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IMPORTANCE OF GLUTAMINE AND METHIONINE IN GROWTH PERFORMANCE, VILLUS CHARACTERISTICS, AND PRESENCE OF INTESTINAL POLYAMINES IN WEANED PIGLETS

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ABSTRACT

Glutamine (Gln) and methionine (Met) are involved in the synthesis of polyamines, which are essential for the functioning of intestinal epithelial cells of weaned piglets (*Sus scrofa domestica* L.). Two experiments were conducted with 21-day-weaned piglets. In the first, the dietary inclusion of Gln (0 and 1.5 %) and Met (0.05 and 1.05 %) was evaluated during the first post-weaning week. Villus height (VH), Lieberkühn's crypt depth (LCD), putrescine, spermidine, and spermine concentration, and total polyamines in the duodenum, jejunum, and ileum were measured. The average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (FE) were calculated. A randomized complete block design with a 2 × 2 factorial arrangement was used. In the second experiment, the addition of glutamine at four levels (0, 0.7, 1.4, and 2.1 %) in the diet was evaluated for three post-weaning weeks. ADG, ADFI, and FE were measured, and a randomized complete block design was used. In the first experiment, glutamine and methionine levels showed no effect on VH and LCD ($p > 0.05$). The concentration of spermidine and total polyamines in the jejunum improved ($p \leq 0.05$) with glutamine. Regarding growth performance, the level of 1.5 % glutamine in the diet improved the values of ADG and FE ($p \leq 0.05$), without affecting ADFI ($p > 0.05$). In the second experiment, glutamine levels increased ADG and FE ($p \leq 0.01$) during the first week, without modifying ADFI ($p > 0.05$); growth performance in the second and third weeks was similar ($p > 0.05$).

Keywords: functional amino acids, intestinal integrity and functionality.

INTRODUCTION

Weaning causes economic losses in pig farms; piglets *(Sus scrofa domestica* L.) in the first week post-weaning lose weight, consume little feed, and have diarrhea (Cranwell, 1995; Campbell *et al*., 2013). A possible cause of these negative effects is the atrophy of intestinal villi, since the shedding of intestinal cells is greater than their renewal, which decreases the digestion and absorption of nutrients (Pluske *et al*., 1997; Campbell *et al*., 2013).

Polyamines are essential for the growth and proliferation of intestinal epithelial cells by increasing their maturation and renewal (Johnson, 1996; Kusano *et al*., 2008; Flynn *et al*., 2009). Putrescine, spermine, and spermidine are polyamines from colostrum and sow's milk that contribute to gut maturation in lactating piglets (Cheng *et al*., 2006). Low concentration or absence of polyamines in the diet of piglets generates changes in the function and structure of the intestine after weaning (Rezaei *et al*., 2016).

Glutamine (Gln) and methionine (Met) participate in polyamine synthesis (Wu *et al*., 1997; Rezaei *et al*., 2013). Gln is a non-essential amino acid (AA), but in situations of prolonged stress (weaning or acute illness), it is not synthesized in sufficient quantity, becoming a conditionally essential AA (Wang *et al*., 2009; Wu *et al*., 2014). As for Met, Shoveller *et al*. (2005) and Wu *et al*. (2014) indicate that it is a sulfur-branched essential AA whose main function is to initiate protein synthesis. In order to reduce weaning stress, the use of antibiotics, probiotics, prebiotics, and even the addition of AA in the diet has been studied (Campbell *et al*., 2013).

Gln is the AA with the most beneficial post-weaning effects, as it is versatile in cell physiology and metabolism (Wu *et al*., 2007). Gln is abundant in the 39 proteins of living plant and animal tissues, but there is no established requirement to include it in balanced feed for pigs at any stage. However, recent studies indicate that the addition of 1 % Gln in the diet prevents intestinal atrophy and improves immune function, as well as the performance of weaned piglets (Li *et al*., 2007). However, the combined effect that Gln and Met have on the diet of weaned piglets is not completely clear.

In the present study, the response of Gln and Met addition was evaluated, individually and combined, in diets for weaned piglets on growth performance, intestinal villus length, and intestinal polyamines concentration in the first week after weaning.

MATERIALS AND METHODS

The present research was conducted at the Swine Experimental Unit of the Institute of Agricultural Sciences of the Autonomous University of Baja California, Mexico. Animal handling was carried out in accordance with the ethical and biosafety standards of the Council for International Organizations of Medical Sciences (CIOMS, 1986), complying with the Mexican standard (NOM-062-ZOO-1999) for the use of animals in experimentation (DOF, 2001).

Experiment 1

Eighty piglets [Yorkshire × (Landrace × Duroc)], 21 days old, were randomly distributed in four diets (1: addition of 0 % Gln and 0.05 % Met; 2: 1.5 % Gln and 0.05 % Met; 3: 0 % Gln and 1.05 % Met; and 4: 1.5 % Gln and 1.05 % Met) (Table 1) with five replicates. The experimental unit consisted of four animals of similar weight and sex, and a randomized complete block design with a 2 × 2 factorial arrangement was used. The animals were housed in weaning cages with metal walls (120 × 110 cm base, 70 cm height), plastic floors, and automatic waterers, with free access to water and feed.

Table 1. Composition of the experimental diets for piglets (*Sus scrofa domestica* L.) (Experiment 1).

Ingredients (%)	Control	Glutamine	Methionine	Gln + Met
Wheat	66.8	66.8	66.8	66.8
Soybean meal (PC 47.5 %)	27	27	27	27
L-lysine	0.35	0.35	0.35	0.35
L-threonine	0.1	0.1	0.1	0.1
DL-methionine	0.05	0.05	1.05	1.05
L-glutamine	0	1.5	0	1.5
Calcium carbonate	1.26	1.26	1.26	1.26
Dicalcium phosphate	1.24	1.24	1.24	1.24
Iodized salt	0.25	0.25	0.25	0.25
Antibiotic	0.1	0.1	0.1	0.1
Copper sulfate	0.05	0.05	0.05	0.05
Starch	2.5	1	1.5	0
Vitamins and minerals*	0.3	0.3	0.3	0.3
Total	100	100	100	100
	Calculated analysis			
Metabolizable energy (Mcal kg^{-1})	3.17	3.17	3.17	3.1
Protein	20.78	20.78	20.78	20.78
True digestible lysine	1.37	1.37	1.37	1.37
True digestible threonine	0.87	0.87	0.87	0.87
Methionine + true digestible cysteine	0.38	0.38	1.36	1.36
Calcium	0.8	0.8	0.8	0.8
Available phosphorus	0.4	0.4	0.4	0.4

*Vitamin premix composed of 3000 IU vitamin A, 300 IU vitamin D3, 30 IU vitamin E, 2 mg vitamin K, 1.8 mg thiamine, 0.11 mg vitamin B12, 3.6 mg riboflavin, 0.55 mg folic acid, 0.15 mg biotin, 10 mg Ca pantothenate, and 35 mg niacin. **The Cu-free mineral premix was composed of 600 mg Mg, 0.3 % K, 0.35 mg I, 80 mg Fe, 60 mg Mn, 0.15 mg Se, and 40 mg Zn. Penicillin was the antibiotic added.

The growth performance was measured during one week after weaning by means of the following variables: average daily gain (ADG, g: difference between initial weight and weekly weight divided by the seven days of the week), average daily feed intake (ADFI, g d^{-1}: daily difference between feed offered and rejected), and feed efficiency (FE: ratio between ADG and ADFI).

Experiment 2

In this experiment, 112 piglets were used, with a similar age as in experiment 1. The animals were distributed in four diets (Table 2) with different concentrations of Gln added to the diet (1: no Gln; 2: 0.7 %; 3: 1.4 %; and 4: 2.1 %), with seven replicates. The experimental unit had four pigs of similar weight and sex. The experimental design consisted of randomized complete blocks. Diets were formulated to meet nutritional requirements (NRC, 2012) with ingredients and proportions similar to experiment 1,

Table 2. Composition of the experimental diets for piglets (*Sus scrofa domestica* L.) (Experiment 2).

Ingredients (%)	Level 1	Level 2	Level 3	Level 4
Wheat	66.8	66.8	66.8	66.8
Soybean meal (PC 47.5 %)	27	27	27	27
L-lysine	0.35	0.35	0.35	0.35
L-threonine	0.1	0.1	0.1	0.1
DL-methionine	0.05	0.05	0.05	0.05
L-glutamine	0	0.7	1.4	2.1
Calcium carbonate	1.26	1.26	1.26	1.26
Orthophosphate	1.24	1.24	1.24	1.24
Iodized salt	0.25	0.25	0.25	0.25
Copper sulfate	0.05	0.05	0.05	0.05
Starch	2.5	1.9	1.2	0.5
Vitamins and minerals*	0.3	0.3	0.3	0.3
Total	100	100	100	100
Calculated analysis				
Metabolizable energy (Mcal kg^{-1})	3.17	3.17	3.17	3.1
Protein	20.78	20.78	20.78	20.78
True digestible lysine	1.37	1.37	1.37	1.37
True digestible threonine	0.87	0.87	0.87	0.87
Methionine + true digestible cysteine	0.38	0.38	1.36	1.36
Calcium	0.8	0.8	0.8	0.8
Available phosphorus	0.4	0.4	0.4	0.4

*Vitamin premix composed of 3000 IU vitamin A, 300 IU vitamin D3, 30 IU vitamin E, 2 mg vitamin K, 1.8 mg thiamine, 0.11 mg vitamin B12, 3.6 mg riboflavin, 0.55 mg folic acid, 0.15 mg biotin, 10 mg Ca pantothenate, and 35 mg niacin. **The Cu-free mineral premix was composed of 600 mg Mg, 0.3 % K, 0.35 mg I, 80 mg Fe, 60 mg Mn, 0.15 mg Se, and 40 mg Zn. No antibiotics were added.

with the inclusion of Gln at different levels and without antibiotics. Throughout the study, animals had free access to water and feed. Growth performance was measured with the same variables as in experiment 1 for three weeks post-weaning.

Samples from the intestinal tract

After one week of weaning, 20 piglets from Experiment 1 (three males and two females per treatment) were slaughtered by suffocation with carbon dioxide inside a box, and the entire small intestine was extracted. A longitudinal cut was made to eliminate food residues, cleaning with sterile 0.9 % sodium chloride solution and delimiting the duodenum, jejunum, and ileum. Then, from two sites of each segment, intestinal mucosa was sampled and placed in a 2 mL microtube by scraping with a slide. Another sample was also taken for polyamine analysis. Samples were collected within 15 min after animal slaughter, identified, and immediately stored at -82 °C until analysis.

Intestinal histology

Sections of 2 cm^2 of the three segments of the small intestine were obtained and processed by embedding and kerosene cutting and stained with hematoxylin and eosin. Ten measurements of villus height (VH) and crypt depth of Lieberkühn (LCD) were performed with an optical microscope on each intestinal segment in five pigs per treatment.

Polyamine concentration

Polyamines from the intestinal mucosa were isolated according to Clarke and Tyms (1986). To establish the standards for the polyamines putrescine (Put), spermidine (Spd), and spermine (Spn), the procedure adopted followed the methodology described by Bardocz and White (1998). Polyamines were quantified by high-performance liquid chromatography (HPLC) in a chromatograph (Hewlett Packard 1100 series) with a fluorescence detector, an analytical column of 5 mm internal diameter, and a length of 10 cm. The concentration was obtained using the methodology described by Saarinen (2002), using two mobile phases. Mobile phase A consisted of ammonium acetate (Sigma A-8920) 0.2 M, pH 5; HPLC grade water (J.T. Baker 4218-0) and HPLC acetonitrile (J.T. Baker 9017-03) (10:60:30). Mobile phase B was 0.2 M ammonium acetate pH 5, water (J.T. Baker 9180-02), and acetonitrile (J.T. Baker 9180-02) (10:5:85). Excitation and emission fluorescence lengths were 250 and 540 nm, respectively.

The statistical analysis of growth performance, polyamine concentration, and intestinal villus height was performed with the GLM procedure of the SAS version 9.1 statistical program (SAS Institute Inc., Cary, NC, USA), under a randomized complete block design. Any difference whose p was lower than or equal to 0.05 was considered significant.

RESULTS AND DISCUSSION

Experiment 1

The analysis of variance (Table 3) showed that in the first post-weaning week, the addition of 1.5 % Gln to the diet individually improved ($p \leq 0.05$) ADG and FE without affecting ADFI ($p > 0.05$). The inclusion of Met in the diet did not affect growth performance ($p > 0.05$). An interaction ($p \leq 0.01$) between Gln and Met was observed in ADG and FE. The results of previous studies of Gln addition in piglet diets (Wu *et al*., 1996; Haynes *et al*., 2009; Cabrera *et al*., 2013) are inconsistent, with a general tendency to increase ADG and FE, which is consistent with the results observed in the first week of this experiment.

There were no differences (Table 4) in villus height or crypt depth in the different segments of the small intestine ($p \geq 0.059$), which contrasts with results from other researchers (Wu *et al*., 1996; Lee *et al*., 2008; Cabrera *et al*., 2013) where they included Gln to prevent intestinal atrophy in pigs and mice. However, an increasing trend

Table 3. Effect of the addition of glutamine (Gln) and/or methionine (Met) in the first post-weaning week in diets for piglets (*Sus scrofa domestica* L.) on average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (FE).

Control	Glutamine	Methionine	Gln + Met	Probability value		
				Gln	Met	Gln*Met
		ADG (g d^{-1})				
8.0^{c} ± 0.01	60^{a†} ± 0.01	37^{b} ± 0.01	32^{b} ± 0.01	0.006	0.894	0.001
		ADFI (g d^{-1})				
109 ± 0.01	121 ± 0.01	120 ± 0.01	121 ± 0.19	0.112	0.114	0.138
		FE (ADG $ADFI^{-1}$)				
0.14^{c} ± 0.12	0.45^{a†} ± 0.11	0.28^{b} ± 0.13	0.23^{cb} ± 0.11	0.001	0.241	0.001

†Values with different letters on the same line are different ($p \leq 0.05$).

Table 4. Response to the addition of glutamine (Gln) and/or methionine (Met) in the first post-weaning week in piglet (*Sus scrofa domestica* L.) diets on Lieberkühn's crypt depth (LCD) and intestinal villus height (VH).

Segment	Diet 1	Diet 2	Diet 3	Diet 4	Probability		
					Gln	Met	Gln*Met
			Depth (LCD; µm)				
Duodenum	271 ± 38.1	287 ± 12.4	293 ± 12.1	280 ± 26.7	0.336	0.181	0.547
Jejunum	333 ± 28.2	264 ± 14.6	273 ± 12.9	281 ± 37.6	0.257	0.434	0.158
Ileum	293 ± 26.5	276 ± 16.5	267 ± 27.4	234 ± 33.9	0.293	0.162	0.754
			Height (VH; µm)				
Duodenum	259 ± 19.6	303 ± 18.2	320 ± 26.3	317 ± 25.5	0.364	0.108	0.292
Jejunum	272 ± 15.3	325 ± 15.1	291 ± 8.9	281 ± 28.5	0.183	0.417	0.059
Ileum	284 ± 18.9	272 ± 21.1	266 ± 9.1	244 ± 26.2	0.308	0.253	0.803

Diet 1: addition of 0 % Gln and 0.05 % Met; diet 2: 1.5 % Gln and 0.05 % Met; diet 3: 0 % Gln and 1.05 % Met; diet 4: 1.5 % Gln and 1.05 % Met. The mean and standard error of each treatment are presented.

($p \geq 0.059$) in VH in the jejunum was observed. This indicates the need to increase the number of replicates (in the present research there were five replicates with four piglets each per treatment), improve the precision of the measurements, or increase the weeks of evaluation (only the first week, the most critical at weaning, was evaluated) in future research on this subject. The variables analyzed (VH and LCD) indicate the integrity and capacity of the intestine to digest and absorb nutrients. This integrity and capacity are impaired when piglets are weaned (Duan *et al*., 2016). Therefore,

normal maintenance of intestinal morphology by individual inclusion of 1.5 % Gln during the first post-weaning week improves these functions (Baba *et al*., 2005; Basson, 2007; Hou *et al*., 2010).

An increase (Table 5) in the concentration of spermidine (Spd) and total polyamines in the jejunum was observed, presumably due to increased polyamine synthesis in enterocytes. This is a result of increased activity of ornithine decarboxylase, an enzyme responsible for polyamine synthesis (Wu *et al*., 2000a). The intestinal concentration of polyamines would suggest that Gln enhances the activity of epithelial cells (Chen *et al*., 2014). The results indicate that Gln is a conditionally essential AA, especially in stressful situations such as weaning (Wu, 2009; Duan *et al*., 2016).

Table 5. Jejunal concentration of spermidine and total polyamines (mmol g^{-1}) with addition of glutamine (Gln) and/or methionine (Met) to diets for piglets (*Sus scrofa domestica* L.) in the first post-weaning week.

Met (%)	Gln (%)		Mean
	0	1.5	
	Spermidine		
0.05	3.28	4.14	3.71
1.05	3.46	3.58	3.52
Mean	3.37[b]	3.86[a]	
	Total polyamines		
0.05	8.25	9.36	8.81
1.05	8.33	8.76	8.54
Mean	8.29[b]	9.06[†a]	

[†]Means with different letters in the same row are different ($p \leq 0.05$).

Gln is important in the intestinal synthesis of polyamines, essential nutrients for cell division and proliferation. However, weaning piglet diets contain little or no ornithine (direct precursor of polyamines), whose main precursor is arginine (Arg), which is synthesized from Gln (Wu *et al*., 2000b; Wu *et al*., 2014). Polyamine synthesis from Arg is the main pathway for enterocyte turnover during weaning (Rezaei *et al*., 2013). In other words, the absence of polyamines reduces small intestinal turnover. Since it is economically unfeasible to include polyamines in the diet, AA precursors of these essential nutrients must be added (Cheng *et al*., 2006; Pegg, 2008). However, in the present study, a higher concentration of spermidine and total polyamines was observed only with Gln.

Finally, although there was no effect of Met in the present study on growth performance, histology, and intestinal concentration of polyamines, it could be explained because

some authors consider that Met is not metabolized by the intestinal mucosa (Wu *et al*., 1996; Chen *et al*., 2009; Chen *et al*., 2014). However, Stoll *et al*. (1998) reported that approximately 50 % of dietary Met is metabolized in the first intestinal step, originating cysteine. Most of the circulating cysteine is derived from endogenous synthesis.

The activation of polyamine synthesis is facilitated by ornithine decarboxylase (ODC) and S-adenosylmethionine decarboxylase (SAMD). The activities of these enzymes occur within a few hours after feed intake (Moore and Swendseid, 1983; Shoveller *et al*., 2005). The response time of SAMD depends on ODC activity, since SAMD requires putrescine (a product of ODC activity) to form spermidine and spermine (Brosnan and Brosnan, 2006).

In the liver and intestine, SAMD activity reaches its peak before ODC activity, implying that putrescine concentration is insufficient for SAMD to produce spermidine and spermine (Moore and Swendseid, 1983). The coenzyme S-adenosyl methionine, a precursor of SAMD, is composed of adenosine triphosphate (ATP) and Met; therefore, weaning in piglets is a limiting factor for SAMD synthesis, since the organism is in a state of negative energy balance due to low or no feed intake at that stage (Gong *et al*., 2008).

Experiment 2

In the first week after weaning (Table 6), dietary Gln levels increased average daily weight gain ($p \leq 0.0084$) and feed efficiency ($p \leq 0.0103$). The best response was obtained by adding 2.1 %. These results are not related to ADFI but to a higher nutrient absorption (Gln) due to the increase in the concentration of this AA in the feed, since in the first week the intake was similar between diets ($p \leq 0.1933$).

In the second and third post-weaning weeks, no significant differences ($p > 0.05$) were observed between the levels of Gln inclusion in the diet for any variable; however, it influenced ADG and FE (due to greater absorption and better utilization of nutrients) in the first week so that the accumulated weight of the piglets at the end of the study period was 50 % higher ($p \leq 0.001$) than the initial one. In contrast, Wu *et al*. (1996) observed an improvement in FE during the second post-weaning week by adding different doses of Gln at 1 % as the dose of best response, without observing differences in ADG, ADFI, and FE at weeks 1 and 3.

Glutamine is also important for other metabolic processes in animals. Gln, via glutamate, forms α-ketoglutarate, which is involved in the synthesis of oxaloacetate, and in turn, in the formation of glucose via the Krebs cycle (Hou *et al*., 2010). Gln is the main energetic substrate of ATP in constantly multiplying cells: erythrocytes, lymphocytes, macrophages, and renal cells (Wu *et al*., 1996; Rezaei *et al*., 2013). This AA stimulates various growth factors in the damaged mucosa and enhances activity in signaling pathways, which helps repair the intestinal barrier (Wang *et al*., 2008).

The mucosa of the intestinal epithelium is rich in glycoproteins synthesized from glucosamine 6-phosphate, in which Gln participates (Basson, 2007). Therefore, a good supply of glutamine must be ensured in the diet of piglets at weaning. The addition of

Table 6. Response of glutamine (Gln) addition level during the first three post-weaning weeks in diets for piglets (*Sus scrofa domestica* L.) on average daily weight gain (ADG), average daily feed intake (ADFI) and feed efficiency (FE).

