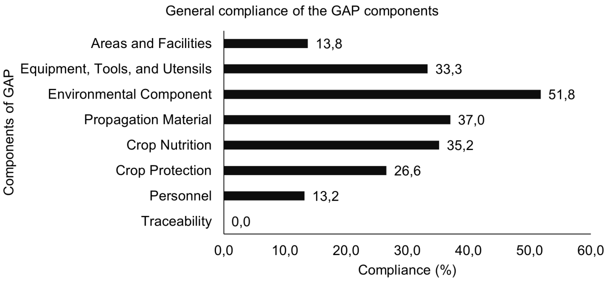

Fig. 2: *Overall compliance of the components of GAP in the nine evaluated farms.*

A percentage compliance analysis of the seven components of the GAP was conducted to analyse the components with the highest and lowest compliance. The farms El Nogal, El Guásimo, and El Pedregal exhibited the highest compliance percentages with GAP. El Nogal and El Guásimo farms showed similar patterns of high compliance in various components, among which crop protection stands out with 80 %, demonstrating excellent management in protecting crops against pests and diseases. The components Equipment, Utensils and Tools, Environmental Component, Propagation Material, and Crop Nutrition exhibited compliance percentages above 60 %, evidencing that both farms carry out proper management and maintenance of their equipment, utensils, and tools, implement practices that support environmental sustainability, use high-quality propagation material, and apply fertilisation and crop nutrition practices.

For its part, La Vega and La Ramada farms exhibited intermediate compliance percentages and high similarities, especially in components related to equipment, utensils, and tools, environmental aspects, material propagation, and crop nutrition. The third group comprised La Esperanza, La Osa 1, and La Osa 2, which showed the lowest compliance with GAP components (Table 1).

In relation to the study of the level of implementation of GAP on strawberry-producing farms belonging to the ASMUR, none of the evaluated farms fully complied with the seven fundamental requirements mandated by ICA Resolution. In relation to the "Areas and Facilities" component, only La Aguaita farm has sanitary facilities and handwashing systems for workers that meet the minimum hygiene and pollution prevention conditions. None of the farms has an area for the temporary storage of harvested products or meets the water quality assessment requirements.

Regarding the "Crop Nutrition" component, four farms have documented procedures for the preparation of organic fertilisers. Only two farms maintain records of all pesticide applications, and three farms have the necessary protective equipment for pesticide application, as well as a separate storage area for products and housing. In relation to the major requirements, all farms have permits from relevant authorities to use water sources for irrigation and processes and comply with the permitted volumes according to records.

Almost all farms, except for La Esperanza, have areas for storing agricultural inputs with solid structures, appropriate roofs, and lighting. These areas are separated from housing, food storage, packaging material for agricultural products, flood-prone areas, and water sources. In eight farms, the water source used in agricultural activities was identified, and agricultural inputs have registration from ICA and are purchased from stores authorized by this entity. In seven of the farms (except El Pedregal and La Esperanza), no garbage or accumulated waste was found, and pesticide containers undergo the triple-rinse process and are then rendered unusable (perforated) without destroying the label, following necessary precautions.

None of the farms met the major requirements, which include the lack of informative signs about cleanliness and hygiene, the absence of informative signs about preventing hazards related to agricultural inputs and personal protection, the lack of records of maintenance and cleaning activities, the absence of risk assessment in the area and the lack of an action plan to mitigate them, the lack of records of compost preparation and a plan for phytosanitary protection of the crop under the principle of Integrated Pest Management (IPM), the absence of an emergency or contingency management plan, and the non-implementation of a traceability plan to monitor products.

In seven out of the nine evaluated farms (excluding La Osa 1 and La Osa 2), minor requirements related to the rational management of water in irrigation systems, proper handling of plant material from phytosanitary pruning, and the practice of crop rotation were met. Additionally, in five farms (La Vega, El Nogal, La Ramada, El Guásimo, La Aguaita), it was observed that equipment and tools are kept in good condition and cleanliness. However, none of the farms meet the following minor requirements: the absence of a first aid kit, the lack of a multipurpose fire extinguisher in a visible location, the absence of a list of Maximum Residue Limits (MRL) established in Colombia, and the lack of a documented continuous training plan for personnel.