Variable	Dietary glutamine level (%)				*p* value
	0	0.7	1.4	2.1	
			First week		
ADG (g)	-10.9 ± 0.01	2.9 ± 0.01	12 ± 0.01	28.9 ± 0.01	0.0084
ADFI (g d^{-1})	119 ± 0.01	129 ± 0.01	130 ± 0.01	135 ± 0.01	0.1933
FE	-0.089 ± 0.02	0.021 ± 0.03	0.094 ± 0.06	0.21 ± 0.08	0.0103
			Second week		
ADG (g)	123 ± 0.01	122 ± 0.01	135 ± 0.01	142 ± 0.01	0.8266
ADFI (g d^{-1})	241 ± 0.01	243 ± 0.01	218 ± 0.01	214 ± 0.01	0.2979
FE	0.52 ± 0.01	0.49 ± 0.01	0.63 ± 0.01	0.67 ± 0.01	0.2602
			Third week		
ADG (g)	170 ± 0.01	174 ± 0.02	182 ± 0.01	184 ± 0.01	0.9104
ADFI (g d^{-1})	341 ± 0.02	346 ± 0.02	349 ± 0.01	364 ± 0.01	0.7956
FE	0.49 ± 0.03	0.47 ± 0.04	0.51 ± 0.03	0.52 ± 0.02	0.6756
			Accumulated time (day 1 to 21)		
ADG (g)	94 ± 0.01	100 ± 0.01	110 ± 0.01	118 ± 0.01	0.5818
ADFI (g d^{-1})	234 ± 0.01	239 ± 0.01	232 ± 0.01	238 ± 0.01	0.4289
FE	0.31 ± 0.02	0.33 ± 0.03	0.41 ± 0.01	0.47 ± 0.01	0.3154
			Weight (kg)		
Initial	4.71 ± 0.12	4.69 ± 0.13	4.73 ± 0.14	4.72 ± 0.12	0.9969
Final	6.69 ± 0.12	6.77 ± 0.14	7.04 ± 0.14	7.21 ± 0.12	0.0461
Accumulated	1.98 ± 0.01	2.1 ± 0.01	2.31 ± 0.01	2.48 ± 0.01	0.001

Mean and standard error of means are presented for each treatment.

Gln in the diet prevents arginine (Arg) deficiency during weaning in piglets; Arg is an essential AA for young animals and is synthesized from Gln in pigs (Wu *et al*., 1996; Kim and Wu, 2004, 2009; Cabrera *et al*., 2013). Arg reduces plasma urea concentrations, increases plasma creatine and ornithine levels in pigs, and increases polyamine synthesis (Wu *et al*., 2005; Wu *et al*., 2009). Arg requirements in young mammals, including piglets, are particularly high (0.75 %) (He *et al*., 2009).

In summary, dietary addition of Gln prevents intestinal injury and improves nutrient absorption in post-weaned piglets. The effects of Gln are associated with intestinal cell proliferation (indicated by increased polyamines), which improves the growth performance of piglets in the first post-weaning week (Lobley *et al*., 2001).

CONCLUSIONS

The addition of 1.5 % glutamine in the diet improves weight gain and feed efficiency of newly weaned piglets and increases the concentration of spermidine and total

polyamines in the jejunum during the first week after weaning, without affecting the height and depth of intestinal villi or the concentration of putrescine and spermine. The best response to the addition of glutamine on weight gain and feed efficiency was observed in the first post-weaning week. There was no effect of adding methionine to the diet on growth performance, intestinal villi, or polyamine concentration.

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Agrociencia

PATHWAYS TO ORGANIC CONVERSION IN KYRGYZSTAN: MOTIVATIONS, BARRIERS, AND IMPLICATIONS

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ABSTRACT

Kyrgyzstan and the global community consider organic farming as a crucial element of sustainable agricultural growth. Kyrgyzstan is advocating for organic agriculture; nevertheless, due to low conversion rates, more effective measures are required. This study aims to explore the motivations for converting to organic farming and the challenges faced by farmers in the Issyk-Kul province of Kyrgyzstan. A survey of 142 certified organic farmers from four aimaks in the Issyk-Kul province, Kyrgyzstan, was analyzed using descriptive statistics and confirmatory factor analysis to examine motivations for organic farming and post-conversion challenges. The results indicate that farmers' decisions to transition to organic farming were primarily driven by environmental and health concerns, while pro-environmental ideologies and visionary motivations had comparatively less influence. Key challenges faced after conversion included limited access to agricultural inputs and difficulties with market access. Education levels and dependence on organic farming as a primary income source were significant factors influencing the decision to adopt organic practices. This study provides important insights into the drivers and barriers of organic farming in Kyrgyzstan. To promote organic agriculture effectively, policymakers must address challenges related to agricultural inputs and market access while considering the connections between education, livelihoods, and motivations for adopting organic practices.

Keywords: organic farming, organic aimak, sustainable agriculture, economic feasibility.

INTRODUCTION

Organic farming has appeared as a response to the destructive effects of modern industrial production systems and a solution to overcome the growing disbalance between humanity and the surrounding environment. It has demonstrated enormous potential to unite ecological farming techniques and the conceptual core of sustainability while ensuring adequate levels of food production (Ume, 2023). Successful market promotion has made organic farming one of the most dynamic and rapidly expanding sectors of sustainable agriculture (Moyer and Sinclair, 2020; Trusova *et al.*, 2021b).

Despite the substantial growth of the global organic market's turnover, problematic aspects of the organic sector's development can be observed in many regions worldwide, regardless of the economic power of the countries and governmental support. For instance, Siepmann and Nicholas (2018) emphasize that the goals of reaching 20 % organic areas in Germany by 2010 remained unattainable and were postponed. According to Kociszewski *et al*. (2020), only 5–15 % of all farms can convert to organic agriculture in Poland. Dissatisfaction with the pace of organic conversion was expressed by other researchers representing developed countries (Cranfield *et al*., 2009; Han *et al*., 2021). Thus, the organic conversion process is an indispensable part of a global organic agenda with persistent acuteness for the overall success of global and regional organic movements. Against this background, scientists and policymakers have posed the question of organic conversion and its facilitation (Madelrieux and Alavoine-Mornas, 2012; Läpple and Kelley, 2013; Hofmann *et al*., 2022).

The basis of the current study was an analysis of the "Organic aimak" project implemented by the Federation of Organic Development (FOD) "Bio-KG," which was established in 2012 after the First National Organic Forum in Kyrgyzstan (FAO, 2020). FOD "Bio-KG" promotes Participatory Guarantee Systems (PGS) as an alternative to the costlier third-party certification in Kyrgyzstan and supports smallholders by disseminating relevant information, organizing fairs and exhibitions of organic produce, and certifying farmers in organic aimaks (administrative territorial units under district level). The private organic standard developed by FOD "Bio-KG" was recognized by the International Federation of Organic Agriculture Movements (IFOAM). The organic aimak approach is advocated by the Kyrgyz government and is expected to serve as a national model for the promotion of organic principles and practices. Also, PGS certification is recognized by the Kyrgyz organic agriculture legislation (Karabassov *et al*., 2022; Ranjan *et al*., 2019).

Residents of the organic aimaks made collective decisions to farm organically and withdraw from the use of chemicals. The organic aimak model of development of organic farming in Kyrgyzstan is unique in the sense of aligning organic principles with the mindsets of Kyrgyz farmers and the cultural and historical aspects of agriculture. In other words, the overarching goal of the organic aimak model is not to radically modify but rather harmonize local and global advancements in organic agriculture.

Decades of research on organic conversion have allowed the observation of certain commonalities in farmers' motivations to convert. Studies such as those conducted by Aoki (2014) and Han *et al*. (2021) have shown that motivational factors often include financial motives. Similarly, Bui and Nguyen (2020) demonstrated that financial considerations influenced farmers' decisions to convert to organic farming. Market access was described by Liu *et al*. (2019) as a main conversion factor. On the other hand, Siepmann and Nicholas (2018) found that personal ideologies and networking are vital to ensure organic conversion. Kociszewski *et al*. (2020) pointed out that farmers' and their families' health and environmental conservation factors influence farmers' decisions to convert to organic farming. However, it is common that researchers find multiple conversion motivations and their confluence.

In addition to motivational factors, numerous studies have explored the obstacles associated with conversion to organic agriculture. Bui and Nguyen (2020) emphasize that the lack of knowledge on organic farming and insufficient financial support are the main impeding factors, whereas Liu *et al*. (2019) argue that lower yields and the educational background can be barriers for organic conversion. In their overview of organic farming in India, Avasthe *et al*. (2019) identified various obstacles to organic conversion, such as the lack of available organic fertilizers and plant protection means, a poorly developed organic market to obtain premiums, insufficient knowledge and skills to engage in organic agriculture, lack of governmental support, and relevant agricultural policies to support the promotion of organic farming. Partap (2010) detailed some of the key constraints emerging during the pre-adoption stage and confronting farmers in Asian countries, such as the deeply ingrained structural problems of the agricultural sector associated with small land plots and lacking alternatives to ensure food security on a farm level. Obviously, the promotion of agroecological approaches, including organic farming, and the introduction of better land-use patterns require a deeper understanding of farmers' motives to adopt one or another agricultural practice (Marr and Howley, 2019; Papanikolaou *et al*., 2024; Salvador *et al*., 2022).

Motivations for conversion to organic farming must be at the center of researchers' efforts to understand farmers' mindsets and inform decision-making processes (Király *et al*., 2022; Shahini *et al.,* 2022). Bolis *et al*. (2017) found that sustainable development was, in many ways, determined by decision-making. In turn, decisions are influenced by socio-economic and environmental factors. As farmers' motivations and conversion barriers influence decisions, changes in attitudes and motives represent acute sustainability issues. These factors may be common to all countries and touch upon similar dimensions, such as economic, political, environmental, social, philosophical, and technical. However, visible commonalities vary in intensity and influence on the resulting farmers' choices. It entails the need for an individual approach to each case of organic promotion, even within a given country (Mendes *et al*., 2022; Manta *et al*., 2023). This aspect of organic conversion prompted the present research in the context of organic farming in the Issyk-Kul province of Kyrgyzstan.

The emergence of organic farming in Kyrgyzstan is difficult to trace back. Lack of available studies, statistical data, and the absence of the term "organic agriculture" in Kyrgyz legislation until recently represent obstacles for researchers. It may be assumed that numerous smallholders experienced significant financial difficulties after the abrupt end of the Soviet era's centralized governmental support and had to farm organically, although unintentionally and unknowingly. A similar pattern of informal non-certified organic farming has been reported by some researchers (Aoki, 2014; Mero *et al*., 2023). After gaining independence in 1991, Kyrgyzstan pursued a market economy paradigm that sharply changed farming patterns. State-led agricultural complexes (known as "kolkhoz" and "sovkhoz") were dismantled, and their lands were distributed (Lerman and Sedik, 2009).

To date, the Kyrgyz government's strategic vision is fully associated with organic principles and organic farming as a framework for current and future agricultural

development. This vision is reflected in the main strategic policy document, namely, the National Development Strategy of the Kyrgyz Republic 2018–2040. The government's adoption of a five-year action plan in 2017 aimed to augment the number of certified and non-certified organic farmers to 20 thousand by the end of 2022. However, the government's commitment was confronted with the evident problem of a low conversion rate. According to the latest statistics from IFOAM, the total number of organic farmers in Kyrgyzstan reached 1144 in 2021, including those in conversion (Willer *et al*., 2023). Moreover, in 2022, there were 1097 PGS organic farmers and 3000 PGS producers involved (Anselmi and Castro, 2023). Available statistical data illustrate that the planned indicators have yet to be developed.

The main purposes of this study are to improve the understanding of organic conversion patterns in Issyk-Kul province, Kyrgyzstan, by investigating the motivation factors and barriers after transition and to examine the relationship between the motivations and demographic variables. To achieve these purposes, a questionnaire-based survey was conducted among organic farmers in four organic aimaks. This study represents the first scientific attempt to investigate the motivational factors for organic conversion and their respective barriers in organic aimaks. The Theory of Planned Behavior (TPB), a framework that examines how attitudes, perceived social pressure, and perceived ability to perform a behavior shape intentions and actions, was applied alongside a confirmatory factor analysis. The findings are expected to shed light on the current processes in the Kyrgyz organic sector and inform decisions taken by stakeholders.

MATERIALS AND METHODS

The study concerns organic farmers of the Issyk-Kul region of Kyrgyzstan, bordering Kazakhstan and China. The region covers 43 100 km^2 and has a population of more than 500 000 people, mostly rural residents (NSCKR, 2021). Issyk-Kul province grows various organic crops: potatoes, apples, garlic, carrots, apricots, berries, and medicinal plants. Lake Issyk-Kul has the status of a protected ecological and economic zone. This status was granted under the Law of the Kyrgyz Republic No. 115 "On sustainable development of the ecologic-economic system of Lake Issyk-Kul". The Issyk-Kul province of Kyrgyzstan was chosen for this study due to its considerable popularity among tourists, economic potential, favorable climate, and the need to protect the environment. The study covered four organic aimaks: Aral, Kun-Chigysh, Aksuu, and Tosor (Figure 1), using information from certified organic farmers from these aimaks. According to the Bio-KG, in 2022 there were 398 certified organic farms, including 171 in Aral, 153 in Aksuu, 58 in Kun-Chigysh, and 16 in Tosor (FAO, 2020). All participants had a PGS certificate.

A questionnaire was developed based on a literature review, interviews with organic farmers, discussions with experts in organic agriculture, and the TPB—a framework widely used to understand decision-making, including farmers' choices to adopt organic farming (Maleksaeidi and Keshavarz, 2019). The TPB posits that behavioral

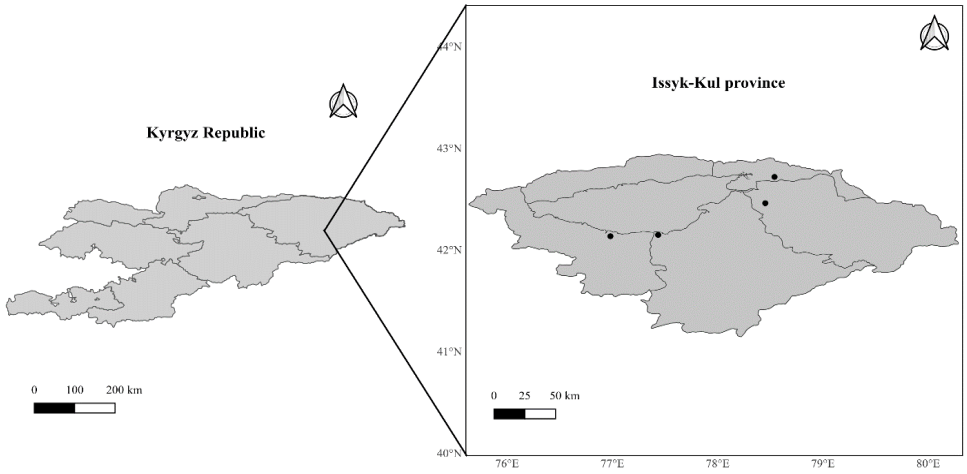

Figure 1. Map of the study area. Black dots show the locations of the organic aimaks (Aral, Aksuu, Tosor, and Kun-Chigysh – clockwise).

intentions are influenced by attitude, subjective norm, and perceived behavioral control. Attitude reflects the individual's perception of the benefits of a behavior, subjective norm refers to social pressure, and perceived behavioral control captures the perceived ease or difficulty of performing the behavior. These factors jointly determine intention, which predicts behavior. The flexibility of the TPB allows for the inclusion of context-specific variables, making it suitable for analyzing the motivations and barriers faced by Kyrgyz farmers in transitioning to organic farming (Tama *et al*., 2021; Yang *et al*., 2022; Khazieva, 2022). Its validity in studying farmers' behavioral patterns has been demonstrated in multiple studies, confirming its relevance to this research (Han *et al*., 2021; Yang *et al*., 2022; Zhang *et al*., 2020; Senger *et al*., 2017).

The questionnaire survey was conducted in December 2022 among about 40 % of organic farmers from the four selected organic aimaks in the Issyk-Kul province. The criteria for the selection of respondents were: organic certification, membership in the "Organic aimak" project, and cultivation of plants. Questionnaires were distributed to 160 randomly selected PGS-certified organic farmers, of whom 158 completed the questionnaires (98.75 % response rate). All respondents signed an informed consent form. After removing 16 duplicate questionnaires, the sample size was settled at 142 respondents.

The collected data was analyzed using descriptive statistics to summarize the demographic and farm characteristics. Data analysis was performed using R and the lavaan package (Rosseel, 2012). Variables with Kaiser-Meyer-Olkin (KMO) value <0.7 and factor loadings <0.5 were excluded (Shrestha, 2021). Confirmatory factor analysis (CFA) was conducted to evaluate 12 conversion motivation variables and 7 post-conversion barrier variables. Internal consistency was assessed using Cronbach's alpha and Raykov's rho, while model fit was evaluated with fit indices, including Root

Mean Squared Error of Approximation (RMSEA), Standardized Root Mean Square Residual (SRMR), Comparative Fit Index (CFI), and Tucker-Lewis Index (TLI).

RESULTS AND DISCUSSION

The sample included a diverse group of respondents (Table 1), predominantly male (88.7 %) and aged between 56–65 years (42.9 %). Most respondents were from the Aral (43.7 %) and Aksuu (37.3 %) aimaks, reflecting the uneven distribution of organic farmers across the region. Educational backgrounds varied among the participants, with 64.1 % having completed higher education and 35.2 % holding vocational qualifications. However, only 7 % of the respondents had professional agricultural education, indicating a potential gap in specialized knowledge related to organic farming.

Table 1. Respondents' profile and farm characteristics (n=142) evaluated in four organic aimaks in the Issyk-Kul province, Kyrgyzstan.

Variables	Description	Frequency	%
Sex	1 = Male	126	88.7
	0 = Female	16	11.3
Age (full years)	≤35	13	9.2
	36–45	16	11.3
	46–55	49	34.5
	56–65	61	42.9
	>65	3	2.1
Location of the interviewed organic farmers (by organic aimak)	Aksuu	53	37.3
	Aral	62	43.7
	Kun-Chigysh	21	14.8
	Tosor	6	4.2
Education background level	Secondary school	1	0.7
	Vocational education	50	35.2
	Higher education	91	64.1
Professional agricultural education	1 = Yes	10	7
	0 = No	132	93
Size of organic farmland (ha)	≤1.1–2.0	28	19.7
	2.1–3.0	69	48.6
	3.1–4.0	31	21.8
	>4.0	14	9.9
Experience of organic agriculture	≤5 years	26	18.3
	6–10 years	114	80.3
	>10 years	2	1.4
Organic farming as a main income source	1 = Yes	109	76.7
	0 = No	33	23.3

The size of organic farmlands ranged from small holdings of 1.1–2.0 ha (19.7 %) to larger plots exceeding 4.0 ha (9.9 %), with 48.6 % of farmers cultivating land within the 2.1–3.0 ha range. The majority of the farmers (80.3 %) had 6–10 years of experience in organic farming, while 18.3 % had less than 5 years of experience. Organic farming was reported as the primary income source for 76.7 % of the participants, while 23.3 % relied on additional income sources, including school teaching, municipal service, animal husbandry, beekeeping, and small-scale businesses.

Confirmatory factor analysis of motivations for organic conversion

To understand what motivates farmers to switch to organic farming, respondents were asked to select one appropriate option from a five-point Likert scale (from 1 "strongly disagree" to 5 "strongly agree") to share their attitudes (Table 2). There are three motivational factors, namely the environmental and human health, motivation of pro-environmental ideology, and vision-supportive motivations.

Standardized factor loadings of 0.5 or higher were considered acceptable for inclusion in the model, with values above 0.7 indicating stronger contributions. Consequently, three indicators loaded significantly on Factor 1, two indicators loaded significantly on Factor 2, and one indicator of Factor 3 had significant loading. One indicator in Factor 3 demonstrated close significance (0.681). Two other indicators had acceptable loadings (>0.5). Among the five indicators of Factor 1, three indicators loaded the highest. The indicator "I wanted to improve soil fertility and its health on my farm" has the highest factor loading, followed by "I thought organic farming would increase my longevity" and "I wanted to care about Issyk-Kul Lake." Factor 2 consists of three indicators, of which "I considered my farm as a part of nature" loaded significantly, followed by "Organic farming fits my ethical views." The indicator "I wanted to follow my religious traditions based on environmental stewardship" was of lesser significance but with the acceptable factor loading. The indicator "I had a vision of my farm as a prosperous organic enterprise" has the highest loading for Factor 3. Closely related to it is the indicator "I wanted to provide the local community and potential consumers with healthy produce," followed by "I wanted to reduce the overall costs by excluding chemicals from the production process."

The explored factors have good internal consistency and acceptable construct reliability (Cronbach's alpha >0.7; Raykov's rho >0.7). The robust fit indices of the CFA model (Table 3) for farmers' organic conversion motivations demonstrated acceptable fit indices.

Confirmatory factor analysis of barriers after conversion

To identify barriers after organic conversion, the surveyed organic farmers were asked to assess the challenges they faced after the conversion period by choosing one option from a five-point Likert scale (from 1 "not at all" to 5 "extremely serious"). CFA resulted in a two-factor model covering the factors of agri-input deficiency and market access challenges. All indicators of Factor 1 and one indicator of Factor 2 had

Table 2. Factors, factor loadings, measurements, and coefficients of observed variables for the confirmatory factor analysis (CFA) model of motivations for organic conversion in four organic aimaks in the Issyk-Kul province, Kyrgyzstan.

Factors and their indicators	Factor loadings	Mean	SD	Cronbach's alpha	Raykov's rho (omega)	*p*-value
Factor 1: Environmental and human health						
I wanted to care about future generations	0.635	4.65	0.57			
Organic farming would positively contribute to the environment	0.672	4.63	0.58			
I wanted to improve soil fertility and its health on my farm	0.775	4.51	0.70	0.84	0.82	0*
I wanted to care about Issyk-Kul Lake	0.709	4.43	0.67			
I thought organic farming would increase my longevity	0.742	4.39	0.70			
Factor 2: Motivation of pro-environmental ideology						
I considered my farm as a part of nature	0.833	3.39	0.72			
Organic farming fit my ethical views	0.704	3.27	0.71	0.74	0.74	0*
I wanted to follow my religious traditions based on environmental stewardship	0.578	2.42	0.80			
Factor 3: Vision-supportive motivations						
My farm design and operations were suitable for easier conversion	0.53	3.70	0.64			
I wanted to provide the local community and potential consumers with healthy produce	0.681	3.59	0.75			
I wanted to reduce the overall costs by excluding chemicals from the production process	0.665	3.51	0.78	0.71	0.77	0*
I had a vision of my farm as a prosperous organic enterprise	0.70	3.17	0.53			

*Significant at $p < 0.001$; n = 142, $\chi^2 = 55.626$, degrees of freedom = 47, *p*-value (chi-square) = 0.182. SD: standard deviation.

highly significant factor loadings (≥0.7) (Table 4). The other two indicators of Factor 2 had acceptable factor loadings higher than 0.5. One indicator of Factor 1, "Lack of organic fertilizers," showed the highest factor loading, followed by "Lack of extension services for organic farmers," "Spread of pests," and "Spread of weeds." Factor 2 was comprised of three indicators, of which "Large distance to the local markets" loaded the highest, whereas two other indicators had acceptable factor loadings.

Table 3. Robust fit indices of confirmatory factor analysis (CFA) model on organic conversion motivations in four organic aimaks in the Issyk-Kul province, Kyrgyzstan.

Fit indices	Acceptable value*	Extracted value	Result
Root Mean Square Error of Approximation (RMSEA)	Close to 0.06 or less	0.042	Accepted
Comparative Fit Index (CFI)	Close to 0.95 or greater	0.980	Accepted
Tucker Lewis Index (TLI)	Close to 0.95 or greater	0.971	Accepted
Standardized Root Mean Square Residual (SRMR)	Close to 0.08 or less	0.066	Accepted

*Acceptable values adopted from Brown (2015).

Table 4. Factors, factor loadings, measurements, and coefficients of observed variables of the confirmatory factor analysis (CFA) model of the barriers after conversion period in four organic aimaks in the Issyk-Kul province, Kyrgyzstan.

Factors and their indicators	Factor loadings	Mean	SD	Cronbach's alpha	Raykov's rho (omega)	*p*-value
Factor 1: Agri-input deficiency						
Lack of extension services for organic farmers	0.84	2.35	0.76	0.9	0.85	0*
Lack of organic fertilizers	0.951	2.11	1.12			
Spread of weeds	0.72	3.3	1.02			
Spread of pests	0.78	2.73	1.22			
Factor 2: Market access challenges						
Poor cooperation with other organic farmers in my organic aimak	0.629	2.3	0.87	0.74	0.78	0*
Large distance to the local markets	0.845	2.18	1.12			
Low demand for my organic produce	0.666	1.58	0.68			

*Significant at $p < 0.001$; n = 142, $\chi^2 = 12.93$, df = 11, *p*-value (chi-square) = 0.298. SD: standard deviation.

All latent variables had sufficient internal consistency (Cronbach's alpha >0.7) and construct reliability (Raykov's rho >0.7). The robust fit indices of CFA model for the barriers after conversion period (Table 5) showed acceptable values.

Table 5. Robust fit indices of the confirmatory factor analysis (CFA) model for the barriers after conversion period in four organic aimaks in the Issyk-Kul province, Kyrgyzstan, based on Brown (2015).

Fit indices	Acceptable value	Extracted value	Result
Root Mean Square Error of Approximation (RMSEA)	Close to 0.06 or less	0.039	Accepted
Comparative Fit Index (CFI)	Close to 0.95 or greater	0.997	Accepted
Tucker Lewis Index (TLI)	Close to 0.95 or greater	0.993	Accepted
Standardized Root Mean Square Residual (SRMR)	Close to 0.08 or less	0.035	Accepted

Regression analysis of organic conversion motivations

To identify potential links between factors for organic conversion and demographic variables, three multiple regression analyses were conducted by the number of revealed conversion factors. First, it was tested whether the residuals of the regression models followed a normal distribution. The results of the Kolmogorov-Smirnov test suggest that the residuals do not significantly deviate from the normal distribution ($p > 0.05$). Second, some multicollinearity was found in regression model 1 for two predictors, namely the motivation of pro-environmental ideology (VIF = 5.23) and vision-supportive motivations (VIF = 5.35). According to James *et al*. (2021), VIF values >5 can be considered problematic. Following the researchers' recommendation, one composite variable was created to replace the two aforementioned predictors in regression model 1. VIF reassessment revealed that all predictors in regression models had acceptable VIF values <2. Next, authors conducted the Breusch-Pagan test for heteroscedasticity. The results of the test showed that there was no strong evidence of heteroscedasticity in authors' models ($p > 0.05$) (Table 6).

For regression model 1, the environmental and human health model was statistically significant ($R^2 = 0.31$, F (8.133) = 7.53, $p < 0.001$). It was found that the following independent variables significantly predicted motivation of the environmental and human health: composite variable ($p < 0.001$, $\beta = 0.485$): for every unit increase in the composite variable, the response variable is expected to increase by 0.485 units; organic farming as a main income source ($p < 0.01$, $\beta = 0.231$): for every unit increase in organic farming as a main income source, the response variable is projected to increase by 0.231 units.

For regression model 2, the motivation of the pro-environmental ideology model was statistically significant ($R^2 = 0.91$, F (9.132) = 156, $p < 0.001$). It was found that the following independent variables significantly predicted motivation of pro-environmental ideology: environmental and human health ($p < 0.001$, $\beta = 0.365$): for every unit increase in motivation of environmental and human health, the response variable will increase by 0.365 units; vision-supportive motivations ($p < 0.001$, $\beta =$

Table 6. Regression models for organic conversion motivations evaluated in four organic aimaks in the Issyk-Kul province, Kyrgyzstan.

Predictors	Environmental and human health			Motivation of pro-environmental ideology (MPEI)			Vision-supportive motivations (VSM)		
	B	SE B	β	B	SE B	β	B	SE B	β
EHH	-	-	-	0.446	0.035	0.365**	-0.469	0.055	-0.347**
MPEI	0.386^{cv}	0.059^{cv}	0.485^{cv}**				1.21	0.044	1.091**
VSM				0.704	0.026	0.781**	-	-	-
Sex	-0.125	0.085	-0.111	0.007	0.037	0.05	-0.074	0.049	-0.049
Age	-0.001	0.003	-0.017	0	0.001	-0.002	0	0.002	-0.008
Edu	-0.013	0.059	-0.018	-0.05	0.026	-0.052	0.009	0.033	0.090*
Prof_edu	0.093	0.119	0.067	-0.045	0.052	-0.027	0.035	0.068	0.019
Size_OF	0.007	0.015	0.037	0.003	0.007	0.014	-0.003	0.009	-0.013
Exp_OA	-0.012	0.013	-0.076	-0.003	0.006	-0.017	0.007	0.008	0.034
MIS	0.194	0.066	0.231*	-0.112	0.03	-0.11**	0.141	0.039	0.124**

CV denotes values for the composite variable (MPEI+VSM) in the regression model 1; n=142. EHH: environmental and human health; Edu: education background level; Prof_edu: professional agricultural education; Size_OF: size of organic farmland; Exp_OA: experience of organic agriculture; MIS: organic farming as a main income source; B: unstandardized coefficient; SE B: standard error of the unstandardized coefficient (B); β: standardized regression coefficient; *$p < 0.01$; **$p < 0.001$.

0.781): for every unit increase in vision-supportive motivations, the response variable will increase by 0.781 units; organic farming as a main income source variable ($p < 0.001$, $\beta = -0.11$): for every unit increase in organic farming as a main income source variable, the response variable is projected to decrease by 0.11 units.

Finally, for regression model 3, the vision-supportive motivations model was statistically significant ($R^2 = 0.88$, $F(9.132) = 107.5$, $p < 0.001$). It was identified that the following independent variables significantly predicted vision-supportive motivations: environmental and human health ($p < 0.001$, $\beta = -0.347$): for every unit increase in motivation of environmental and human health, the response variable will decrease by 0.347 units; motivation of pro-environmental ideology ($p < 0.001$, $\beta = 1.091$): for every unit increase in motivation of pro-environmental ideology, the response variable will increase by 1.091 units; education background level ($p < 0.01$, $\beta = 0.09$): for every unit increase in education level, the response variable will increase by 0.09 units; organic farming as a main income source ($p < 0.001$, $\beta = 0.124$): for every unit increase in organic farming as a main income source, the response variable will increase by 0.124 units.

Standardized β of the motivation of pro-environmental ideology exceeded one. In some cases, it can indicate multicollinearity, but the VIF value of this variable assumes low multicollinearity (VIF=1.72). It might imply very high influence of ideological considerations on farmers' vision-supportive motivations.

Motivations for organic conversion

As the study revealed, there were multiple motivations for organic conversion and barriers organic farmers in organic aimaks faced. Based on the results, farmers' conversion motivations were three-fold and related to environmental and human health, pro-environmental ideology, and vision-supportive aspects. It was identified that environmental and human health was a dominant conversion factor. Soil fertility and soil health were highly important conversion motivations for farmers. Organic farming is seen as an appropriate technique to improve soil health and, thereby, contribute to better personal health and future generations' welfare (Vinyukov *et al.*, 2022; 2023). Soil fertility, as one of the driving forces of organic conversion with relation to Kyrgyz farmers in Jalal-Abad province, was reported by Kaegi *et al*. (2017). Motivations of environmental and personal health are commonly cited by the researchers with regards to organic conversion. Initial motivation of caring for future generations was aligned with the farm vision of providing consumers with wholesome produce.

Each region has its own pattern of organic conversion with a unique combination of factors (Chen *et al.*, 2024a; 2024b). As expected, organic farmers of Issyk-Kul province were highly concerned with environmental protection due to close proximity to Lake Issyk-Kul. It may be one of the reasons for the absence of clearly expressed motivation of profitability among the indicators. Another aspect touches upon the domestic organic market, which is at an embryonic stage (Babajani *et al*., 2023). Prices for local organic and conventionally grown products do not significantly vary in the domestic market. It might raise the question of the economic sustainability of the converted organic farms. Financial considerations are typical driving forces of organic conversion (Bui and Nguyen, 2020; Han *et al*., 2021). However, it is not uncommon when organic farmers grow organic crops for their own consumption. As the interviewed farmers reported, farm productivity largely remained on the pre-conversion level. Thus, organic conversion did not negatively affect the economic viability of the organic farms. It implies that agricultural zones with traditional farming can convert with fewer financial risks.

Further, in accordance with the vision-supportive motivations, farmers who opted for organic farming in organic aimaks had reasonable expectations of future financial benefits. These results are not fully consistent with the findings of the study by Kaegi *et al*. (2017) on organic farmers from Jalal-Abad province of Kyrgyzstan supported by the "Bio-Cotton" project, which identified soil fertility and financial motivations as the main factors. Unlike the "Bio-Cotton" project, organic aimaks do not target export markets and have a goal of developing the domestic market first and familiarizing Kyrgyz small farmers with organic principles. However, farmers of Issyk-Kul province noted that they wanted to reduce the use of chemicals and, thereby, cut the costs and reach farm prosperity as a part of their vision. It could be viewed as a subtle indication of an intention for enhanced financial stability in the long run.

It is important to highlight that the motivation of pro-environmental ideology was quite influential in farmers' decisions to convert. An idea of a farm as an

indispensable component of nature is derived from the philosophy of holism and typical to committed organic farmers who have strong beliefs in organic farming as a part of their personal ideologies (Zymaroieva *et al.*, 2021; Yermakov *et al.*, 2021). It is worth to mentioning that both religious beliefs and the philosophy of holism coexist within one factor of motivation of pro-environmental ideology. It may be the case of mutual enrichment between emerging religious traditions and new values brought by the organic movement. The authors could find strong positive attitudes toward organic farming supported by suitable farm design to facilitate transition. Thus, two of the three main components of TPB (attitudes toward the behavior and PBC) were significant in explaining organic conversion in organic aimaks. In contrast to several studies (Sapbamrer and Thammachai, 2021), subjective norms did not seemingly influence farmers' intentions to convert. Therefore, results underline the prevalence of the internal motivations.

Barriers to organic conversion

The second CFA model on barriers after conversion revealed two major areas of organic farmers' concerns, namely agri-input deficiency and market access challenges. Lack of agri-inputs, as a major barrier, was characterized by poor access to extension services and organic fertilizers. Spread of weeds and pests was described by the surveyed farmers as serious to some extent. In modern agricultural paradigms, knowledge has become an input that ensures optimal use of physical inputs (fertilizers, pesticides, machinery) (Shahini *et al.*, 2023; İsmayilov *et al.*, 2022). As described earlier, merely 7 % of the survey respondents had professional agricultural backgrounds. It explains high dependence on additional agricultural extension support for farmers in conversion. Organic farmers in organic aimaks reported that they were confronted with the lack of extension services after the transition period. Lack of customized extension services to meet the needs of organic farmers presented a significant challenge. Findings by Karki *et al*. (2011) and Läpple (2010) show that training and access to the necessary information are vital for the adoption of organic farming and prevention of reversion. In general, the transfer of knowledge by extension officers is critical for organic conversion. Lacking extension support appears to be a root cause of declined farm performance (Mukambaeva *et al.*, 2024). Thus, further studies are needed to investigate the role of agricultural extension in the promotion of organic farming in organic aimaks.

Interestingly, subjective norms were not influential conversion motivations. Some other researchers identified social norms as the main barriers to organic conversion. What is interesting to observe here is the role of organic aimak as an association of organic farmers. In their research on spatial distribution of organic farming in the United States, Kuo and Peters (2017) found that close proximity to organic farming areas stimulated organic conversion in neighboring areas. However, as statistical data show, the number of organic aimaks and organic farmers does not grow substantially in surrounding areas. Collective attitudes and actions can play a crucial role in individual decision-making. According to Sapbamrer and Thammachai (2021), membership in

associations and active participation in the life of the local community have a positive effect on the organic conversion process. The authors' findings illustrate that the synergetic potential of the membership of organic aimak appears to be underutilized as a motivational factor.

The next impeding factor reported by organic farmers was the marketing of organic produce. An overwhelming majority of the organic farmers were small-scaled and needed collective actions to facilitate access to agricultural markets. However, it was found that poor interactions among organic farmers represent a barrier to better marketing. In other words, the lack of collaborative actions may be disadvantageous for all members of organic aimaks. Geographical locations of the large, profitable markets create additional barriers for organic farmers in Issyk-Kul province to sell their produce. Mostly, organic farmers tended to access markets in the capital city of Bishkek, which was mentioned by farmers as the primary target outside of Issyk-Kul province. Noteworthy, almost the same number of organic farmers sold their produce in other districts of Issyk-Kul province and other provinces of Kyrgyzstan. Low demand for organic produce was reported by the farmers as a minor difficulty and may be seen as a temporary obstacle (Kociszewski *et al*., 2020).

Policy and practical implications

Overall, conversion obstacles were not rated high and were described by the organic farmers on average as minor ones. It may be explained with reference to one of the conducive indicators identified in the CFA model on motivations for organic conversion. Surveyed organic farmers emphasized that their farm design and field operations were suitable for easier conversion. These results are in accordance with Aoki (2014), who found that farmers engaged in traditional chemical-free agriculture (so-called informal organic) were capable of easier conversion to certified organic farming. Concerns over personal and environmental health, the growing global market of organic products, and changing dietary habits are likely to contribute to faster expansion of organic farming (O'g'li and Karshiboevna, 2024; Yeraliyeva *et al.*, 2016). For Kyrgyzstan, the design and implementation of agricultural policies based on scientifically proven results could significantly contribute to the promotion of organic farming.

To identify potential relationships between organic conversion factors and demographic variables, three multiple regression models were run. The results of multiple regression analysis indicated that age, gender, size of organic farmland, experience of organic farming, and professional agricultural education did not affect motivations for organic conversion. On the other hand, a strong relationship was found among the three factors described in the CFA model of motivations for organic conversion. All models showed that three conversion factors are closely interlinked. It was found that reliance on organic farming as the main income source significantly influences all three conversion factors. This suggests that a level of farmers' engagement in organic farming as an economic activity significantly affects motivations for organic conversion. Factors of

environmental and human health and vision-supportive motivations demonstrated a significant negative relationship. The reason for that is not clear and indicates the need for further investigation. The authors hypothesize that there may be controversy between personal benefits and public interests. Also, findings indicated that education level positively affected vision-supportive motivations.

The results show that organic conversion is a multidimensional phenomenon. It may indicate that organic promotion policies can be effective only if multiple factors are taken into account. Thus, the practical implication of the findings is that policies aimed at promoting organic agriculture should transcend pure economic stimulation and include the whole array of factors in order to be effective. Next, customized agricultural extension services should be introduced to facilitate the conversion process. As it was found, the lack of the needed information may be the primary cause of the decreased farm performance and one of the components of the inputs' deficiency. Non-agricultural educational backgrounds, insufficient knowledge on organic farm management, coupled with poor access to relevant information and agricultural inputs, may undermine farmers' positive image of successful organic farming and preclude farmers from conversion (Trusova *et al.,* 2021a). Therefore, the establishment of specialized extension systems is of high importance to strengthen the capacities of currently operating organic aimaks and reduce uncertainties common for the promotion of new approaches (Pimentel *et al*., 2005).

As this study showed, social norms do not play a significant role in farmers' decision-making. Thus, the "Organic aimak" initiative should strengthen collaborative ties among members of organic aimaks to untap underutilized potential of social interaction by organizing more joint events and developing positive images of organic farmers and organic aimaks as responsible stewards of natural resources with strong personal beliefs and ethical values. Finally, local organic farm shops offering permitted organic inputs should be established to provide organic farmers with the whole spectrum of the necessary organic fertilizers and bio-pesticides. Successful cases of vermiculture and compost production based on local raw materials should be replicated to ensure a multiplication effect. Therefore, measures to support local production of organic inputs should be considered when designing agricultural policies.

CONCLUSIONS

This research explored the motivations for organic conversion and the barriers encountered post-conversion among Participatory Guarantee Systems (PGS)-certified organic farmers in the Issyk-Kul province of Kyrgyzstan. Analysis revealed that the primary motivation for transitioning to organic farming stemmed from environmental and health concerns, particularly the need to improve soil health, enhance personal well-being, and ensure environmental sustainability. The most significant barriers faced by farmers after conversion were deficiencies in agricultural inputs, including limited access to organic fertilizers and extension services, as well as challenges related

to market access. Farmers reported difficulties in building cooperative networks and accessing distant markets, compounded by low local demand for organic produce. Interestingly, social pressure and norms did not emerge as significant factors influencing the decision to convert or challenges faced thereafter.

Regression analysis underscored strong interconnections between the three motivational factors and highlighted the importance of organic farming as a primary income source in shaping farmers' decisions. Education level positively influenced vision-supportive motivations, emphasizing the role of knowledge in fostering sustainable farming practices. These findings underscore the need for policymakers to develop targeted interventions that address key challenges, such as improving access to agricultural inputs, enhancing market integration, and expanding extension services tailored to the unique needs of organic farmers. Additionally, fostering educational programs and collaborative initiatives within organic aimaks can amplify motivation and reduce barriers.

By offering insights into the organic conversion patterns of farmers in Issyk-Kul, this study provides a foundation for shaping policy and educational efforts to promote organic agriculture. Future research should involve larger and more diverse samples across various regions and stakeholders, including consumers and policymakers, to deepen the understanding of the dynamics underlying organic farming transitions in Kyrgyzstan.