Table 1: *Percentage compliance of indicators for each of the components of Good Agricultural Practices in the nine farms studied.*

	Farms								
	1	*2*	*3*	*4*	*4*	*6*	*7*	*8*	*9*
GAP components	*Percentage compliance of indicators*								
Areas and facilities	6.3	18.8	31.3	12.5	6.3	18.8	0.0	0.0	25.0
Equipment, utensils, and tools	33.3	66.7	33.3	0.0	33.3	66.7	0.0	0.0	66.7
Environmental component	66.7	66.7	100.0	33.3	66.7	66.7	0.0	0.0	66.7
Propagation material	66.7	66.7	33.3	0.0	66.7	66.7	0.0	0.0	33.3
Crop nutrition	33.3	66.7	50.0	0.0	33.3	66.7	16.7	33.3	16.7
Crop protection	0.0	80.0	20.0	0.0	0.0	80.0	0.0	0.0	60.0
Personnel	0.0	33.3	33.3	0.0	0.0	33.3	0.0	0.0	0.0
Total	29.5	57.0	43.0	6.5	29.5	57.0	2.4	4.8	38.3

Farm 1. La Vega; 2. El Nogal; 3. El Pedregal ; 4. La Esperanza; 5. La Ramada; 6. El Guásimo; 7. La Osa 1; 8. La Osa 2.; 9. La Aguaita.

The main strengths on the farm are focused on crop protection, including staff training in pesticide handling and the use of chemicals permitted by the ICA. Regarding the environmental component, strawberry producers demonstrate awareness by complying with regulations, such as identifying water sources for various tasks on the farm, obtaining water use permits, and implementing rational water resource management. The main deficiencies found include the lack of adequate protective equipment, the absence of a documented training plan for staff, and the lack of an emergency or contingency management plan.

None of the farms complied with the traceability component, which refers to the ability to trace the history and origin of a product throughout its supply chain (FAO & OMS, 2023). According to ICA (2017) traceability involves maintaining documentary records that include information about the origin of materials and parts used, as well as the history of processes applied to the product.

No documents were found on any of the farms that would allow verification of crucial information such as site, plot, or greenhouse identification, product or variety name, harvest date, quantity produced per site or plot, and immediate customer. Although the farmers are aware of this information, they do not keep corresponding records.

The lack of monitoring in the supply chain processes is a common issue, especially among small-scale producers, which can result in a decrease in the quality and performance of products. Therefore, it is crucial to supervise and control the stages of acquisition, distribution, and transformation of the supply chain to ensure food quality, especially in operations experiencing significant variations (Herrera & Orjuela, 2012).

3.2 Soil evaluation in different farms

The soils of the nine analysed farms exhibit various textural classes, with variations in pH and organic matter content at the two depths assessed. pH levels range from extremely acidic in some farms to moderately acidic in others. Organic matter varies from sufficient to very high and generally decreases with soil depth, except in two farms. The soils in these farms are shallow due to the slope of the terrain (Table 2).

Indicators of soil quality and health were assessed using the Good Practices Guide. The presence of earthworms in A and B horizons was deficient in most farms. Organic matter in the A horizon was rated as good in most farms, but in the B horizon, El Pedregal, La Vega, and El Guásimo farms received poor or fair ratings. Soil texture (loam, clay loam, silt loam, and sandy loam) received the highest ratings across all farms (Fig. 3).

Regarding root presence, El Pedregal and La Aguaita farms had a fair rating in horizon A, while the other farms were rated as good. In horizon B, El Guásimo and La Vega had poor quality in terms of root presence, while El Nogal, La Osa 1, and La Osa 2 received a fair rating. In the remaining farms, this indicator was good. The soil odour was rated as fair or good in all farms, indicating the absence of poor drainage problems. Structural stability was considered poor only on El Nogal farm, while in the other farms, it was rated as fair or good. The overall condition of the plants was good in all farms (Fig. 3).

The low acidic pH of the soils as well as conventional management practices, such as the application of agrochemicals, may be negatively affecting the development of earthworms in strawberry production farms and could contribute to the low presence of earthworms on the farms. A cor-

Table 2: *Physicochemical properties of the soils in the nine strawberry-producing farms in Monteadentro village.*