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Agrociencia

THE MEANING OF 'SUSTAINABILITY' IN DAIRY CATTLE FARMING. A REVIEW OF THE CONCEPT

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ABSTRACT

It is clear that the long-term viability and existence of the planet's life support systems are seriously threatened by environmental degradation. To address this reality, it is necessary to quantify the impacts of human activities that cause this degradation, particularly food production systems. Assessing these impacts in terms of sustainability is therefore essential to quantify their contribution to the overall problem and to design and implement effective policies, corrective measures and compensation mechanisms. Among these systems, dairy cattle production is one of the most questioned due to its high environmental impacts. The concept of sustainability is very broad and in order to address it, this study aims to examine the different existing narratives for its conceptualization, applied to the dairy sector in particular. To this end, a systematic literature review was carried out, which led to the identification of 56 studies whose common objective was to assess the sustainability of cow's milk production. The analysis of this literature, carried out using the SALSA protocol, shows the coexistence of several approaches to defining sustainability, considering simultaneously the three dimensions that make it up: environmental, social and economic. The aim of this study is to identify and typify these different ways of approaching the concept of sustainability, as a useful contribution to the subsequent design of standardized frameworks, methodologies and tools, congruent with the diverse contexts in which dairy farming is developing in the areas of origin of the studies reviewed.

Keywords: sustainability, assessment, dimensions, indicators, concept.

INTRODUCTION

The concept of planetary boundaries was first introduced to define the safe operating space for humanity within the Earth's systems (Rockström *et al.*, 2009). Agricultural production has an impact on several planetary boundaries, as it involves significant use of land, water, and energy resources and generates greenhouse gas emissions. Dairy production intersects significantly with the concepts of planetary boundaries

and sustainability, the latter being a recurrent term in the agricultural sector today. Among the many edges of this topic, its evaluation is one of the most diffuse. The first notable difficulty is to find a definition that leaves no room for ambiguity. The concept of "sustainable development" formally appeared on the scene in 1987, as a fundamental contribution of the report Our Common Future, also known as the "Brundtland Report" (WCED, 1987). This document had the merit of recognizing the interrelationship between the environment, society and economy. Although it represented a global effort in the face of multiple warnings of an impending environmental crisis, economic growth still remains as the main driver of wellbeing in current policies.

It should be noted that the term "sustainable development" encompasses two distinct concepts: development and sustainability, each of which can be understood in different ways, depending on the perspective from which it is viewed. These points were taken into account by the Food and Agriculture Organization of the United Nations (FAO) as early as 1991, when a definition of "sustainable agriculture" was formally established: it must be environmentally non-degrading, technically appropriate, economically viable and socially acceptable (FAO, 1991). This definition includes two fundamental aspects: on the one hand, a long-term view ("present and future generations"), and on the other, the importance of the three dimensions or perspectives that must be addressed to create adequate conditions for sustainability: environmental, social and economic. In order to achieve a system that is sustainable across generations, these three dimensions must reach a minimum level (or threshold) of sustainability (Elkington, 1998). However, the conceptual and operational definition of these dimensions remains an open topic of discussion. The boundaries between them, as expressed by the indicators used in the assessment, do not seem to be precise, and it is necessary to establish criteria to define them and create common bases for their evaluation.

Ensuring the viability of the planet's life-support systems is an issue that cannot be postponed (Rockstrom *et al.*, 2023). However, the production models prevailing in most of the world economy are impeding this goal and leading to the depletion of this unique legacy of natural capital (Costanza *et al.*, 2014; Nadal, 2011) and it is not surprising that the interactions between its environmental, social and economic spheres constitute a continuous source of conflicts. Turning the above around implies a shift from previous approaches to sustainability: primary production must cease to be considered as a mere economic activity, and instead be contemplated in its interrelationship with the environmental and social perspectives of productive systems (Rockström *et al.*, 2009). A serious analysis of its viability must include these three dimensions. Thus, studies in the agricultural field have evolved from focusing almost exclusively on issues such as economic evaluation, technological intensification and productivity increase, to research from a holistic perspective. The concept of sustainability comprises multiple, often conflicting objectives that are not clearly defined in terms of measurable variables, due to the complexity of the interactions that

occur between social, economic and ecological dimensions and their consequent lack of understanding. That which is valuable from an economic perspective frequently impacts adversely on the environmental and social (Chopin *et al*, 2021). The connection between ecological stress and social conflict is widely documented (Rockström *et al.*, 2009; WCED, 1987). Causal relationships can be found in both directions: a conflict can appear as the origin of environmental degradation and this in turn can generate social differences (Steinfeld *et al.*, 2006). Humanitarian conflicts such as those that have occurred in recent times in Haiti, Somalia, Sudan, Rwanda, Ukraine and Palestine, characterized by ethnic differences, overpopulation or famine, also represent calls for attention to environmental problems accumulated over time (Costanza *et al.*, 2014).

The greatest challenge facing food production today is its sustainability, threatened by the availability of natural resources, the pressures on them (Foley *et al*., 2005, Rockström *et al.*, 2023) and the resulting social and economic problems. Rectifying this course requires the ability to assess the sustainability of agricultural activity. To this end, several initiatives have been developed over the last few decades to quantify the sustainability of agriculture in general, and of its different sectors in particular. Within the primary sector, livestock farming is one of the most questioned activities because of its environmental impact (Steinfeld *et al.*, 2006), which makes its evaluation a priority matter. However, this task is complicated by the heterogeneity of the livestock sector and the vastness of its distribution around the planet. The practice of assessing sustainability requires in the first instance that the term be defined in operational terms, which is usually done by disaggregating the concept into its different fundamental dimensions, which in turn are broken down into themes or components that derive in measurable objectives (Chopin *et al.*, 2021). There exists a variety of methods focused on partial sustainability assessments, in which the environmental and economic perspectives predominate (Arvidsson *et al*., 2020). However, for the integral assessment of sustainability, the range of options is more limited. The aim of this paper is to distinguish and contrast the sustainability concepts which support these latter methods, based on a review of the existing literature. In the discussion section, emphasis is placed on the current ambiguity in the definition of the different dimensions of sustainability, a matter that has a significant impact on their design and also affects the choice of the specific indicators with which each of them is evaluated. Another relevant aspect, also elaborated in the discussion, is the contextuality of these methods, which is strongly associated with their origin, the researcher's interests and the objectives to which they obey. Assessing the sustainability of dairy production systems would greatly benefit from a clear definition of the boundaries and scope of its three dimensions. This would be a step forward in defining research priorities in this area and, consequently, in developing more appropriate assessment methodologies. It should be noted that the scope of this paper is limited to the analysis of sustainability concepts and to some observations on the selection of sustainability indicators, as found in the collection of articles reviewed. The further review of the different methodologies and their indicators is not included here due to space limitations and will be presented in a future publication.

MATERIALS AND METHODS

The typological category *systematized review*, selected according to the classification established by Grant and Booth (2009), was used to conduct the bibliographical search and further analysis of the material. It is characterized as a solid and reproducible method for the search, categorization, and synthesis of published knowledge on a particular topic. The results elucidate current advances in the subject and contrast with other retrospective approaches, as well as opening the possibility of exploring new perspectives on the subject and highlighting the existing gaps in the knowledge of the subject. The search, appraisal, synthesis and analysis of relevant literature were carried out according to the SALSA protocol (Search, AppraisaL, Synthesis, Analysis), which allows the scope of the review to be narrowed according to the objective being considered (Grant and Booth, 2009). This process consists of the following phases:

1. Search: a search for contributions to the topic in databases
2. Appraisal: the application of criteria defined for the inclusion/exclusion of studies.
3. Synthesis: of narrative and tabular types.
4. Analysis: presenting a synthesis of the current state of the knowledge and areas of opportunity for future research.

The search was delimited by two objectives:

a) To identify literature that deals with methodologies to evaluate sustainability in cattle milk production, considering its three dimensions: environmental, social, and economic.
b) Once identified the relevant literature, the next requirement was that it should also include an empirical validation of the proposed methodology.

The search was performed in the databases Web of Science and ScienceDirect for English-language publications, and in Redalyc and SciELO for open access publications in Ibero-American journals, Google Scholar for general English-language publications, and Google Académico for general Spanish-language publications. For each of these, search terms were defined according to the characteristics of the particular search engine; i.e., Web of Science allows high levels of specificity in the identification of documents, in contrast to the search engine of Google, which yields very generic results and a high number of irrelevant documents. The relatively small number of results obtained from Google Scholar was due to the decision to restrict the keyword search exclusively to article titles. If this adjustment were not made, the number of results returned by the search engine would be unmanageable for the purposes of this study. The search in Google Scholar enabled the capture of some additional references that did not appear in the other databases.

The search terms used were chosen to match the search engine of each database or source consulted. The period considered for all databases was January 2000 to August 2024 (Table 1).

Table 1. Search terms used in the identification of scientific publications related to the evaluation of dairy production sustainability in its three dimensions: environmental, social, and economic.

Database	Search terms
Web of Science	Dairy OR cattle livestock (Title) AND sustainab* OR integral* (Topic) AND environment* AND soci* AND econom* (Topic) AND assessment OR valuation OR index OR indicator OR appraisal OR estimat* (Topic) NOT buffalo OR goat OR sheep OR camel (Topic)
Science Direct	Title: dairy OR cattle OR cow OR milk Title, abstract, keywords: (social OR socioeconomic) AND (economical OR economic) AND (environment OR environmental) AND (sustainable OR sustainability)
Redalyc	(Evaluación OR cuantificación OR indicadores) AND (sustentabilidad) AND (“producción lechera” OR lechería OR leche) AND (ambiental AND ecológica AND económica AND social) NOT (oveja OR cabra OR caprino)
SciELO	ti:(“producción lechera” OR lechería OR leche) AND (ab:(sustentabilidad OR sustentable)) AND (ab:(evaluación OR cuantificación OR medición OR indi*))
Google Scholar	intitle:(dairy OR milk OR cattle) AND intitle:(sustainable OR sustainability) AND intitle:(assessment OR appraisal OR index) AND intext: (“three pillars” OR “triple bottom line”) AND intext:(environmental AND social AND economic) -buffalo -goat -sheep -industry -transport -transportation
Google Académico	allintitle:(evaluación OR indicadores) + (sustentabilidad OR sostenibilidad) + (leche OR lechera OR lechería) -cabra -oveja -bufalo -transporte

Geographic restrictions were not considered, since the aim was to determine the progress made both in developed countries, where most of the literature originates, and in developing countries, particularly those of Latin America. For this last reason, in addition to articles written in English, the review also included documents published in Spanish and Portuguese. During the course of the individual article reading and revision, snowballing was used as an aid to include relevant articles not captured in the search but referenced within the body of literature. Each article under review was filtered through the inclusion and exclusion criteria (Table 2).

Table 2. Criteria of inclusion and exclusion of literature.

Category	Criterion
Inclusion	Search terms appear as specified Publication in a peer-reviewed journal Original research on methodologies to assess sustainability in cow's milk production, in its three dimensions Empirical validation of the methodology is included Articles written in English, Spanish, or Portuguese language Articles published between January 2000 and August 2024
Exclusion	Generic evaluation studies, applied to other production systems, not specifically for cow's milk production Methodologies that consider only one or two dimensions

RESULTS AND DISCUSSION

Bibliographic review

The outcome of the systematic search, in terms of the number of articles detected and included from each data base, is detailed in Table 3. Regarding the origin and validation of the studies, 32 come from Europe, 20 from Latin America, where Brazil is prominent with six articles, Mexico with three and the remaining four equally from Africa (Tanzania), North America (Canada), Asia (India), and Oceania (Australia). The relative proportions of each zone are shown in Figure 1. The minimal presence of these latter three regions and its respective countries, which rank among the largest global milk producers, is noteworthy.

Table 3. Database of origin of the articles included in the review phase.

Database	Articles detected	Articles included
Web of Science	227	29
Science Direct	70	12
Redalyc	1,102	7
SciELO	1	0
Google Scholar	512	5
Google Académico	101	1
Other references (snowballing)	5	2
Total	**2,017**	**56**

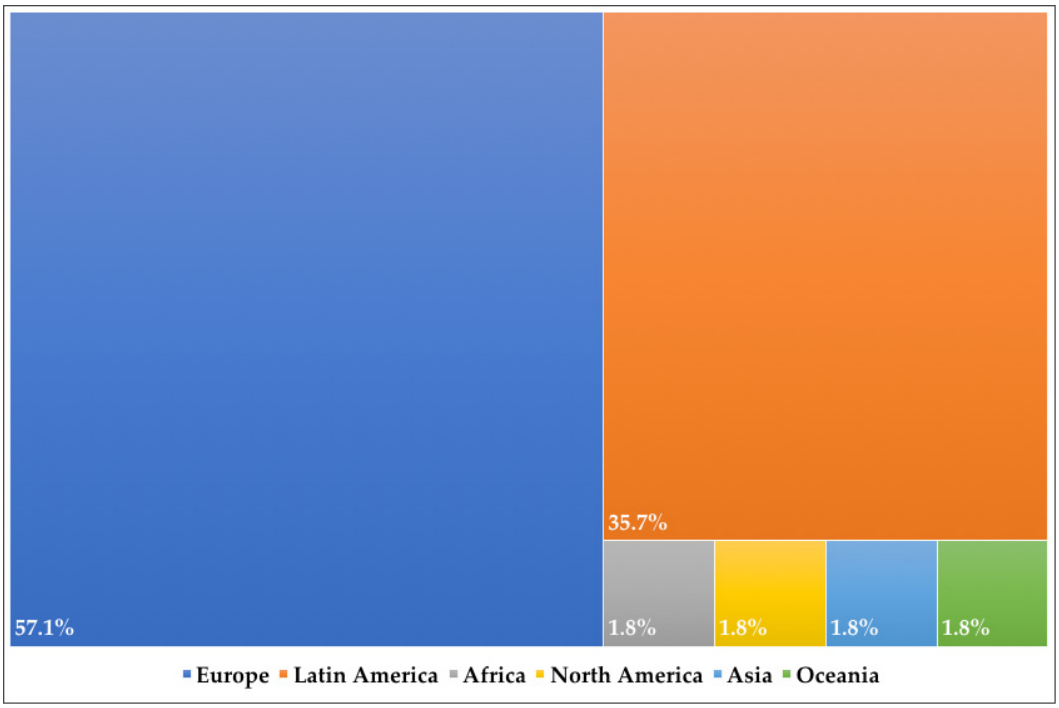

Figure 1. Origin of the articles included in the review.

Sustainability conceptions and indicators selection

The variety of indicators used to evaluate each dimension of sustainability reflect the wide gamut of sustainability conceptions applicable for each dimension, as viewed by each author. Organizing these contrasts in a comprehensible manner was the next step in the analysis.

The contribution of agriculture to the welfare of society has been, until recent times, usually determined by its economic contribution. However, sustainability studies nowadays tend to integrate economic assessment with environmental performance and the overall welfare of society. This leads one to note the lack of a consensual definition of "sustainability", despite its widespread use and relevance. In the first instance, the assessment of sustainability requires that it be defined in operational terms, creating an association with measurable variables. This results in a complex categorization but allows for a common language that facilitates discussion among stakeholders about the complex relationship between natural and human systems. Bockstaller *et al*. (2009) highlight the diversity of approaches and the lack of a formal methodology to compare them. Therefore, a number of preliminary choices and assumptions need to be made before defining a sustainability framework. These stem from a set of basic questions, as arised by Lélé and Norgaard (1996), regarding the definition of "sustainability": *'What is to be sustained, at what scale, and in what form? Over what time period and with what level of certainty? Through what social process and*

with what tradeoffs against other social goals?'. Little research has focused on this line, and a tool capable of comprehensively assessing dairy systems in particular, viewing economic, environmental and social sustainability as a complex interactive system, is not yet available. As an example, widely used methodologies such as life cycle analysis (LCA), which could ideally combine the environmental dimension, economic costing, and even the social aspect has not been explored enough (Chen and Holden, 2017; Rivera-Huerta *et al*, 2019). Designing such a tool should at first focus on establishing the necessary definitions of the different dimensions of sustainability, delineating their boundaries and potential assessment methodologies.

This is an open debate: there is a multiplicity of tools for sustainability assessment, covering a broad spectrum of objectives, from the general to the particular. Several methods exist designed for the assessment of agriculture in general, and susceptible of being adapted to different productive sectors through the contextualization of their attributes and indicators: SAFA, Sustainability Assessment of Food and Agriculture (FAO 2014), RISE, Response Inducing Sustainability Evaluation (Häni *et al*., 2003), IDEA, Indicators of Durability of Agricultural Exploitations (Zahm *et al.,* 2008), MOTIFS, Monitoring Tool for Integrated Farm Sustainability (Meul *et al.,* 2008) and MESMIS, Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (Astier *et al.,* 2012) are relevant examples of this kind. In addition, 39 different methods specifically designed for the dairy sector were identified. The following table lists the 56 references reviewed, the country or region in which they were validated, and the application for which they were originally designed (Table 4).

Table 4. Papers included in the review, country/region of origin and original application of the methodology.

No.	Reference	Country/ region	Aplication
1	Cruz F, Pardo D, Horcada A, Mena Y. 2024. An Assessment of Sustainability of Dual-Purpose, Dairy and Beef Cattle Production Systems in the Cundinamarca Department (Colombia) Using the MESMIS Framework. Sustainability 16 (16): 7054. https://doi.org/10.3390/su16167054	Colombia	Agriculture (adapted)
2	Fariña S, Vigil Moreno O, Candioti F, Villanueva C, Sanchez Ledezma W, Moscoso C, Cajarville C, Charlón V, Urbina Abaunza L, Guacapiña Viteri A *et al.* 2024. Milk production systems in Latin America and the Caribbean: Biophysical, socio-economic, and environmental performance. Agricultural Systems 218: 103987. https://doi.org/10.1016/j.agsy.2024.103987	Latin America	Dairy

Table 4. Continue.

3	Oyinbo O, Hansson H. 2024. Information provision and preferences for more sustainable dairy farming: Choice experimental evidence from Sweden. Agricultural and Resource Economics Review 53 (1): 119–143. https://doi.org/10.1017/age.2023.33	Sweden	Dairy
4	Pavanello C, Franchini M, Bovolenta S, Marraccini E, Corazzin M. 2024. Sustainability Indicators for Dairy Cattle Farms in European Union Countries: A Systematic Literature Review. Sustainability 16 (10): 4214. https://doi.org/10.3390/su16104214	Europe	Dairy
5	Sánchez-Hidalgo M, Tadich T. 2024. Use of Delphi methodology to select sustainability indicators on dairy farms: an exploration of environmental, economic, social and animal welfare dimensions. Austral Journal of Veterinary Sciences 56 (2): 91–97. https://doi.org/10.4206/ajvs.562.05	Latin America	Dairy
6	Feil AA, do Amaral CC, Schreiber D, Maehler AE. 2023. Sustainability performance of small and medium dairy enterprises in Brazil. Sustainable Production and Consumption 39: 301–310. https://doi.org/10.1016/j.spc.2023.05.024	Brazil	Dairy
7	Lovarelli D, Leso L, Bonfanti M, Porto SMC, Barbari M, Guarino M. 2023. Climate change and socio-economic assessment of PLF in dairy farms: Three case studies. Science of the Total Environment 882: 163639. http://dx.doi.org/10.1016/j.scitotenv.2023.163639	Italy	Dairy
8	Robling H, Hatab AA, Säll S, Hansson H. 2023. Measuring sustainability at farm level –A critical view on data and indicators. Environmental and Sustainability Indicators 18: 100258. https://doi.org/10.1016/j.indic.2023.100258	Sweden	Dairy
9	Torres Jara de García GP, Durand-Chávez LM, Quispe-Ccasa HA, Linares-Rivera JL, Segura Portocarrero GT, Calderón TR, Vásquez Pérez HV, Maicelo Quintana JL, Ampuero Trigoso G, Robles Rodríguez RR *et al.* 2023. Sustainability of livestock farms: The case of the district of Moyobamba, Peru. Heliyon 9 (2): e13153. https://doi.org/10.1016/j.heliyon.2023.e13153	Peru	Dairy
10	Wilfart A, Baillet V, Balaine L, Díaz de Otálora X, Dragoni F, Krol DJ, Fratczak-Müller J, Rychla A, Rodriguez DGP, Breen J *et al.* 2023. DEXi-Dairy: an ex-post multicriteria tool to assess the sustainability of dairy production systems in various European regions. Agronomy for Sustainable Development 43 (6): 82. https://doi.org/10.1007/s13593-023-00935-3	Europe	Dairy
11	Zhu L, Schneider K, Lansink AO. 2023. Economic, environmental, and social inefficiency assessment of Dutch dairy farms based on the dynamic by-production model. European Journal of Operational Research 311 (3): 1134–1145. https://doi.org/10.1016/j.ejor.2023.05.032	Nederlands	Dairy

Table 4. Continue.

12	Zira S, Röös E, Rydhmer L, Hoffmann R. 2023. Sustainability assessment of economic, environmental and social impacts, feed-food competition and economic robustness of dairy and beef farming systems in South Western Europe. Sustainable Production and Consumption 36: 439–448. https://doi.org/10.1016/j.spc.2023.01.022	Europe	Dairy
13	Jiménez C, Marín K, Jácome E, López V, Larrea R. 2022. Indicadores para la evaluación de sustentabilidad de pequeños productores de leche de la provincia de Cotopaxi. Revista Recursos Naturales Producción y Sostenibilidad 1 (1): 50–60. http://190.15.139.149/index.php/RENPYS/article/download/487/584	Ecuador	Agriculture (adapted)
14	Iseppi L, Rosa F, Bassi I. 2022. A Multi-Criteria Decision approach for the sustainable dairy farm management. Quality-Access to Success 23 (191). 242–252. https://dx.doi.org/10.47750/QAS/23.191.29	Italy	Dairy
15	Zhu L, Lansink AO. 2022. Dynamic sustainable productivity growth of Dutch dairy farming. PLoS ONE 17 (2): e0264410. https://doi.org/10.1371/journal.pone.0264410	Nederlands	Dairy
16	Da Silva MF, Castro Moreira MV, Gameiro AH. 2021. Relationship between cost and sustainability indicators in milk farms. Custos e Agronegocio Online 17 (4): 358–388. http://www.custoseagronegocioonline.com.br/numero4v17/OK%2017%20sustentabilidade%20english.pdf	Brazil	Dairy
17	Díaz de Otálora X, Del Prado A, Dragoni F, Estellés F, Amon B. 2021. Evaluating three-pillar sustainability modelling approaches for dairy cattle production systems. Sustainability 13 (11): 6332. https://doi.org/10.3390/su13116332	Europe	Dairy
18	Torres-Lemus E, Martínez-García CG, Prospero-Bernal F, Arriaga-Jordán CM. 2021. On-farm assessment of the sustainability of small-scale dairy systems with three methods based on indicators. Tropical Animal Health and Production 53 (208): 1–17. https://doi.org/10.1007/s11250-021-02658-7	Mexico	Agriculture (adapted)
19	Novaira B, Gimenez G, Marini PR. 2021. Sustentabilidad asociada al traspaso generacional en un tambo. FAVE Sección Ciencias Veterinarias 20 (1): 50–58. https://doi.org/10.14409/favecv.v20i1.9768	Argentina	Dairy
20	Roesch A, Nyfeler-Brunner A, Gaillard G. 2021. Sustainability assessment of farms using SALCAsustain methodology. Sustainable Production and Consumption 27: 1392–1405. https://doi.org/10.1016/j.spc.2021.02.022	Switzerland	Agriculture (adapted)
21	Balaine L, Dillon EJ, Läpple D, Lynch J. 2020. Can technology help achieve sustainable intensification? Evidence from milk recording on Irish dairy farms. Land Use Policy 92: 104437. https://doi.org/10.1016/j.landusepol.2019.104437	Ireland	Dairy

Table 4. Continue.

22	Bánkuti FI, Prizon RC, Damasceno JC, De Brito MM, Pozza MSS, Lima PGL. 2020. Farmers' actions toward sustainability: A typology of dairy farms according to sustainability indicators. Animal 14 (S2): s417–s423. https://doi.org/10.1017/S1751731120000750	Brazil	Dairy
23	Rios GP, Botero S. 2020. An Integrated Indicator to Analyze Sustainability in Specialized Dairy Farms in Antioquia–Colombia. Sustainability 12 (22), 9595. http://dx.doi.org/10.3390/su12229595	Colombia	Dairy
24	Zanin A, Dal Magro CB, Kleinibing Bugalho D, Morlin F, Afonso P, Sztando A. 2020. Driving sustainability in dairy farming from a TBL perspective: Insights from a case study in the West Region of Santa Catarina, Brazil. Sustainability 12 (15): 6038. https://doi.org/10.3390/su12156038	Brazil	Dairy
25	Munyaneza C, Kurwijila LR, Mdoe NS, Baltenweck I, Twine EE. 2019. Identification of appropriate indicators for assessing sustainability of small-holder milk production systems in Tanzania. Sustainable Production and Consumption 19: 141–160. https://doi.org/10.1016/j.spc.2019.03.009	Tanzania	Dairy
26	Chen W, Holden NM. 2018. Tiered life cycle sustainability assessment applied to a grazing dairy farm. Journal of Cleaner Production 172: 1169–1179. https://doi.org/10.1016/j.jclepro.2017.10.264	Ireland	Dairy
27	Godoi MG, Bánkuti FI, Moreira M, Prizon RC, Kuwahara KC, Soares dos Santos M, Damasceno JC. 2018. Development and application of a sustainability assessment model for dairy production systems. Semina: Ciências Agrárias 39(6): 2685–2702. https://doi.10.5433/1679-0359.2018v39n6p2685	Brazil	Dairy
28	Kocjančič T, Debeljak M, Žgajnar J, Juvančič L. 2018. Incorporation of emergy into multiple-criteria decision analysis for sustainable and resilient structure of dairy farms in Slovenia. Agricultural Systems 164: 71–83. https://doi.org/10.1016/j.agsy.2018.03.005	Slovenia	Agriculture (adapted)
29	Micha E, Heanue K, Hyland JJ, Hennessy T, Dillon EJ, Buckley C. 2017. Sustainability levels in Irish dairy farming: a farm typology according to sustainable performance indicators. Studies in Agricultural Economics 119 (2): 62–69. http://dx.doi.org/10.7896/j.1706	Ireland	Dairy
30	Neves AP, Ríos-Osorio LA, Cassarino JP, Mayer PH. 2017. Propuesta metodológica para la caracterización socioecológica de unidades familiares de producción y vida en el campo. Revista Mexicana de Ciencias Agrícolas 8 (6): 1409–1426. https://doi.org/10.29312/remexca.v8i6.311	Brazil	Socioecology (adapted)

Table 4. Continue.

31	De Olde EM, Oudshoorn FW, Sørensen CA, Bokkers EA, de Boer IJ. 2016. Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice. Ecological Indicators 66: 391–404. http://dx.doi.org/10.1016/j.ecolind.2016.01.047	Denmark	Agriculture (adapted)
32	Chand P, Sirohi S, Sirohi SK. 2015. Development and application of an integrated sustainability index for small-holder dairy farms in Rajasthan, India. Ecological Indicators 56: 23–30. http://dx.doi.org/10.1016/j.ecolind.2015.03.020	India	Dairy
33	Van Asselt ED, Capuano E, Van der Fels-Klerx, HJ 2015. Sustainability of milk production in the Netherlands –A comparison between raw organic, pasteurized organic and conventional milk. International Dairy Journal 47: 19–26. http://dx.doi.org/10.1016/j.idairyj.2015.02.007	Nederlands	Dairy
34	Vargas JC, Benítez D, Torres V, Ríos S, Soria S. 2015. Factors determining the efficiency of milk production in systems of double purpose in Pastaza province, Ecuador. Cuban Journal of Agricultural Science, 49(1): 17–21. http://scielo.sld.cu/pdf/cjas/v49n1/cjas03115.pdf	Ecuador	Dairy
35	Salas-Reyes IG, Arriaga-Jordán CM, Rebollar-Rebollar S, García-Martínez A, Albarrán-Portillo B. 2015. Assessment of the sustainability of dual-purpose farms by the IDEA method in the subtropical area of central Mexico. Tropical Animal Health and Production 47 (6): 1187–1194. https://doi.org/10.1007/s11250-015-0846-z	Mexico	Agriculture (adapted)
36	Elsaesser M, Jilg T, Herrmann K, Boonen J, Debruyne L, Laidlaw AS, Aarts F. 2014. Quantifying sustainability of dairy farms with the DAIRYMAN sustainability-index. Grassland Science in Europe 20: 367–376. https://www.europeangrassland.org/fileadmin/documents/Infos/Printed_Matter/Proceedings/EGF2015.pdf#page=386	Germany	Dairy
37	Buys L, Mengersen K, Johnson S, Van Buuren N, Chauvin A. 2014. Creating a *Sustainability Scorecard* as a predictive tool for measuring the complex social, economic and environmental impacts of industries, a case study: Assessing the viability and sustainability of the dairy industry. Journal of Environmental Management 133: 184–192. http://dx.doi.org/10.1016/j.jenvman.2013.12.013	Australia	Industry (adapted)
38	Dolman MA, Sonneveld MPW, Mollenhorst H, de Boer IJM. 2014. Benchmarking the economic, environmental and societal performance of Dutch dairy farms aiming at internal recycling of nutrients. Journal of Cleaner Production 73: 245–252. http://dx.doi.org/10.1016/j.jclepro.2014.02.043	Nederlands	Dairy
39	Jaklič T, Juvančič L, Kavčič S, Debeljak M. 2014. Complementarity of socio-economic and emergy evaluation of agricultural production systems: The case of Slovenian dairy sector. Ecological Economics 107: 469–481. http://dx.doi.org/10.1016/j.ecolecon.2014.09.024	Slovenia	Agriculture (adapted)

Table 4. Continue.

40	Rodríguez I, Torres V, Martínez O, Orta LD. 2014. Evaluación técnica, socioeconómica y medioambiental de una empresa genética de Mayabeque, Cuba, mediante el modelo estadístico de medición de impacto (MEMI). Revista Cubana de Ciencia Agrícola 48 (3): 219–226. https://www.redalyc.org/articulo.oa?id=193032133003	Cuba	Dairy
41	Acosta-Alba I, Lopéz-Ridaura S, van der Werf HM, Leterme P, Corson MS. 2012. Exploring sustainable farming scenarios at a regional scale: an application to dairy farms in Brittany. Journal of Cleaner Production 28: 160–167. http://dx.doi.org/10.1016/j.jclepro.2011.11.061	France	Dairy
42	Binder CR, Schmid A, Steinberger JK. 2012. Sustainability solution space of the Swiss milk value added chain. Ecological Economics 83: 210–220. https://doi.org/10.1016/j.ecolecon.2012.06.022	Switzerland	Industry (adapted)
43	Meul M, Van Passel S, Fremaut D, Haesaert G. 2012. Higher sustainability performance of intensive grazing versus zero-grazing dairy systems. Agronomy for Sustainable Development 32: 629–638. https://doi.org/10.1007/s13593-011-0074-5	Belgium	Agriculture (adapted)
44	Oudshoorn FW, Kristensen T, Van Der Zijpp AJ, de Boer IJM. 2012. Sustainability evaluation of automatic and conventional milking systems on organic dairy farms in Denmark. NJAS-Wageningen Journal of Life Sciences 59 (1–2): 25–33. https://doi.org/10.1016/j.njas.2011.05.003	Denmark	Dairy
45	Arias-Reverón J, Calvo C, Chaves N, Granados MDM, Hernández JR, Uribe-Lorío L, WingChing-Jones R. 2012. Uso de indicadores para determinar la sostenibilidad de tres proyectos productivos de universidades en Costa Rica. UNED Research Journal 4 (2): 203–212. https://doi.org/10.22458/urj.v4i2.9	Costa Rica	Dairy
46	Bélanger V, Vanasse A, Parent D, Allard G, Pellerin D. 2012. Development of agri-environmental indicators to assess dairy farm sustainability in Quebec, Eastern Canada. Ecological Indicators 23: 421–430. https://doi.org/10.1016/j.ecolind.2012.04.027	Canada	Dairy
47	Tommasino H, García Ferreira R, Marzaroli R, Gutiérrez R. 2012. Indicadores de sustentabilidad para la producción lechera familiar en Uruguay: análisis de tres casos. Agrociencia Uruguay 16 (1): 166–176. https://doi.org/10.31285/agro.16.583	Uruguay	Dairy
48	Kuosmanen T, Kuosmanen N. 2009. Role of benchmark technology in sustainable value analysis. An application to Finnish dairy farms. Agricultural and Food Science 18: 302–316. https://doi.org/10.23986/afsci.5953	Finland	Industry (adapted)

Table 4. Continue.

49	Vayssières J, Guerrin F, Paillat JM, Lecomte P. 2009. GAMEDE: A global activity model for evaluating the sustainability of dairy enterprises Part I–Whole-farm dynamic model. Agricultural Systems 101 (3): 128–138. https://doi.org/10.1016/j.agsy.2009.05.001	France	Dairy
50	Vayssières J, Bocquier F, Lecomte P. 2009. GAMEDE: A global activity model for evaluating the sustainability of dairy enterprises. Part II – Interactive simulation of various management strategies with diverse stakeholders. Agricultural Systems 101(3): 139–151. https://doi.org/10.1016/j.agsy.2009.05.006	France	Dairy
51	Del Prado A, Scholefield D. 2008. Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. The Journal of Agricultural Science 146 (2): 195–211. https://doi.org/10.1017/S0021859608007727	United Kingdom	Dairy
52	Meul M, Van Passel S, Nevens S, Dessein J, Rogge E, Mulier A, Van Hauwermeiren A. 2008. MOTIFS: a monitoring tool for integrated farm sustainability. Agronomy for Sustainable Development 28 (2): 321–332. https://doi.org/10.1051/agro:2008001	Belgium	Agriculture (adapted)
53	Parra-López C, Groot JCJ, Carmona-Torres C, Rossing WAH. 2008. Integrating public demands into model-based design for multifunctional agriculture: An application to intensive Dutch dairy landscapes. Ecological Economics 67 (4): 538–551. http://dx.doi.org/10.1016/j.ecolecon.2008.01.007	Nederlands	Agriculture (adapted)
54	Van Calker KJ, Berentsen PBM, Giesen GWJ, Huirne RBM. 2008. Maximising sustainability of Dutch dairy farming systems for different stakeholders: A modelling approach. Ecological Economics 65 (2): 407–419. https://doi.org/10.1016/j.ecolecon.2007.07.010	Nederlands	Dairy
55	Kirner L, Kratochvil R. 2006. The role of farm size in the sustainability of dairy farming in Austria: An empirical approach based on farm accounting data. Journal of Sustainable Agriculture 28 (4): 105–124. https://doi.org/10.1300/J064v28n04_09	Austria	Dairy
56	Hernández Valenzuela D, Herrera Haro JG, Pérez Pérez J, Vázquez Agustín S. 2006. Índice de sustentabilidad para el sistema bovino de doble propósito, en Guerrero, México. REDVET. Revista Electrónica de Veterinaria 7 (9): 1–11. https://www.redalyc.org/articulo.oa?id=63612675002	Mexico	Agriculture (adapted)

At this point, it is worth highlighting the relevance of tools adapted and contextualized to local needs. As interest in sustainability assessment began to rise, most proposed methodologies approached evaluation as a linear process —a straightforward, step-by-step progression that assumes a direct relationship between actions and outcomes. However, these methodologies often lacked a solid foundation for deriving meaningful and appropriate indicators, limiting their ability to address the complex and interconnected nature of sustainability. Emphasis was placed in the obtention of a final rating among the technological and management options, instead of exploring a change in management practices or venturing in joint analysis which might include the local producers (Astier *et al., 2008)*. Top-bottom designs, in which the tools are developed by people not directly involved in the productive process (academic, technical or political experts), yield very different priorities than those that result when stakeholders are given the opportunity to participate in this design process. In this case, there is a risk that the priorities of the stakeholders may lead to a bias in the design of the methodology, as the perception of the farmers, who may not be aware of the environmental impact issues, may differ from the environmental aspects considered as precise indicators of sustainability. Or, conversely, when actors not closely related to the farm and its context make decisions about processes with which they are unfamiliar. Munyaneza *et al.* (2019), comparing the indicators resulting from top-bottom and bottom-up design processes, for the specific case of Tanzania, reports that *'in the list of environmental indicators, some were noticeable by their absence. Indicators considered relevant in other studies, such as greenhouse gas emissions and manure use were rejected by the respondents as not relevant in this study context. This could be explained by the subsistence nature of the studied milk production systems, where economic indicators are more relevant to stakeholders than environmental indicators.'* The plain quotation is relevant, since such is the case in poor or underdeveloped countries, where producers are primarily concerned with survival over any other priority. In this regard, it's worth mentioning successful experiences where the involvement of small farmers in rural areas has been essential to achieving successful results in developing alternatives for natural resource management. (Astier *et al.,* 2012; García-Barrios and González-Espinosa, 2017)

De Olde *et al.* (2017) adds to this debate, by delineating a framework to assess the choices involved in the development of a sustainability assessment tool and question their implications in such development, as well as the influence of personal context, values, assumptions and understandings. In the absence of a general agreement in this regard, the debate on the definition of *sustainability* remains open, leading to the coexistence of a wide variety of positions on the subject. Most of authors who reflect on the issue of sustainability acknowledge the fact that the concept is broad and requires a broad consensus as well. Paradoxically, the next common step in this process is for each author to add his or her own preferred definitions, which in turn contributes to the lack of consensus (Bell and Morse, 2008) and the iteration of this loop. In order to clarify some basic points, the following subsections elaborate on the discussion of the three dimensions of sustainability.

Environmental sustainability

In its original form, sustainability was closely associated to maintaining environmental quality (Bell and Morse, 2008), however since the introduction of the definition by the WCED (1987) the concept widened to include economic and social welfare as well. Environmental sustainability is largely associated with two different mainstreams: environmental impacts and ecosystem services. Livestock farming has a high degree of responsibility in the environmental impact of human activities and is the cause of a large part of the world's greenhouse gas emissions (Steinfeld *et al.*, 2006; Arvidsson *et al.*, 2020; De Olde *et al.*, 2016). Measurement of this type of impact, as well as others like acidification and eutrophication, is usually performed with Life Cycle Assessment (LCA) methodologies, the normal standard worldwide for this type of evaluation.

Application of LCA methods is particularly well suited to account for interactions among livestock systems, the environment, and on-farm management decisions, through integrated modelling approaches, more or less complex, depending on the scope of the analysis. On the other hand, biophysical tools are not best suited for adequately capturing social and economic sustainability issues, because they employ different valuation perspectives (Gasparatos and Scolobig, 2012). The assessment of the environmental dimension entails another type of difficulty, due to the diversity of production systems on the planet, their heterogeneity, and the difficulty involved in their quantification (Chopin *et al.*, 2021). Under current methodologies, environmental attributes such as biodiversity are still far from reaching the level of importance that they deserve as a global priority. Only a handful of the articles reviewed considered take biodiversity into account as a theme or indicator, and mostly in a shallow manner. The same undervaluation also applies to ecosystem services, which are essential to life and thus key indicators for an adequate representation of sustainability.

A broader criteria approach is crucial for developing an appropriate policy framework towards sustainable agriculture. Several authors point out that the actions at farm level are negligible, so to achieve significant improvements towards long-term sustainability the mainstream economic system needs to be redesigned (Costanza *et al.*, 2014; Nadal, 2011). Keeping yields high enough to sustain economic benefits often delivers results not in line with environmental targets. Consequently, questions raise regarding whether sustainable farming should be rewarded as an ecosystem service or whether the environmental targets defined today are feasible for the dairy sector. An analysis of global livestock production systems shows that in the future, within the context of a carbon-constrained economy and strong competition for natural resources, particularly land and water, livestock intensity might be severely affected. For instance, the demand for animal foods may be diminished by environmental and socioeconomic factors, such as concerns about human health, green production systems, and changes in socio-cultural values. Societal values and goals also make a difference, which largely depend on local contexts. For instance, in some developed economies, food production may not be a major social issue since self-sufficiency guarantees the national supply. But in contrast, keeping the viability of rural regions,

a goal closely linked to sustainable agriculture and forestry, is a hot social topic and thus appears reflected in agricultural policy measures (Mann and Gazzarin, 2004).

Social sustainability

Although the integration of the social dimension into the definition of sustainability has progressed, the proliferation of social sustainability concepts has led to a problem on which most authors agree: there is no homogeneity in this matter (Janker *et al.*, 2019). Criticism of the previous neglect of the social dimension in the concept of sustainability has led to increased attention to this aspect. However, this progress is not yet sufficient to develop a consistent understanding of what the social dimension actually means. Littig and Griessler (2005) put it in these words: *'social sustainability appears to be more a catchword of politicians than a well-developed concept'.*

The need for a common understanding of the social dimension of sustainability in agriculture is evolving into a new paradigm for social sustainability: sustainable development must be socially inclusive, equitable and participatory, with equity for marginalized segments. These concerns should be taken into account when considering the long-term sustainability of agricultural systems, but their practical boundaries are currently a matter of contextual definition: they shift according to the origin of the study and the interests of the researcher. Although there may be conceptual agreement, the operationalization of social sustainability assessment differs, and it is possible to observe two clearly defined lines: a) developed countries (mainly Europe) and b) developing countries (Latin America, Africa and Asia).

Social acceptance of a production system implies that it must be integrated into its social-cultural context, be respectful of people and animals, and contribute to equitable management of resources. This social pillar is related to the search for a more equitable distribution of profit, in a manner that favors social inclusion, a dignified life, and generalized access to resources and social services, to improve rights and reduce the differences between the living standards of the population, particularly in minorities and discriminated sectors.

While the debate continues, the assessment of social sustainability is currently based on indicators such as social welfare, employment, marginalization, income distribution, social "bads" (work-related illness, accidents, safety), and even animal welfare and milk quality, both of which are considered social demands and therefore included by several authors as indicators of social sustainability. A common problem in underdeveloped areas of the world is the low educational level of farmers. It constitutes a barrier to driving changes and evaluating productive systems. In such cases, economic urgency obscures the underlying social problem and prevails in the eyes of farmers as the main dimension of sustainability (Munyaneza *et al*., 2019).

In developed countries, the assessment of social sustainability is also strongly associated with labor conditions (de Olde *et al.*, 2016). In certain contexts, the assessment of social sustainability allows the addressing of potential problems related to insufficient income that can lead to the financial dependence of farmers on economic schemes as state

subsidies, which may represent an important source of income for primary producers. In such countries, labor efficiency is a relevant indicator of social sustainability. The social contribution of the production system is signified by the labor indicator, which corresponds to the amount of employment in farms. However, employment is an ambiguous category: it can be assigned to both the social and economic dimensions of sustainability.