Farm	Horizon	Soil depth (cm)	pH	SOM (%)	Clay (%)	Silt (%)	Sand (%)	Texture class
La Vega	A	9.5	5.3	6.8	18	22	60	Loam
	B	14.8	4.9	5.8	19	23	58	Loam
El Nogal	A	19.5	4.5	11.7	29	29	42	Loamy silt
	B	13.5	5.4	11.5	36	24	40	Loamy clay
El Pedregal	A	12	5.9	9.6	19	21	60	Loamy sand
	B	15	5.14	11.2	26	26	48	Loam
La Esperanza	A	30	5.6	25.9	26	24	50	Loam
	B	25	4.9	12.5	22	26	52	Loam
La Ramada	A	18.8	5.3	10.9	29	23	48	Loamy clay
	B	8.5	4.9	9.5	27	23	50	Loam
El Guásimo	A	10.8	6.1	18.2	30	24	46	Loamy clay
	B	22	4. 8	14.1	44	28	28	Clay loam
La Osa 1	A	13	4.9	12.7	27	25	48	Loam
	B	13	4.3	12.7	32	18	50	Loamy clay
La Osa 2	A	15	4.7	15.5	28	16	56	Loam
	B	15	4.6	14.9	29	21	50	Loam
La Aguaita	A	10	4.6	20.2	24	26	50	Loam
	B	16	5.5	6.9	29	23	48	Loam
Mean			5.1	12.8	27.4	23.4	49.1	
Standard deviation			0.5	4.9	6.2	3.2	7.5	
Maximum			6.1	25.9	44.0	29.0	60.0	
Minimum			4.3	5.8	18.0	16.0	28.0	

SOM: Soil organic matter.

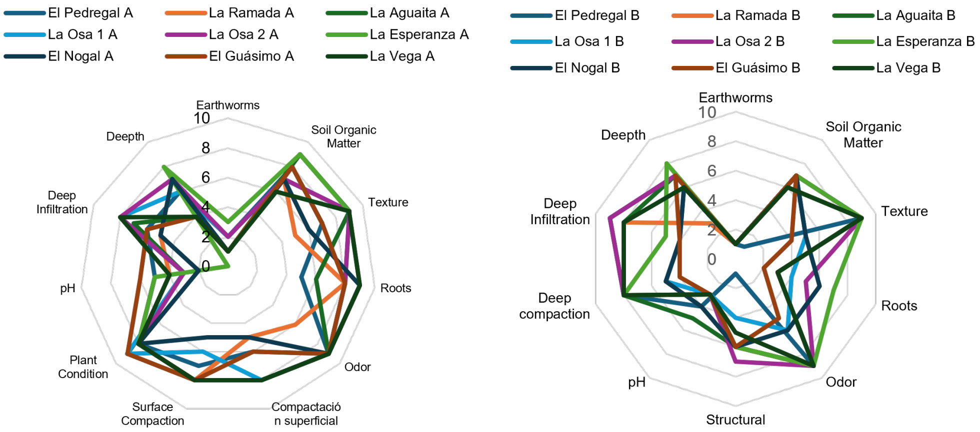

Fig. 3: *Soil quality in two horizons (A and B) in the nine strawberry-producing farms. Scale for interpreting soil quality indicators: Poor: 1-3; Regular: 4-6; Good: 7-9.*

relation analysis was conducted, showing significantly positive relationships between organic matter and soil structural stability (R^2=0.674), and between soil texture and odour (R^2=0.931), surface compaction (R^2=0.754), and deep compaction (R^2=0.858).

4 Discussion

According to the findings of this study, strawberry producers in Pamplona face a significant challenge: the lack of incentives for adopting GAP. It is crucial to note that the Development Plan for the Municipality of Pamplona (2020-2023) highlights GAP certification as a vital indicator (Alcaldía de

Pamplona, 2020). This underscores the importance of GAP within local governance and strategic goals. In this sense, the Association of Rural Women of the Pamplona Province has benefited from a project aimed at enhancing the quality of strawberries at every stage, from cultivation to commercialisation. Nevertheless, producers from ASMUR in the Monteadentro village report that despite receiving training in GAP, there is a pressing need for further support, including practical activities and, critically, financial incentives to pursue GAP certification effectively.

Achieving GAP certification would enable these strawberry growers to access international markets, enhance the quality of their products, and improve the efficiency of resource use such as water and fertilisers. This would contribute to long-term cost reductions and help reduce the environmental impact of agricultural activities. Additionally, such certification ensures the safety of food products for consumption and facilitates access to both local and international incentives and financial support.

However, this project currently faces limitations, specifically a lack of budg*et al*located for the necessary farm modifications to meet certification standards. This gap highlights a critical barrier that could prevent producers from integrating into more robust marketing chains, including export markets. The University of Pamplona is addressing some of these challenges through an extension project aimed at bringing strawberry producers closer to GAP certification. This initiative provides essential training and support, positioning it as a key player in overcoming the barriers to certification and enhancing the overall sustainability of strawberry production in the region.

Similarly to this study, the adoption of Good Agricultural Practices (GAP) in Colombia has been limited by the high cost of investment in agricultural infrastructure (Gutiérrez-Guzmán *et al.*, 2012); a lack of incentives and difficulty in securing better market prices (Martínez *et al.*, 2019); reliance on both governmental and non-governmental financial support for the expansion of sociotechnical projects (Ortiz *et al.*, 2017; Tatis *et al.*, 2021); and deficiencies in extension services as well as difficulties in accessing credit and loans (Martínez *et al.*, 2022).

In relation to the soil assessment, it was found that the low pH of the soils in strawberry-producing farms in Pamplona is attributed to high precipitation, organic matter content, and the frequent application of chicken manure by producers. Although organic matter levels are considered high in tropical conditions, in cold climates at altitudes above 2000 m asl, these values are common (Osorio, 2012). Previous studies in the region showed acidic pH in forest and pasture soils but neutral pH in intensive cultivation soils, suggesting the practice of liming. Soils with similar textures and high organic matter contents were also found (Valenzuela & Visconti, 2018).

Another study in similar climatic conditions in Pamplona found slightly acidic pH values and low levels of organic carbon, associated with soil management practices, with limited inputs of organic matter compared to strawberry producers in the area (González-Pedraza *et al.*, 2023).

To carry out the enhancement of the components required by the ICA regulations, it is essential to provide ongoing training through entities or associations on the importance of GAP certification. In cases where farms lack specific areas designated for this purpose, it is advisable to, together with farm managers, identify, locate, and construct these areas in accordance with the current ICA regulations. Furthermore, maintaining a high level of hygiene in these facilities is crucial to prevent accidents, intoxications, and contamination, thus ensuring the safety of the products. A detailed record of all maintenance and cleaning tasks should be kept, following established protocols and procedures.

The traceability component, currently not met by any of the farms, should commence from the production units, where all activities related to strawberry production, including dates, responsible parties, and inputs used, among others, must be documented. Additionally, it is imperative to ensure that each link in the chain possesses the necessary legal documentation to avoid potential issues when marketing the product. To enhance the biological activity of the soil on farms, it is recommended to lime the soil prior to analysing exchangeable aluminium levels in order to calculate the most appropriate doses. Additionally, the application of organic fertilisers such as vermicompost is recommended, along with crop rotation involving nitrogen-fixing plants, such as give a specific possibility. Subsequently, these legumes should be incorporated into the soil as green manure after allowing them to rest for three to four weeks, enabling their integration into the soil to protect against erosion and weed control.

In farms with established strawberry crops, it is recommended to implement associated crops that complement each other without competing. To carry out this polyculture practice, it is necessary to associate crops with different vegetative characteristics and root developments, taking advantage of the various soil strata. Strawberries associate well with crops such as garlic, onions, spinach, and lettuce, which can be established in intercalated rows especially when the harvest is done manually as is the case of Pamplona. Finally, it is recommended to intensify the use of living barriers by employing plants such as marigold and chamomile, which promote the activity of beneficial pollinating insects and contribute to the biological control of pests (Fountain, 2022).

5 Conclusions and recommendations

The evaluation of nine strawberry-producing farms highlighted significant shortcomings in the adoption of GAP, particularly in the areas of facilities, equipment, and traceability. Additionally, the study revealed concerning signs about the soil health across these farms, with a limited presence of earthworms suggesting poor biological quality. These findings underscore the need for targeted interventions to enhance soil health and adherence to GAP, which could facilitate better certification outcomes and sustainable farming practices. Considering the shortcomings identified, the following recommendations are proposed:

- Implement ongoing training programs for farm managers, emphasising the importance and requirements of GAP, with a focus on areas such as facilities, equipment, and traceability.
- Farms lacking specific areas to meet GAP requirements should identify, locate, and construct facilities in accordance with current ICA regulation.
- Establish rigorous protocols for the maintenance and cleaning of facilities, maintaining detailed records of all tasks performed to ensure product safety.
- Initiate a traceability system from production units, meticulously documenting all activities related to strawberry production, including dates, responsible parties, and inputs used.
- Promote the practice of associated polycultures that complement strawberries without competing and implement living covers to enhance soil health and control weeds.
- Intensify the use of living barriers, incorporating plants such as marigold and chamomile to encourage beneficial insect activity and contribute to the biological control of pests.
- Crop rotation can reduce the need for pesticides, and composting and organic fertilisers enhance soil biological activity. Additionally, it is proposed to continue the application of amendments to increase soil pH and promote biological activity.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Alcaldía de Pamplona (2020). Plan de desarrollo 20-23 municipio de Pamplona. "*Pamplona es más*". http://pamplona-nortedesantander.gov.co/Transparencia/Paginas/Plan-de-Desarrollo.aspx.