In contrast, in many developing countries, dairy production units are mostly managed by family labor, in many cases with predominantly female labor, as in India (Chand *et al.*, 2015). For Mann and Gazzarin (2004), when family interests predominate in a dairy enterprise, the owners' revenue turns into a social indicator, since maintaining a sufficient income is one of the main conditions allowing farms to continue to operate and thereby fulfill a social function: that of supplying dairy products to urban consumers.

The profit or income from family labor is therefore considered a social attribute. This indicator, in per capita terms, can be related to average consumption in rural areas: the higher the per capita income in relation to consumption, the greater the social sustainability of the enterprise. Gender equality has become an important attribute of the social dimension of sustainability since, in some areas, women work equally in the family dairy enterprise. Another important indicator of social sustainability in developing countries is the harshness of the work, i.e., the conditions under which it is carried out, particularly in the case of physical labor (Chand *et al.*, 2015).

It is important to emphasize that, under this perspective, family production units are more than a profitable enterprise: they are a livelihood, both social and ecological, for families in the agrarian space. For this reason, there are other processes –besides the productive process– that must be integrated into the conception of family production units as socioecological systems, such as the collective reflection on sustainability problems, the socioecological description of complex agricultural systems, and understanding their socio-ecological resilience in order to collaborate in decisions towards sustainability (Neves *et al.*, 2017). In general terms, this social dimension is related to the continued satisfaction of basic human needs such as food, shelter and socialization, as well as the right to culture, security, justice, freedom, education, employment and recreation.

Economic sustainability

The depletion of essential resources is a clear sign that the global economic system, as it is currently configured, is causing serious damage to the planetary ecosystems (Nadal, 2011; Costanza *et al.*, 2014). From a theoretical perspective, economic sustainability can be considered in two ways: The first focuses on the sustainable use of natural resources, which implies that economic sustainability is achieved when economic activity is not conducted at the expense of natural resource depletion This concept corresponds to the principle of "strong" sustainability (Giddings *et al.*, 2002). The second focuses on the growth of the economic system in terms of gross domestic product, which implies

the substitutability of the different forms of capital. This latter principle corresponds to the concept of "weak" sustainability, originally derived from the WCED report (WCED, 1987).

In order to assess the economic performance of production units, the common practice in all of the studies reviewed is to resort to the use of financial-accounting indicators, which focus on providing monetary information, since the survival of the productive system itself depends on its financial viability (Arvidsson *et al.*, 2020). Such indicators of financial performance and technological efficiency of the farms are the most commonly used, although some studies have integrated not mainstream socioeconomic concepts such as *Sustainable Value* (Kousmanen and Kuosmanen, 2009) and *Net Social Benefit* (Parra-López *et al.*, 2007). Both of these concepts focus on the creation of economic value for society as a whole, based on a more or less efficient use of the resources available for productive activity, and are valued in monetary terms. This is practical in the case of marketable goods but has its drawbacks in the valuation of benefits that do not have a clear market value (e.g. habitat quality and biodiversity), which are instead valued using other *ad-hoc* methods.

Indicators selection

Of the three dimensions, the economic appears as the most clearly defined, since it is based on widely used indicators that can be easily expressed in a common quantitative term –monetary– while the social dimension is undoubtedly the one with the most diffuse characterization since the indicators used are less consistent, due to the lack of a common currency, such as monetary in the case of the economic dimension or biophysical in the case of the environmental dimension. In some studies, social indicators are reduced to labor indicators, while others include more variety, such as social welfare, property, food security, education, quality of life, social organization and participation, landscape heritage, and intergenerational transfer. For the attribute of animal welfare, which is a societal demand, some studies oversimplify its assessment to a single biophysical indicator –the somatic cell count in milk.

Within the set of indicators selected to evaluate sustainability, certain cases appear in two or even three dimensions, i.e., they are assigned to one or the other criterion at the author's discretion. For example, animal welfare, milk quality and dependence on subsidies appear in all three dimensions, although the first two of them only reach a significant level in the social dimension, and subsidies tilt towards the economic dimension. In the case of the environmental dimension, greenhouse gases (GHG) are the most recurrent indicator, followed closely by energy consumption. The low incidence of assessment of ecosystem services as environmental variables is notable. This can be partly explained by the type of papers selected for analysis, as well as the complexity inherent to the assessment.

CONCLUSIONS

The systematized literature search identified 56 articles addressing the topic of sustainability assessment in dairy production from the perspective of its three dimensions. This set of studies provides a useful picture of the state of knowledge on the subject, from which several aspects can be highlighted. First, the fact that a great variety of dairy production systems coexisting on the planet greatly complicates the task of designing a "universal" application method. This leads to the development of field research in various directions, in which the local interest of the researcher is often the determining factor. Measuring sustainability is a task with a high degree of intrinsic complexity, and the variety of possible techniques and approaches to the problem act to further complicate the task.

As a result of this review, it has been possible to identify several priority areas of opportunity for the future in this field. First, there is a notorious lack of homogeneity in the definition of the dimensions of sustainability. It seems clear that this is a contextual problem, i.e. one that may have different solutions depending on the particular conditions of each region or production system. It is also clear that there is no common path or established methodology for selecting indicators. Given the large number of possible indicators, in the range of hundreds, it seems necessary to have a standardized methodology or protocol to identify those that are most appropriate in a given context. As mentioned in the previous paragraph, this is a problem that requires local solutions.

As a consequence of the above points, it is not surprising that a wide range of evaluation methodologies is available. Selecting the most appropriate one in a given context becomes a challenge that requires solutions that have not yet been fully developed. The creation of a methodology adapted to the conditions of family systems in developing countries is a field that deserves to be explored in the future.

Much of the literature reviewed coincides in highlighting the lack of tools and standardized methodologies to carry out an integrated evaluation that measures the potential impacts, both positive and negative (trade-offs), that strategies employed in one dimension can have on the others. One of the major problems to be solved lies precisely in this fact; methodologies for the selection, collection, and analysis of indicators suitable for evaluating dairy farms are still multiple and temporally and spatially specific, making it difficult to establish relationships and connections between the results of one or another study. The catalog of proposals has been increasing, particularly in the last 15 years however, no consensus has been reached in establishing uniform conceptions of sustainability which allow to monitor the state of dairy systems, in a way that adapts to the specific characteristics of each region. As shown in this review, the multiplicity of conceptions suggests that the sustainability assessment of dairy farms is more an emerging field than a neatly defined issue. This is a rather complex issue, which correlates the state of the environment, production factors, technology, scarce resources availability and societal priorities as key drivers.

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Rickettsia OCCURRENCE IN COMMERCIAL PAPAYA (*Carica papaya* L.) PLANTATIONS WITH BUNCHY TOP DISEASE IN COLIMA, MEXICO

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ABSTRACT

Phytoplasmas, viruses, and rickettsiae (*Rickettsia* spp.) are the etiological agents of the bunchy top disease (BT) in papaya (*Carica papaya* L.) in several Caribbean countries. In Mexico, phytoplasmas have been reported in papaya plants with BT-like symptoms, but the incidence of *Rickettsia* is unknown. Considering that *Rickettsia* is associated with BT in other countries, it was hypothesized that these bacteria are also present in Colima, Mexico, where this disease is a phytosanitary concern. The objective of this work was to determine the incidence of *Rickettsia* in commercial papaya plantations with BT, as well as weeds and insects related to this crop in Colima. Using polymerase chain reaction (PCR) and sequencing of the rickettsial-specific flavoprotein subunit of the succinate dehydrogenase (*sdh*A) gene, 28 % (54 out of 192) symptomatic and 23.43 % (15 out of 64) asymptomatic papaya samples, as well as 9.77 % (17 out of 174) and 5.95 % (11 out of 185) weeds and insect morphospecies, respectively, tested positive for *Rickettsia*. The presence of *R. bellii* in *sdh*A-positive samples was confirmed by PCR with *R. bellii*-specific primers, sequencing and phylogenetic analysis of the citrate synthase (*glt*A) gene in 5.79 % of symptomatic papaya plants, 82.35 % of weeds, and 45.45 % of insects. Weeds positive for *R. bellii* were *Amaranthus palmeri* S. Watson, *Euphorbia hirta* L., *E. hyssopifolia* L., *Anoda cristata* (L.) Schltdl., *Zinnia maritima* Kunth, *Parthenium hysterophorus* L., *Echinochloa colona* (L.) Link., and *Richardia scabra* L. Insects positive for *R. bellii* were *Balclutha mexicana* Blocker (Hemiptera: Cicadellidae) and *Chlorotettix emarginatus* Baker (Hemiptera: Cicadellidae). This is the first time that *Rickettsia* species have been reported in commercial papaya plantations with BT in Mexico.

Keywords: *Rickettsia*, *sdh*A gene, *glt*A gene, bunchy top disease.

INTRODUCTION

Papaya (*Carica papaya* L.) is the most economically important plant species in the Caricaceae family. It is cultivated in 64 countries around the world, with Mexico being the third major producer and the main supplier to the US and Canadian markets (FAO, 2020; SIAP, 2020). Papaya production in Mexico is concentrated in the south-southeast and central-occident regions, where Oaxaca, Colima, and Chiapas are the top producer states (SIAP, 2020). In Mexico, several viruses and species of *Colletotrichum* limit the papaya industry, but recently, the bunchy top disease (BT) has emerged as an important phytosanitary concern, particularly in producing areas of Colima.

Cook (1931) was the first to report the BT, which has since become of economic importance in the Dominican Republic, Cuba, Haiti, Jamaica, and Puerto Rico (Martorell and Adsuar, 1952; Arocha *et al*., 2003; Luis-Pantoja *et al*., 2015). BT-affected papaya plants exhibit a typical shortening of internodes of apical younger leaves, resulting in a 'bunchy' appearance. Affected leaves display yellowing, crinkling, chlorosis, mottling, mosaic, and/or marginal necrosis and curved petioles (Story and Halliwell, 1969; Acosta *et al*., 2013). Etiological agents of BT include viruses (Bird and Adsuar, 1952) and phytoplasmas (Story and Halliwell, 1969). Later, it was confirmed that bacteria of the genus *Rickettsia* were present in papaya plants with BT in Costa Rica, Puerto Rico (Davis *et al*., 1998), and Cuba (Arocha *et al*., 2003; Luis-Pantoja *et al*., 2015).

Rickettsia is the causal agent of several important human diseases, but its occurrence in commercial crop plantations is little known. In addition to papaya, *Rickettsia* has only been associated with strawberry (*Fragaria* × *ananassa* Dutch.) asymptomatic plants or showing lethal yellows disease in Australia (Streten *et al*., 2005). Caspi-Fluger *et al*. (2012) stated that cotton (*Gossypium hirsutum* L.), basil (*Ocimum basilicum* L.), and black nightshade (*Solanum nigrum* L.) can be infected with *Rickettsia* under controlled conditions by viruliferous whiteflies (*Bemisia tabaci* Genn.). Among arthropods (mites, ticks, and insects), *Rickettsia* appears to be a common endosymbiont (Caspi-Fluger *et al*., 2012; Ishii *et al*., 2013), indicating that these animals are natural hosts for these bacteria. Transmission into plants has only been proved successfully for papaya leafhopper (*Empoasca papayae* Oman) (Acosta *et al*., 2017) and whitefly (Caspi-Fluger *et al*., 2012; Shi *et al*., 2021).

Considering that phytoplasmas have only been detected in papaya plants exhibiting BT-like symptoms in Mexico (Poghosyan *et al*., 2004; Rojas-Martínez *et al*., 2011) and that *Rickettsia* is associated with BT in other countries (Davis *et al*., 1998; Arocha *et al*., 2003), it was hypothesized that these bacteria are also involved in commercial papaya plantations with BT and that it is present in papaya-associated weeds and insects. Therefore, this study aims to determine the occurrence of *Rickettsia* species in commercial papaya plantations with BT incidence, as well as in weeds and insects associated with this crop in Colima, Mexico.

MATERIALS AND METHODS

Biological sampling

In November and December 2019, foliar samples were collected from 64 commercial papaya plantations in Tecomán, Colima, Ixtlahuacán, and Armería municipalities, which have the largest cultivated area of papaya in the state of Colima, Mexico (Figure 1). The samples showed dieback or apical leaves with shortening of internodes, yellowing, chlorosis, marginal necrosis, and curved petioles, indicating BT (Story and Halliwell, 1969; Acosta *et al*., 2013).

During sampling in each plantation, the leaf blade and petiole of four papaya plants (three symptomatic and one asymptomatic) were collected. Furthermore, 174 weeds (the three most frequent species) located within a one-meter radius of the sampled papaya plants, as well as 185 insect morphospecies, were collected from either papaya or weeds. Insects were captured using beating entomological nets and preserved in 96 % ethanol at room temperature until further analysis.

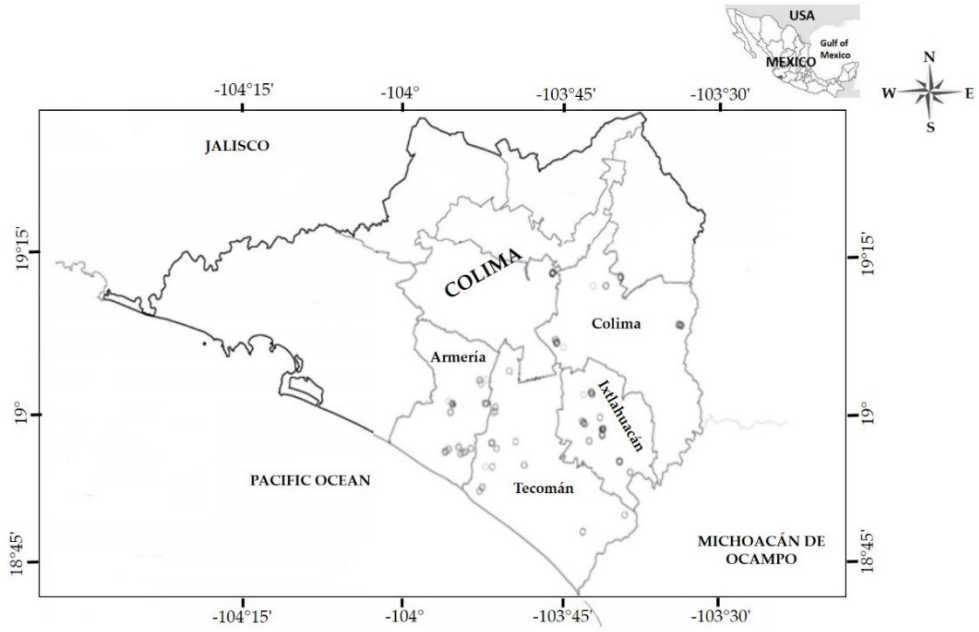

Figure 1. Geographic map of Colima, Mexico. In 2019, papaya plants (*Carica papaya* L.), weeds, and insects with asymptomatic and bunchy top disease were gathered from Tecomán, Colima, Ixtlahuacán, and Armería municipalities in Colima, Mexico. Circles denote collection points in each municipality.

DNA isolation and quality validation

DNA was extracted from 10 g of fresh tissue consisting of midribs and petioles from papaya and weed leaves following the protocol described by Ahrens and Seemüller (1992). Insect DNA was extracted from 1 to 5 specimens of each morphospecies using the method described by Stillson and Szendrei (2020). Plant and insect DNA quality was evaluated by PCR amplification of the chloroplast ribosomal protein S16 gene (*rps16*) (Oxelman *et al*., 1997) or mitochondrial cytochrome c oxidase subunit I gene (*COI*) (Folmer *et al*., 1994), respectively.

Rickettsia spp. identification

Rickettsia in papaya, weeds, and insects was detected by PCR amplification of a 705-bp fragment of the rickettsial-specific flavoprotein subunit of the succinate dehydrogenase gene (*sdh*A) with primers PBTF1/PBTR1 (Davis *et al*., 1998). A clone of the *Rickettsia sdh*A gene in pGEM-T Easy vector (Promega, USA), provided by the National Phytosanitary Reference Center, was used as a positive control. DNA extracted from *Rickettsia*-free papaya leaves (confirmed as negative by PCR for the *sdh*A gene) was used as negative control. Amplicons of three positive papaya samples were purified with the Wizard SV Gel and PCR Clean-Up System (Promega, USA), according to the manufacturer's instructions, and sequenced at Macrogen Inc. (Seoul, South Korea). The resulting sequences were analyzed with the MEGA X program (Kumar *et al*., 2018) and the BLASTn function of the National Center for Biotechnology Information (NCBI) (https://blast.ncbi.nlm.nih.gov/Blast.cgi) and registered at the GenBank (NCBI). The obtained sequences (Accession numbers MT103330–MT103332) were similar to *R. bellii sdh*A gene isolates.

To verify whether all positive samples that were amplified for the *sdh*A gene belonged to the *R. bellii* species, PCR reactions with *R. bellii*-specific primers [which amplify a 338-bp fragment of the citrate synthase gene (*glt*A)] (Szabó *et al*., 2013) were carried out. Additionally, the *glt*A sequences of three randomly selected samples (one for each papaya, weeds, or insects) were sequenced at Macrogen Inc. (Seoul, South Korea), registered at the GenBank, and used for phylogenetic inference analysis utilizing the neighbor-joining method with 1000 bootstrap replicates using MEGA X (Kumar *et al*., 2018), as well as the *glt*A gene sequences of other *Rickettsia* species (Table 1).

Weeds and insects positive for *R. bellii* were further identified at the species level by Carlos L. Leopardi-Verde (Colima University, Mexico) and Edith Blanco-Rodríguez (Postgraduate College, Mexico).

RESULTS AND DISCUSSION

Rickettsia was shown to be associated with BT in Colima, Mexico, by evaluating two different rickettsial-specific genes (*sdh*A and *glt*A) in DNA matrices from papaya and papaya-associated weeds and insects. The *Rickettsia sdh*A was detected in 54 out of 192

Table 1. *Rickettsia* spp. *glt*A gene sequences used for phylogenetic analysis.

Species	Origin	Host source	GenBank accession number
R. tarasevichiae	Russia	*Ixodes persulcatus* Schulze	AM418460
R. Helvetica	Russia	*I. persulcatus*	AM418450
R. Helvetica	Italy	*I. ricinus* L.	AJ427878
R. tamurae	Japan	Ticks	AB114796
R. conorii	Russia	*Homo sapiens* L.	MT667397
R. prowazekii	Spain	*H. sapiens*	U14334
R. aeschlimannii	Russia	*H. sapiens*	MT667402
R. sibirica	Russia	*H. sapiens*	MT667386
R. typhi	USA	*H. sapiens*	U20245
R. rickettsia	Panama	*H. sapiens*	MT814706
R. rickettsia	Brazil	*H. sapiens*	MF988097
R. felis	Taiwan	*Ctenocephalides felis* Bouche	U33922
R. canadensis	Russia	*Haemaphysalis japonica* Warburton	MG545038
R. akari	Taiwan	*C. felis*	U41752
R. akari	Taiwan	*I. granulatus* Supino	MT847612
R. bellii	Argentina	*I. loricatus* Neumann	MT407576
R. bellii	Brazil	*Amblyomma dubitatum* Neumann	MW293870
R. bellii	Mexico	*Carica papaya* L. (this study)	ON303294
R. bellii	Mexico	*Euphorbia hyssopifolia* L. (this study)	ON303295
R. bellii	Mexico	*Balclutha mexicana* Blocker (this study)	ON303296

papaya plants (28.12 %) with shortened apical leaf internodes. These plants showed chlorosis, yellowing, and marginal necrosis (Figure 2A and 2B). Detection of this gene also occurred in asymptomatic papaya plants (15 out of 64, 23.43 %), papaya-associated weeds (17 out of 174, 9.77 %), and insects (11 out of 185, 5.95 %) (Table 2). Intriguingly, these results on *Rickettsia* detection in papaya differ from those reported by Davis *et al*. (1998), Acosta *et al*. (2013), and Luis-Pantoja *et al*. (2015), who found, respectively, 100, 100, and 95 % incidence of *Rickettsia* (*sdh*A gene) in BT-diseased plants from Costa Rica, Puerto Rico, and Cuba but did not register *Rickettsia* DNA in asymptomatic plants. A possible explanation for this could consider that other pathogens, such as phytoplasmas or viruses, which are known etiological agents of BT (Bird and Adsuar, 1952; Story and Halliwell, 1969), are responsible for the symptoms. However, a low detection percentage of the *Rickettsia sdh*A gene was also reported in strawberry plants with lethal yellows disease in Australia, since only 32.23 % of evaluated symptomatic samples tested positive (Streten *et al*., 2005). Another plausible explanation is that *Rickettsia* cells were present in lower numbers given their short lifespan inside plant tissues, which has been reported as two weeks in cotton under artificial inoculation conditions (Shi *et al*., 2021), but is unknown for papaya or other plants. This could result in insufficient *Rickettsia* DNA to be detected using molecular techniques.