Carvajal, V. W. A. & González-Pedraza, A. F. (2021). Diagnóstico del grado de implementación de buenas prácticas agrícolas en el cultivo de cacao (*Theobroma cacao* L.), por parte de los productores del Distrito 1 del municipio de Saravena-Arauca. *Revista digital de Semilleros de Investigación REDSI*, 4(1), 1–16. https://ojs.unipamplona.edu.co/index.php/seminve/article/view/1172/1247.

Castellanos, L., Martínez, G., Castro, M., & Villamizar, C. (2019). Alternativas para el control de la hernia de las crucíferas en coliflor en el municipio Mutiscua, provincia de Pamplona, Norte de Santander. *Ciencia y Tecnología Agropecuaria*, 4(2), 75–81. https://ojs.unipamplona.edu.co/index.php/rcyta/article/view/1014/1124.

Chaguala Villarreal, I. A. (2022). Buenas Prácticas Agrícolas y manejo sostenible de los suelos en fincas productoras de cacao (*Theobroma cacao* L.), en el municipio de Tame, departamento de Arauca. *Ciencia y Tecnología Agropecuaria*, 7(1), 28–39. Recuperado a partir de https://ojs.unipamplona.edu.co/index.php/rcyta/article/view/2777/5864.

Cortés, P. E., & Acevedo, O. Á. (2019). Efectividad de cuatro prácticas agroecológicas de conservación de suelos, frente a procesos erosivos hídricos en Guasca-Cundinamarca. *Revista Lasallista de Investigación*, 16(1), 61–74. DOI:10.22507/rli.v16n1a11. https://www.redalyc.org/journal/695/69563162004/html/.

Cruz Villamizar, D. V., Rodríguez Ospino, P. P., Castellanos González, L., & Césped Novoa, N. E. (2022). Validación de una tecnología en producción limpia de fresa a pequeña escala en la finca Sol Vida del municipio de Pamplona, Norte de Santander. *Ciencia y Tecnología Agropecuaria*, 7(1), 3–18. https://doi.org/10.24054/cyta.v7i1.2769.

DANE. (2018). Boletín mensual insumos y factores asociados a la producción agropecuaria. *Sistema de Información de Precios y Abastecimiento del Sector Agropecuario-SIPSA*. Número 67. 148 pp. Gobierno de Colombia. https://www.dane.gov.co/files/investigaciones/agropecuario/sipsa/Bol_Insumos_ene_2018.pdf.

Ezeaku, P. I. (2015). Evaluation of agro-ecological approach to soil quality assessment for sustainable land use and management systems. *Scientific Research and Essays*, 10(15), 501–512. https://doi.org/10.5897/SRE10.404.

FAO (2012a). *Manual de Buenas Prácticas Agrícolas para el productor hortofrutícola*. Roma, p. 84. https://www.fao.org/3/as171s/as171s.pdf.

FAO (2012b). *Manual Técnico Buenas Prácticas Agrícolas –BPA en la producción de tomate bajo condiciones protegidas*. https://www.fao.org/3/a1374s/a1374s02.pdf.

FAO (2016). *Estado mundial del recurso suelo (EMRS) – Resumen Técnico*. Organización de las Naciones Unidas para la Alimentación y Agricultura y Grupo Técnico Intergubernamental de Suelos, Roma, Italia.

FAO & GTIS. (2015). *Estado Mundial del Recurso Suelo (EMRS) – Resumen Técnico*. Organización de las Naciones Unidas para la Alimentación y Agricultura y Grupo Técnico Intergubernamental del Suelo, Roma, Italia. https://www.fao.org/3/i5126s/I5126S.pdf.

FAO & MADS. (2018). *Guía de Buenas Prácticas para la Gestión y Uso Sostenible de los Suelos en Áreas Rurales*. Organización de las Naciones Unidas para la Alimentación y la Agricultura Bogotá, Colombia y Ministerio de Ambiente y Desarrollo Sostenible. p. 144.

FAO & OMS. (2023). *Comisión del Codex Alimentarius Manual de Procedimiento*. Vigésima octava edición. Roma. https://doi.org/10.4060/cc5042es.

FAO. (2017). *The future of food and agriculture–Trends and challenges*. Annual Report. https://www.fao.org/3/i6583e/i6583e.pdf.

Flórez, M. D. A., & Ochoa, A. (2022). Diagnóstico de Buenas Prácticas Agrícolas y Ambientales en los sistemas productivos de papa y durazno de tres veredas del municipio de Chitagá, Norte de Santander. *Ciencia y Tecnología Agropecuaria*, 7(1), 19–27. Availabe at: https://ojs.unipamplona.edu.co/index.php/rcyta/article/view/2776/5863.

Fountain, M. T. (2022). Impacts of wildflower interventions on beneficial insects in fruit crops: A review. *Insects*, 13(3), 304. https://doi.org/10.3390/insects13030304.

Friedrich, T. (2022). The ongoing search for sustainable agriculture. *Journal of Plant Scence and Phytopathology*, 6, 133–134. https://doi.org/10.29328/journal.jpsp.1001086.

Gee, G. W. & Bauder, J. W. (1986). Particle-size Analysis. In: Klute. A. (Ed.). *Methods of soil analysis: part I-Physical and mineralogical methods*. Agronomy. Second edition, number 9; American Society of Agronomy and Soil Science Society of America; Wisconsin; United States of America p. 383–412.

Global G.A.P. (2016). *Guía para usuarios y autoevaluación para el cumplimiento de la regla sobre seguridad de productos de la FSMA*. Versión 1.0 en español. https://www.globalgap.org/permalink/9bbc82f0-98d8-11e7-98d5-6805ca037347.pdf.

González-Pedraza, A., Méndez Ortega, A. & Quesada Vergara, V. (2023). Respuesta del cultivo de arveja (*Pisum sativum* L.) a la aplicación de abonos orgánicos en el municipio Pamplona, Norte de Santander. *La Granja: Revista de Ciencias de la Vida*, 37(1), 86–101. http://doi.org/10.17163/lgr.n37.2023.07.

Guerrero, Y. T. & González-Pedraza, A. F. (2021). Evaluación del nivel de implementación de buenas prácticas agrícolas en productores de la asociación de plataneros del municipio Tame, Arauca (APTA). *Revista digital de Semilleros de Investigación REDSI*, 4(1), 1–11. https://ojs.unipamplona.edu.co/index.php/seminve/article/view/1176/1251.

Gutiérrez-Guzmán, N., Serra, J. A. & Dussan-Sarria, S. (2012). Priorización de factores críticos para implantar buenas prácticas agrícolas en pequeños productores. *Cuadernos de desarrollo rural*, 9(69), 221–237.

Herrera, M. & Orjuela, J. (2014). Perspectiva de trazabilidad en la cadena de suministros de frutas: un enfoque desde la dinámica de sistemas. *Ingeniería*, 19(2), 63–84.

IBM Corp. Released (2017). *IBM SPSS Statistics for Windows*, Version 25.0. Armonk, NY: IBM Corp.

IDEAM-Instituto de Hidrología, Meteorología y Estudios Ambientales (2014). *Datos homogenizados Normal Climatológica 1981 - 2010*. Bogotá D.C. Colombia.

ICA (2020). *Resolución 082394 de 2020*. Available at: https://www.ica.gov.co/getattachment/446ac25a-0fd7-4fd8-ae9f-2e50f0047c8b/2020R82394.aspx.

ICA. (2017). *Resolución 30021 del 28 de abril de 2017*. Available at: www.ica.gov.co/getattachment/9d8fe0fa-66d2-4feb-9513-cbba30dc4844/2017R30021.aspx.

Instituto Geográfico Agustín Codazzi (IGAC). (2012). Estudio general de suelos y zonificación física de tierras del departamento Norte de Santander. In *Bogotá: Imprenta Nacional*. Available at: https://www.igac.gov.co/es/catalogo/estudio-general-de-suelos-y-zonificacion-de-tierras-de-norte-de-santander.