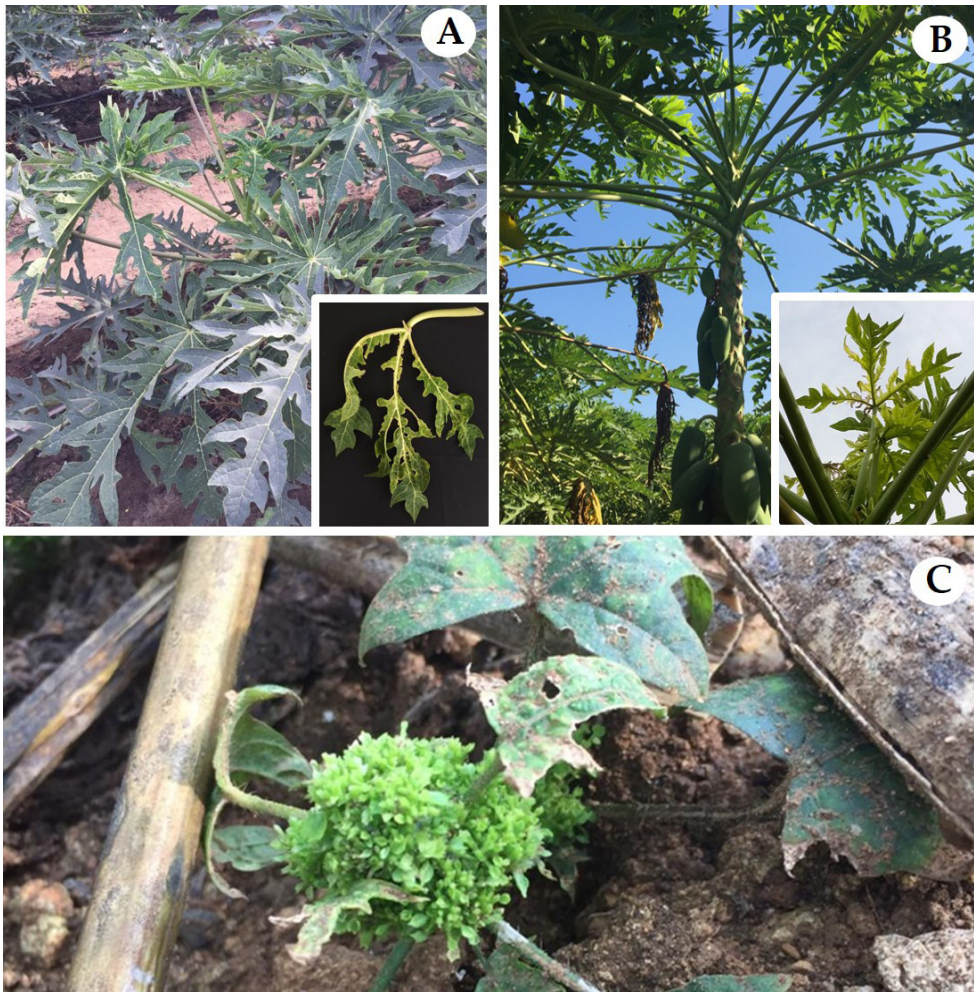

Figure 2. Papaya plants and papaya-associated weeds in Colima, Mexico, exhibiting symptoms associated with *Rickettsia bellii*. A and B: *Carica papaya* L. plants with shortened apical leaf internodes, giving a bunchy appearance, showing chlorosis, yellowing, and marginal necrosis; C: *Anoda cristata* (L.) Schltdl. with vegetative proliferation.

The positive detection of *Rickettsia sdh*A gene in asymptomatic papaya and weed samples can be explained by the fact that these bacteria induce a symptomless phenotype in cotton, basil, and black nightshade plants after its artificial inoculation with viruliferous whiteflies (Caspi-Fluger *et al*., 2012), and further justified positive results reported for asymptomatic strawberry plants in Australia (Streten *et al*., 2005). The similarity between the percentage detection in asymptomatic and symptomatic papaya samples in the present research may also be explained by this observation. Lower *Rickettsia* detection in papaya-associated insects clearly indicates that this bacterium has a limited host range and natural occurrence as an endosymbiont.

Table 2. *Rickettsia* occurrence in commercial papaya (*Carica papaya* L.) plantations with bunchy top disease in Colima, Mexico.

Municipality	Positive samples for *Rickettsia* from the total number of examined samples				Positive samples for *R. bellii* among total positive samples for *Rickettsia*		
	Papaya		Weeds	Insects	Papaya	Weeds	Insects
	Symptomatic	Asymptomatic					
Armería	7 of 48 (14.58 %)	1 of 16 (6.25 %)	3 of 31 (9.68 %)	3 of 60 (5.00 %)	2 of 8 (25.00 %)	2 of 3 (66.66 %)	1 of 3 (33.33 %)
Colima	26 of 48 (54.17 %)	9 of 16 (56.25 %)	10 of 34 (29.41 %)	2 of 32 (6.25 %)	1 of 35 (2.85 %)	9 of 10 (90.00 %)	1 of 2 (50.00 %)
Ixtlahuacán	20 of 48 (41.67 %)	4 of 16 (25.00 %)	1 of 35 (2.86 %)	2 of 46 (4.35 %)	0 of 24 (0.00 %)	1 of 1 (100.00 %)[ǂ]	0 of 2 (0.00 %)
Tecomán	1 of 48 (2.08 %)	1 of 16 (6.25 %)	3 of 74 (4.05 %)	4 of 47 (6.25 %)	1 of 2 (50.00 %)	2 of 3 (66.66 %)	3 of 4 (75.00 %)
Total	54 of 192 (28.12 %)	15 of 64 (23.43 %)	17 of 174 (9.77 %)	11 of 185 (5.95 %)	4 of 69 (5.79 %)[¶]	14 of 17 (82.35 %)	5 of 11 (45.45 %)

[ǂ]Positive weed showed vegetative proliferation. [¶]All positive samples were from bunchy top-diseased plants.

Regarding the occurrence of *Rickettsia* in the municipalities evaluated, Colima and Ixtlahuacán had the highest number of positive symptomatic and asymptomatic papaya plants (Table 2). Colima also had the highest number of positive insect morphospecies, while incidences of *Rickettsia*-positive weeds were similar in all municipalities (Table 2).

After determining the presence of *Rickettsia* through the *sdh*A gene detection analysis, the *Rickettsia* species in the positive samples were identified. Three *sdh*A amplicons obtained from papaya plants were randomly selected and sequenced (GenBank accession numbers MT103330–MT103332). The *sdh*A sequences had a 97.4–97.6 % similarity to *R. bellii* isolated from the United States (GenBank CP000087, CP000849) and Argentina (GenBank CP015010).

Further analysis of the *glt*A gene revealed the presence of *R. bellii*. However, positive results were obtained in only 5.79, 45.45, and 82.35 % of the *sdh*A-positive symptomatic papaya, insect, and weed samples, respectively, indicating that other *Rickettsia* species are present, particularly in papaya and insect samples (Table 2). In the phylogenetic analysis (Figure 3), *glt*A sequences from three samples (*Carica papaya* (Cpa), *Euphorbia hyssopifolia* (Ehy), and *Balclutha mexicana* (Bme)) (GenBank ON303294–ON303296) had a 99 % similarity to the *glt*A gene of *R. bellii* isolate CMS2 from Brazil (GenBank MW293870) and clustered with *R. bellii* from Argentina (GenBank MT407576) and Brazil (GenBank MW293870).

Weeds positive for *R. bellii* were *Amaranthus palmeri* S. Watson (Amaranthaceae), *Euphorbia hirta* L. and *E. hyssopifolia* L. (Euphorbiaceae), *Anoda cristata* (L.) Schltdl.

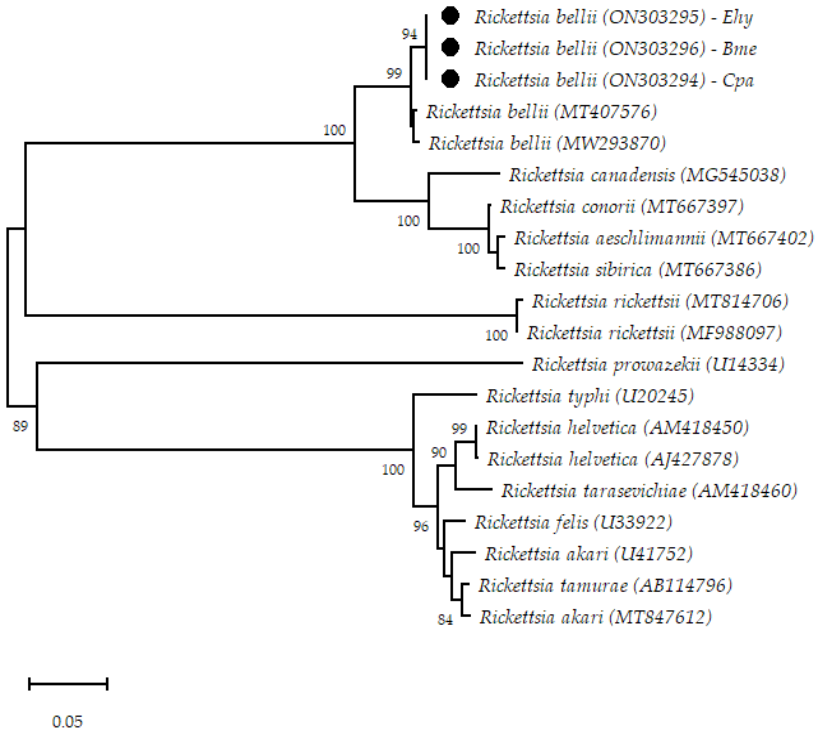

Figure 3. Phylogenetic tree of *Rickettsia bellii* found in papaya (*Carica papaya* L., Cpa), *Euphorbia hyssopifolia* L. (Ehy), and *Balclutha mexicana* Blocker (Bme) (black dots) in Colima, Mexico, as well as other *Rickettsia* species from other parts of the world, using the neighbor-joining method. GenBank identification numbers and bootstrap values (per 1000 replicates, greater than 70 %) are shown in parentheses and tree branches, respectively. The scale bar represents 0.05 nucleotide substitutions per site.

(Malvaceae), *Zinnia maritima* Kunth and *Parthenium hysterophorus* L. (Asteraceae), *Echinochloa colona* (L.) Link. (Poaceae), and *Richardia scabra* L. (Rubiaceae). However, *A. cristata* exclusively showed disease symptoms (Figure 2C). Based on this diversity of the botanical families registered, this result suggests a wide plant host range for *Rickettsia* in commercial papaya plantations. Thus, these plants should be considered alternative (non-crop) hosts and natural inoculum sources of *Rickettsia*. Until now, only the Caricaceae, Rosaceae, Lamiaceae, and Solanaceae had species known as hosts for *Rickettsia* (Davis *et al*., 1998; Streten *et al*., 2005; Caspi-Fluger *et al*., 2012).

Insects positive for *R. bellii* were *Balclutha mexicana* Blocker (Hemiptera: Cicadellidae) and *Chlorotettix emarginatus* Baker (Hemiptera: Cicadellidae). Interestingly, in our study, *E. papayae*, the natural vector of BT-associated *Rickettsia* in papaya in Cuba (Acosta *et al*., 2017), was not found during collecting. Until now, other *Rickettsia*-carrying arthropods included several mites and ticks, whiteflies, and leafhoppers, in

which *Rickettsia* bacteria have a natural occurrence as endosymbionts (Caspi-Fluger *et al*., 2012; Ishii *et al*., 2013; Sánchez-Montes *et al*., 2020; Shi *et al*., 2021; Guzmán-Cornejo *et al*., 2022). Given that *Rickettsia* transmission into plants has only been proved successfully for papaya leafhopper (*E. papayae*) (Acosta *et al*., 2017) and whitefly (*B. tabaci*) (Caspi-Fluger *et al*., 2012; Shi *et al*., 2021), it is possible that the leafhoppers *B. mexicana* and *C. emarginatus* could be responsible for *Rickettsia* transmission from papaya to weeds and vice versa in Colima, Mexico.

In Mexico, the genus *Balclutha* is part of the entomofauna in crops such as blueberry (*Vaccinium corymbosum* L.) (Pérez-Mejía *et al*., 2020), grape (*Vitis vinifera* L.) (Almendra-Paxtlan *et al*., 2021), pepper (*Capsicum* spp.) (Velásquez-Valle *et al*., 2018), and corn (*Zea mays* L.) (Pinedo-Escatel and Moya-Raygoza 2018). *Chlorotettix emarginatus* is a common pest in corn and rice (*Oryza sativa* L.) (Cervantes-Mayagoitia and Huacuja-Zamudio, 2017). However, until now, the presence of *Rickettsia* in these crops has not been addressed.

Altogether, these findings support the hypothesis that *Rickettsia* spp. are involved in commercial papaya plantations with BT in Colima and that they are also present in papaya-associated weeds and insects. In Mexico, the distribution and hosts of *Rickettsia* spp. have been updated recently (Sánchez-Montes *et al*., 2021), but none of the species listed were associated with plants. In the case of *R. bellii*, it has been identified in ticks collected from Jalisco and Hidalgo (Sánchez-Montes *et al*., 2020; Guzmán-Cornejo *et al*., 2022). In Colima, *R. typhi* causing murine typhus in humans has been reported (García-Acosta *et al*., 2017).

CONCLUSIONS

Rickettsia spp. have a natural occurrence in asymptomatic and bunchy top-diseased papaya plants, as well as in papaya-associated weeds and insects in commercial plantations in Colima, Mexico.

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COMMUNITY BUILDING FOR CONFLICT MANAGEMENT IN BESOWO NATURE RESERVE

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ABSTRACT

This research aims to analyze the potential conflict between farmers and stakeholders in Besowo Gadungan Nature Reserve and to develop conflict management strategies through a community building approach. The study employs a mixed methods approach, combining quantitative and qualitative methods. Quantitative data is collected through a survey using open ended questionnaires, while qualitative data is obtained through in-depth interviews and Focus Group Discussions (FGD). Purposive sampling ensures that informants meet relevant criteria. The findings indicate that the lack of communication and coordination between farmers and the reserve management is a significant factor triggering conflict. Differences in understanding regarding natural resource management and regulatory ambiguity also contribute to the situation. Respondents show positive support for the importance of building trust and transparent communication. The proposed community building strategy includes the formation of a sense of community by fostering unity and shared understanding among farmers and stakeholders, active involvement in decision-making, ongoing communication through regular meetings and dialogues, and the use of communication tools such as suggestion boxes or online platforms to facilitate idea exchange and complaints. In conclusion, the study underscores the crucial role of community building strategies in identifying, preventing, and managing potential conflicts. By understanding the root causes and implementing concrete steps to build communities, relations between farmers and stakeholders can be strengthened, creating a harmonious balance in natural resource utilization at Besowo Gadungan Nature Reserve. An inclusive and sustainable approach is expected to generate fair and lasting solutions, maintaining a balance between farmers needs and environmental preservation

Keywords: communication strategies, community building strategy, conflict management, sense of community, sustainable resource management.

INTRODUCTION

Besowo Nature Reserve is one of the conservation areas with high biodiversity and is crucial to preserve in Indonesia(Rustinsyah, 2015). Various types of flora and fauna

are protected by law. According to the East Java Natural Resource Conservation Agency (2014), administratively, Besowo Village is a buffer zone, located in Besowo Village, Kepung District, Kediri Regency, country of Indonesia. The buffer zone surrounds the protected area, aiming to limit human activities in the vicinity to avoid damaging the ecosystem within the area. Natural resources have become an integral part of community life, playing a significant role in social, economic, and political aspects. Recognizing the irreplaceable importance of natural resources for human life, the government established Law Number 5 of 1990 concerning "Conservation of Natural Resources and Ecosystems". The community in Besowo Village relies heavily on forest resources within the conservation area, especially wood, leaves, candlenuts, and bamboo shoots. Most sheep and goat farmers in Besowo Village also depend on forage from Besowo Nature Reserve for their livestock feed.

In certain situations, the utilization of forest resources by goat or sheep farmers and the community in Besowo Village violates regulations, particularly regarding the harvesting of wood and foliage by farmers. Residents living inside or around forest areas are prohibited from transporting, controlling, or possessing forest products without valid documentation (Law No. 18 Article 12 of 2013 concerning Prevention and Eradication of Forest Destruction). This violation has the potential to cause conflicts between farmers and stakeholders. Conflict arises when there is a lack of understanding among various parties. Moreover, conflicts can also emerge due to conflicting interests and objectives among individuals or groups. This situation occurs when there is a gap in social status, inequality in wealth distribution, and imbalance of power in the relationship (Hadiyanto, 2014; Aprylasari et al., 2022). According to Siradjuddin (2015), conflict is a common and frequent occurrence everywhere because social relationships often involve differences in perception, meaning, and interests among individuals or groups involved. Arifandy and Sihaloho (2016) stated that conflicts of interest among stakeholders, including Perhutani, the East Java Natural Resource Conservation Agency (BKSDA), the Besowo Village Government, and the community, subsequently lead to conflict. Conflict can arise when farmers seek forest resources for their business, while other stakeholders have interests in preserving the natural environment in Besowo Gadungan Nature Reserve. This aligns with Wahyudi (2015) opinion that when there are limitations or restrictions on resources such as materials or other means, competition for their use may potentially lead to conflict.

The potential conflict between livestock farmers and stakeholders in Besowo Gadungan Nature Reserve can have detrimental impacts on both environmental sustainability and the socio-economic livelihoods of the local community. To address this conflict potential, efforts are needed to identify potential conflicts that may arise between livestock farmers and other stakeholders, followed by effective management strategies to reduce conflict and build harmonious cooperation between farmers and other stakeholders.

According to research by Irwandi and Chotim (2017), conflict identification includes various aspects such as conflict sources, factors causing conflicts, and conflict

impacts. Conflicts often have multiple causes, generally stemming from issues in the relationships between the involved parties.

Community building was chosen as one of the conflict management strategies because this approach focuses on building strong and mutually beneficial relationships among community members. Faced with the conflict situation between livestock farmers and stakeholders in Besowo Gadungan Nature Reserve, there is a need to enhance social relations and cooperation between both parties to achieve sustainable solutions. Community building is a series of practices aimed at creating or enhancing a sense of togetherness among individuals or groups in a particular area or with shared needs or interests (Hyde and Chavis, 2007). The implementation of community building involves efforts to unite individuals or groups and create a sense of ownership. According to Lazarus et al. (2016), the community building approach can be implemented through various means, including understanding the benefits and targets of community building, mechanisms of community building, developing participatory mechanisms, and building trust relationships.

The community building strategy helps to foster a sense of community, increase active participation, and improve communication among community members. Therefore, this approach not only assists in managing existing conflicts but also strengthens long-term relationships between livestock farmers and stakeholders for sustainable resolutions. Mcmillan and Chavis (1986) explain that a sense of community is a feeling where members feel a sense of ownership, recognize the importance of each other and the group, and share the belief that members' needs will be met through commitment to each other. The community building strategy aims to strengthen the relationship between livestock farmers and stakeholders, foster trust, and reduce the potential for conflict. This aligns with the perspective of Rahmawati et al. (2017), who state that integrating community building strategies into national life requires collaboration among various related stakeholders. The implementation of community building strategies is expected to facilitate the development of a shared understanding in managing natural resources in Besowo Gadungan Nature Reserve. Additionally, through active participation from all parties, sustainable solutions can be generated, ensuring the continuity of livestock farming and environmental preservation while enhancing harmony in the relationship between livestock farmers and stakeholders

MATERIALS AND METHODS

The research was conducted on goat and sheep farmers in the Besowo Gadungan Nature Reserve with stakeholders for 6 months, from July 2023 to January 2024. The location was determined using purposive sampling, which involves selecting locations based on specific considerations. This study uses mixed methods to analyze forest resource conflicts in Besowo Village, Kediri District, East Java Province, Indonesia. Creswell (2009) explains that mixed methods involve combining two research approaches, quantitative and qualitative, in one series of research activities.

The goal is to obtain more comprehensive, valid, reliable, and objective data. The choice of mixed methods in this study is due to its ability to provide a deep and detailed

understanding of an event or social phenomenon. The mixed methods approach is applied to uncover conflicts in forest resource management and identify their causes. Furthermore, the research method used is a case study. The implementation of the case study is carried out through observation, in-depth interviews, and secondary data analysis as analytical tools. The case study strategy applied by the researcher aims to avoid the limitations of understanding bound to a particular theory and focuses more on the researcher's interpretation.

The quantitative research method used is the survey method, utilizing open-ended questionnaires as the primary data collection tool. Survey research involves taking samples from a population and using prepared questionnaires. The population is a collection of subjects or objects with characteristics determined by the researcher for in-depth study, with the aim of drawing relevant conclusions from the research results. The population in question consists of the communities around the Besowo Gadungan Nature Reserve. Meanwhile, the qualitative method used involves in-depth interviews and focus group discussions (FGD) to understand the context, dynamics, and direct experiences of farmers and stakeholders related to conflicts in the Besowo Gadungan Nature Reserve. Qualitative methods also have the capability to explore social realities and processes, as well as meanings derived from the understanding developed by the research subjects (Sitorus, 2021)

Sampling in this study uses purposive sampling, a technique for determining samples based on certain considerations so that they are suitable to be used as informants. This sampling selection is based on specific characteristics of the population, with special consideration given to factors such as gender, age, education level, occupation, number of livestock, and livestock groups that are considered relevant and significant.