Mahecha M. J. G., Castellanos G. L., & Céspedes N. N. (2020). Alternativas para suplir la carencia de fósforo en fresa y disminuir la contaminación ambiental en Pamplona Norte de Santander. *Revista Ambiental Agua, Aire y Suelo*, 11(1), 1–12. https://doi.org/10.24054/aaas.v11i1.384.

Martínez, J. M., Tarazona-Velásquez, R., Martínez-Pachón, E. & Ramos-Zambrano, H. S. (2022). Potato farming in Southwest Colombia: Types of farmers and their technical efficiency. *Ciencia y Tecnología Agropecuaria*, 23(2), e2236. https://doi.org/10.21930/rcta.vol23_num2_art:2236.

Martínez, Z. N., Bokelmann, W. & Pachón, A. F. (2019). Value chain analysis of panela production in Utica, Colombia and alternatives for improving its practices. *Agronomía Colombiana*, 37(3), 297-310. Doi: http://10.15446/agron.colomb.v37n3.78967.

McLean E. O. (1982). Soil pH and lime requirements. Methods of soil analysis: part II- Chemical and Microbiological Properties. In: Page, A. L., Miller, R. H., & Keeney, D. R. (Eds.) *Methods of Soil Analysis*. Part 2. Agronomy Monographs Nº 9. American Society of Agronomy. Madison, WI, EEUU. pp. 199–223.

Ministerio de Agricultura y Desarrollo Rural. (2021). *Cadena de la fresa. Dirección de Cadenas Agrícolas y Forestales*. 22 pp. https://sioc.minagricultura.gov.co/Fresa/Documentos/2021-03-31\,\%20Cifras\,\%20Sectoriales.pdf.

OECD (2015). *OECD Review of Agricultural Policies: Colombia 2015*. OECD Publishing. http://dx.doi.org/10.1787/9789264227644-en.

Ortiz, W., Vilsmaier, U. & Acevedo Osorio, Á. (2017). The diffusion of sustainable family farming practices in Colombia: an emerging sociotechnical niche? *Sustainability Science*, 13(3), 829–847. https://doi.org/10.1007/s11625-017-0493-6.

Osorio N. W. (2012). Cómo interpretar los resultados del análisis de fertilidad del suelo. *Boletín del manejo integral del suelo y la nutrición vegetal*, 1(6), 1–3.

Robertson, P. G. (2015). A Sustainable Agriculture? *Daedalus*, 144(4), 76–89. https://doi.org/10.1162/DAED_a_00355.

Sumberg, J. & Giller, K. (2022). What is 'conventional' agriculture? What is 'conventional' agriculture? *Global Food Security*, 32 (2022), 100617. https://doi.org/10.1016/j.gfs.2022.100617.

Tatis Diaz, R., Pinto Osorio, D., Medina Hernández, E., Moreno Pallares, M., Canales, F. A., Corrales Paternina, A. & Echeverría-González, A. (2021). Socioeconomic determinants that influence the agricultural practices of small farm families in northern Colombia, *Journal of the Saudi Society of Agricultural Sciences*, 21(7), 440-451 https://doi.org/10.1016/j.jssas.2021.12.001.

Valenzuela, I. G. B. & Visconti, E. F. (2018). Influencia del clima, uso del suelo y profundidad sobre el contenido de carbono orgánico en dos pisos altitudinales andinos del departamento Norte de Santander, Colombia. *Revista Colombiana de Ciencias Hortícolas*, 12(1), 233–243. Doi: http://dx.doi.org/10.17584/rcch.2018v12i1.7349.

Vega, H., Castellanos , L., Céspedes , N. & Sequeda, A. (2019). Control alternativo de las enfermedades fúngicas foliares en el cultivo de fresa (Fragaria x ananassa Duch) en el municipio de Pamplona, Norte de Santander. *Ciencia y Tecnología Agropecuaria*, 4(1), 10–21. https://ojs.unipamplona.edu.co/index.php/rcyta/article/view/910.

Velten, S., Leventon, J., Jager, N. & Newig, J. (2015). What Is Sustainable Agriculture? A Systematic Review. *Sustainability*, 7(6), 7833–7865. https://doi.org/10.3390/su7067833.

Westman, C., Hytönen, J. & Wall, A. (2006). Loss-on-ignition in the determination of pools of organic carbon in soils of forests and afforested arable fields. *Communicactions in Soil Science and Plant Analysis*, 37, 1059–1075. https://doi.org/10.1080/00103620600586292.