Research Design, Method, and Sampling Strategy

The data collection method used in this study is through primary data obtained directly from research questionnaires submitted to the community and stakeholders in Besowo Gadungan Nature Reserve. Meanwhile, secondary data can be obtained from documentation, where researchers read and observe, process reports, and notes from the community and stakeholders that will support the research, as well as related research aiming to supplement any deficiencies in primary data.

Variables Used

Independent Variables:

Communication Quality, this variable assesses the effectiveness of communication between farmers and stakeholders, including clarity, frequency, and transparency of information shared.

Stakeholder Involvement, this variable measures the level of participation and engagement of stakeholders in decision-making processes related to resource management.

Dependent Variables:
Perception of Conflict, this variable reflects the respondents' views on the intensity and nature of conflicts experienced in the community, as measured by the Likert scale responses.

Community Trust:
This variable evaluates the level of trust among community members and between farmers and stakeholders, which is crucial for conflict resolution and collaboration.

Data Analysis

The data collected includes both primary and secondary sources. Primary data was gathered through surveys, interviews, and observations, involving a specific number of samples. Secondary data was collected from existing research and reports relevant to the study area.

Comparative Analysis

A comparative analysis was conducted to identify differences between groups or variables. For example, the perceptions of livestock farmers and stakeholders regarding conflicts were compared, as well as the level of stakeholder participation in conflict resolution efforts. This analysis helps to identify significant differences between the groups or variables involved.

Likert Scale Analysis

Data from the Likert scale was processed to provide an overview of tendencies or perceptions regarding the level of conflict. The distribution of respondents' answers on the Likert scale was analyzed to assess the extent of conflict based on respondents' perceptions. Scores of 1-4 were used in the analysis, where a score of 1 indicates a low perception of conflict, and a score of 4 indicates a high perception of conflict. This process offers a detailed understanding of how respondents evaluate and respond to the level of conflic to enables the identification of specific patterns or trends in respondents' perceptions of conflict, whether it tends to increase, decrease, or remain stable. By utilizing the Likert scale scores, this research can produce a more detailed and contextual analysis related to the conflict
under study.

Analysis Conclusion

In the conclusion of the analysis, key findings are presented using descriptive statistics to provide a detailed depiction of the research results. Subsequently, conclusions are drawn regarding the impact of the implementation of the Community Building Strategy (CBS) on perceptions of potential conflict between livestock farmers and stakeholders. The analysis results indicate that the higher the level of CBS implementation, the lower the perception of potential conflict.

RESULTS AND DISCUSSION

RESULT

Source of Conflict

During the research in Desa Besowo, the identification of conflicts highlighted several sources of tension between farmers and Besowo Gadungan Nature Reserve. One of the main sources of conflict is the difference in perspectives regarding the utilization of forest resources. This aligns with the viewpoint of Arifandy and Sihaloho (2016), who stated that the management and utilization of forest resources can potentially lead to conflicts of interest among involved parties, thus creating tension. Farmers tend to view the forest as a resource that supports their farming activities, while Besowo Gadungan Nature Reserve prioritizes conservation and environmental protection aspects. This difference creates conflict because each party has different priorities regarding forest management. Additionally, the rules and policies implemented by Besowo Gadungan Nature Reserve also serve as a source of conflict.

The data results from the Likert scale in Table 1, with a total average score reaching 3.42, indicate a high level of conflict in Besowo Village. This figure suggests the presence of tension or conflict between farmers and stakeholders in the Besowo Gadungan Nature Reserve. The assessment through the Likert scale provides an overview that the potential conflict in this study cannot be ignored, hence the need for handling measures to achieve harmony or balance between the two parties involved, such as communication training and the establishment of shared regulations.

Table 1. Potential Conflicts between Farmers and Stakeholders.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you agree that the potential conflict between livestock farmers and the Besowo Gadungan Nature Reserve stakeholders can affect the sustainability of livestock farming?	0	0	38	32	3,45
Do you think the communication between livestock farmers and the Besowo Gadungan Nature Reserve stakeholders has been effective in managing conflicts?	0	2	32	36	3,48
Do you agree that differences in perception between livestock farmers and the Besowo Gadungan Nature Reserve stakeholders can be a significant source of conflict?	0	4	35	31	3,38
Do you think the concrete efforts made by the Besowo Gadungan Nature Reserve stakeholders in addressing conflicts with livestock farmers have been less than optimal?	0	4	37	29	3,35
Do you believe that increasing mutual understanding between livestock farmers and the Besowo Gadungan Nature Reserve stakeholders can reduce potential conflicts in the future?	0	0	37	33	3,47
Total Average: 3,42					

Competition for Access to Resources

Such competition arises due to the limited natural resources available to farmers in Desa Besowo. It's evident that the high demand for forest resources such as grass, foliage, and wood by various farmers can create an escalating competitive situation. Therefore, the limitation in the availability of natural resources becomes the primary cause of competition among farmers in meeting their livestock business needs.

The Likert scale data from Table 2 yielded a value of 3.43, indicating a significant level of competition for access to resources in Besowo Village. This value reflects tension or conflict in the efforts to access resources such as grass, foliage, and wood by farmers, thus leading to conflicts with the stakeholders of Besowo Gadungan Nature Reserve. This figure provides an overview that the phenomenon of competition for resource access is an important aspect that can trigger conflicts in the area. Therefore, attention and strategic actions are needed to manage competition for resource access, such as inclusive approaches by the nature reserve management involving the formation of discussion forums between farmers and the nature reserve authorities. This can help identify mutually beneficial solutions considering the interests of both parties and environmental sustainability.

Table 2. Competition for Access to Resources.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you experience competition for access to natural resources in the Besowo Gadungan Nature Reserve?	1	3	31	35	3,42
Do you believe that this competition for access can create an imbalance in the supply of resources for farmers around the Besowo Gadungan Nature Reserve?	2	1	34	33	3,4
Do you believe that competition for access to resources can lead to conflicts among farmers around the Besowo Gadungan Nature Reserve?	0	3	32	35	3,45
Do you believe that participatory solutions involving farmers can be an effective step in managing competition for access to resources in the Besowo Gadungan Nature Reserve?	0	0	37	33	3,47
Average Total: 3,43					

Differences in Values and Norms

The data obtained through interviews with farmers and stakeholders at the research site reveal that the values of mutual cooperation and perseverance play a crucial role in managing farming businesses in Desa Besowo. These two values serve as the primary foundation guiding farmers in establishing and running their businesses. Mutual cooperation reflects a strong spirit of collaboration among farmers, where they assist each other in various aspects of farming, such as seeking feed or making

improvements to barn facilities. Additionally, perseverance is a key element highly valued by farmers, demonstrating their dedication and seriousness in facing various daily challenges and difficulties. Husnah (2017) suggests that the community exhibits cultural characteristics that still prioritize familial and communal values, as reflected in their participation in various activities, including mutual cooperation. This indicates that familial and communal aspects remain fundamental pillars of the community culture, forming a strong basis for harmonious and collaborative social interactions. This perseverance is reflected in their commitment to maintaining the sustainability of their farming businesses.

Effective Communication

Amin (2017) stated that communication plays a crucial role in the dynamics of social life, effective communication has the ability to address and resolve conflicts that arise in social interactions, and the ability to communicate well is a key factor in creating mutually beneficial understanding and overcoming potential conflicts. The data obtained through interviews with farmers and stakeholders at the research site reveal that the perception of farmers in Besowo Village towards the communication

The Likert scale data results listed in Table 3 yield a value of 3.42, indicating differences in values and norms in Besowo Village. This value depicts that the conflict between farmers and the stakeholders of Besowo Gadungan Nature Reserve has led to discrepancies in the community's values and norms. These differences in values can be a major trigger for conflict, as each party has different perspectives and principles

Table 3. Differences in Values and Norms.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you believe that differences in values between farmers and the Besowo Gadungan Nature Reserve stakeholders can be a cause of conflict?	0	2	32	36	3,48
Do you think that differences in norms held by farmers and the Besowo Gadungan Nature Reserve stakeholders can hinder efforts of cooperation and mutual understanding in managing forest resources?	2	0	35	33	3,41
Do you believe that a lack of understanding of the norms in place at Besowo Gadungan Nature Reserve can trigger conflicts between farmers and management authorities?	0	2	33	35	3,47
Do you think efforts to enhance understanding and alignment of values and norms between farmers and the Besowo Gadungan Nature Reserve authorities can reduce the potential for conflict?	0	7	32	31	3,34
Do you believe that open dialogue and active participation from both sides can be a solution to address the differences in values and norms that exist?	0	2	35	33	3,44
Average Total: 3,42					

regarding the management of forest resources. Therefore, there is a need for in-depth efforts to understand and address established with the Besowo Gadungan Nature Reserve management tends to be negative. Farmers stated that the communication conducted so far is considered inadequate. One of the main complaints expressed is the lack of direct meetings or gatherings between farmers and the Besowo Gadungan Nature Reserve management to discuss the conflicts occurring in the area.

Based on the data analysis using the Likert Scale from Table 4, a value of 3.47 is obtained. This figure indicates a lack of effective communication between farmers and the stakeholders of Besowo Gadungan Nature Reserve. This phenomenon signifies that the communication that has been ongoing so far is considered inadequate by the respondents, and there is a need for improvement in communicative interaction between the two parties. The research results emphasize the necessity for more intensive and structured efforts in communication, including involving regular meetings or discussion forums. Efforts to enhance communication between farmers and the stakeholders of Besowo Gadungan Nature Reserve should not only be formal but also require a participatory approach. These steps need to involve both parties in designing effective and sustainable communication strategies, thereby creating a positive collaborative environment and minimizing tension. Therefore, meetings and the development of communication initiatives supporting mutual understanding are necessary to overcome communication barriers in Besowo Village

Table 4. Effective Communication.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you think that ineffective communication between farmers and the Besowo Gadungan Nature Reserve authorities can be a cause of conflict in the area?	0	0	37	33	3,47
Do you believe that the lack of direct meetings or discussions between farmers and the Besowo Gadungan Nature Reserve authorities can hinder mutual understanding and conflict resolution?	0	3	32	35	3,45
Do you think that the lack of initiative to organize regular meetings or dialogue forums can be a barrier to creating effective communication?	0	0	36	34	3,48
Do you believe that increased and open communication can help address conflicts between farmers and the Besowo Gadungan Nature Reserve authorities?	0	2	32	36	3,48
Average Total: 3,47					

Factors Causing Conflict

The research involving interviews with farmers and stakeholders in Desa Besowo identified several factors causing conflicts between farmers and the management of

Besowo Gadungan Nature Reserve. Differences in perception and understanding between farmers and the conservation area management regarding the extraction of wood and foliage emerged as the primary factors influencing the conflict dynamics. Based on the Likert scale data in Table 5, a value of 3.42 is obtained. This figure indicates the existence of factors causing conflict between farmers and the stakeholders of Besowo Gadungan Nature Reserve. These factors can trigger tension and differences in views between the two parties. The research highlights the need for a deep understanding of the identified conflict-causing factors. These factors need to be clearly identified to

Table 5. Conflict Causes.

Question	SD 1	D 2	A 3	SA 4	Average
Do you believe that differences in perception between farmers and the managers of the Besowo Gadungan Nature Reserve regarding the harvesting of wood and leaves can be a factor causing conflict in the area?	0	0	33	37	3,52
Do you believe that the ambiguity of rules and regulations regarding the extraction of forest resources in the Besowo Gadungan Nature Reserve area can increase the potential for conflict between farmers and the management of the Besowo Gadungan Nature Reserve?	0	4	32	34	3,42
Do you believe that the involvement of farmers in the policy formulation process and the establishment of more transparent rules can reduce the likelihood of conflicts?	5	1	34	30	3,27
Do you believe that differences in views on the utilization of forest resources between farmers and the managers of the Besowo Gadungan Nature Reserve can be a source of conflict?	0	0	38	32	3,45
Do you believe that a lack of understanding about the rules and restrictions in place can trigger conflicts between farmers and the managers of the Besowo Gadungan Nature Reserve?	0	0	36	34	3,48
Average Total: 3,42					

formulate effective conflict resolution strategies. Furthermore, a deeper understanding of the differences in perception and underlying issues of the conflict will serve as a basis for creating sustainable and fair solutions for both parties. Efforts to resolve conflicts need to be comprehensive, involving active participation from both farmers and the stakeholders of Besowo Gadungan Nature Reserve. A collaborative approach is required to address differences in perspectives and reach mutually beneficial agreements. Additionally, the factors causing conflicts need further scrutiny to design policies and concrete measures that can reduce the potential for conflicts in the future.

Impact of Conflict

The interviews conducted during the research at the location revealed that the conflict between farmers and the management of Besowo Gadungan Nature Reserve has significant consequences. One of the main impacts is the difficulty in building positive relationships between farmers and the conservation area management.

Based on the Likert scale data in Table 6, a value of 3.42 is obtained. This figure indicates that there are impacts of conflict between farmers and stakeholders in Besowo Gadungan Nature Reserve. These impacts can affect various aspects, such as inter-farmer relationships, environmental sustainability, economic and social pressures on farmers, instability in resource supply, and difficulties in developing farming businesses. The impacts of conflict are one of the aspects that require serious attention in addressing emerging issues. Concrete efforts are needed to understand these impacts comprehensively. This understanding can serve as a basis for stakeholders to formulate policies and strategies that minimize negative impacts and support the sustainability of farming businesses and environmental conservation.

Table 6. Impact of Conflict Between Farmers and Stakeholders in Besowo Nature Reserve.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you believe that conflicts between farmers and stakeholders of the Besowo Gadungan Nature Reserve make it difficult to build positive relationships?	0	0	34	36	3,51
Do you believe that these conflicts have a negative impact on the sustainability of the Besowo Gadungan Nature Reserve?	4	0	36	30	3,31
Do you believe that conflicts between farmers and stakeholders of the Besowo Gadungan Nature Reserve increase economic and social pressures on farmers in Besowo Village?	0	0	37	33	3,47
Do you believe that these conflicts cause instability in the supply of resources for livestock businesses?	0	3	35	32	3,41
Do you believe that conflicts between farmers and stakeholders of the Besowo Gadungan Nature Reserve make it difficult for farmers to develop their livestock businesses?	1	2	33	34	3,42
Average Total: 3,42					

Community Building Strategies for Managing Potential Conflicts

The strategy of community building can be defined as an effort to strengthen the bonds among farmers and stakeholders through a participatory approach. Steps such as improving communication, establishing dialogue forums, and developing joint activities can be part of the community building strategy. The implementation of

community building strategy is expected to create a more harmonious environment, minimize conflict potential, and promote the sustainability of both farmers' livelihoods and environmental conservation around Besowo Gadungan Nature Reserve. The success of implementing the community building strategy requires collaboration from various parties, including farmers, stakeholders, and other relevant entities, by building a cohesive community, thereby creating a conducive environment for all involved parties and minimizing conflicts while facilitating sustainable conflict resolution.

Based on the Likert scale data in Table 7, a value of 3.47 is obtained, indicating that the community building strategy has significant potential for implementation in addressing conflicts between farmers and stakeholders in Besowo Gadungan Nature Reserve. This result indicates that efforts to build community and cooperation can be an effective solution in alleviating conflicts occurring in the area

Tabel 7. Community Building Strategy.

Question	SD	D	A	SA	Average
	1	2	3	4	
Do you believe that the Community Building strategy in Besowo Village is effective in identifying potential conflicts between farmers and stakeholders?	0	0	33	37	3,52
Do you believe that the formation of a sense of community between farmers and stakeholders can reduce tension in relationships in Besowo Village?	0	3	34	33	3,42
Do you believe that the success of the Community Building strategy can enhance mutual understanding between farmers and stakeholders regarding conservation policies and objectives?	0	0	36	34	3,48
Average Total: 3,47					

DISCUSSION

Potential Conflict

Conflict Identification

The research conducted in Desa Besowo resulted in findings indicating the presence of conflict between farmers and the authorities of Besowo Gadungan Nature Reserve. This conflict stems from the farmers' activities involving the extraction of forest resources, particularly wood and foliage, which are actually located within the conservation area. This issue reflects the inconsistency between farming activities and conservation efforts implemented by Besowo Gadungan Nature Reserve. Irwandi and Chotim (2017) explain that differences in interests can lead to conflicts, thus institutions must be able to reconcile interests for conflicting parties. These findings provide further understanding of the complexity of conflicts arising from differences in interests between farmers and environmental conservationists.

Social conflict is defined as a social process where individuals or groups strive to achieve their goals by opposing parties, resulting in tension between conflicting interests and values. The conflicts identified during the research can be grouped into two main types. First, there is active participation from farmers in harvesting wood and foliage from the area of Besowo Gadungan Nature Reserve. Second, this conflict is closely related to their farming activities, where the need for forest resources is the main driver for farmers to engage in such extraction. This situation reflects the inconsistency between farming activities and conservation efforts implemented by Besowo Gadungan Nature Reserve. Kinasih (2016) explains that forest utilization often leads to various perspectives between local governments and communities, resulting in differing views. The impact of these differing views can be detrimental to forest sustainability and cause significant damage. While local governments may have specific priorities in forest management, community perspectives may encompass various interests and needs that need to be considered. These differences in perspectives can result in damage to the forest ecosystem, highlighting the importance of formulating an inclusive and sustainable approach to achieve understanding and balance between community interests and forest management objectives. Understanding the motives and urgency behind the actions of wood and foliage extraction by farmers is crucial in formulating balanced and sustainable solutions for both parties.

The identification of these conflicts forms a strong basis for formulating resolution strategies that consider the sustainability of farming activities and the conservation of the Besowo Gadungan Nature Reserve area. Muchtar (2016) states that achieving a balanced solution requires a participatory approach involving all relevant parties, aiming to ensure contributions and perspectives from various stakeholders so that decisions made reflect shared needs and aspirations. This approach can create concrete steps to reduce tension between farmers and the authorities of Besowo Gadungan Nature Reserve, while also supporting the balance between farmers' economic interests and environmental conservation efforts, which are the goals of Besowo Gadungan Nature Reserve.

Source of Conflict

Efforts to mitigate conflicts for the sake of development involve establishing effective communication mechanisms between farmers and the authorities of Besowo Gadungan Nature Reserve. This aligns with the statement by Siregar and Usriyah (2021) indicating that good communication serves not only to convey information but also plays a role in persuading conflicting parties, thus effective communication can encourage conflicting parties to achieve peace. Increasing mutual understanding of policies, regulations, and conservation goals can be the first step towards creating consensus. Additionally, initiatives to hold regular meetings or discussion forums between both parties can help build better relationships, reduce tension, and seek mutually beneficial solutions.

Economic influence also drives conflict. This aligns with Siradjuddin (2015) statement that conflict often arises from economic interests when resources become limited,

competition for access and control over those resources can trigger conflict. The limited natural resources available to farmers can have a negative impact on their economy. Utilization of forest resources in the conservation area becomes an option for farmers to meet their livestock feed needs, leading to tension between the economic interests of farmers and conservation principles. Finally, the urgent need for farmers to meet their livestock needs is one source of conflict. Factors such as difficulty in obtaining alternative feed outside the conservation area can drive farmers to continue extracting resources from protected areas, causing conflict with the management of Besowo Gadungan Nature Reserve.

Competition for Access to Resources

The competition arises due to the limited natural resources available to farmers in Desa Besowo. It is evident that the high demand for forest resources such as grass, foliage, and wood by various farmers can create a situation of heightened competition. Therefore, the limitation in the availability of natural resources becomes the primary cause of competition among farmers in meeting their livestock business needs. The issue of competition for access to resources has negative impacts on the sustainability of livestock farming (Amam, et al., 2021). Farmers experiencing competition may struggle to meet their livestock feed needs, resulting in economic and social pressures. Competition intensifies as the number of livestock requiring feed increases, creating prolonged dynamics of competition. Moreover, this competition can also lead to supply instability of resources, which in turn can affect the overall productivity and welfare of farmers. Access competition is one contributing factor to the conflict between farmers and the authorities of Besowo Gadungan Nature Reserve. Arifandy and Sihaloho (2016) state that addressing the issue of competition for access to resources requires collaborative efforts and better management from all relevant parties, including farmers, stakeholders, and forest management authorities. Inclusive and sustainability-oriented steps can help create fair and sustainable solutions to maintain a balance between farmers' needs and environmental conservation.

Differences in Values and Norms

The conflicts that arise are related to the different perspectives of each party regarding the management of forest resources in the area. Budimanta (2008) revealed that natural resources essential for human life create a level of complexity in interactions among various parties with interests in their management. Farmers tend to view the forest as a resource that can support their farming activities, while the authorities of Cagar Alam place more emphasis on conservation and environmental protection aspects. Marina and Dharmawan (2011) stated that differences in values can create mismatches in thinking patterns and approaches to forest resources. Farmers who rely on the forest as a source of feed and wood for their farming activities encounter obstacles with the conservation policies implemented by Besowo Gadungan Nature Reserve. On the other hand, the authorities of Cagar Alam prioritize environmental

conservation, leading to tension in managing and utilizing forest resources. Efforts are needed to understand and respect the differences in values and norms between farmers and conservation authorities. A participatory approach needs to be applied to achieve mutual understanding and formulate solutions that can meet the interests of both parties(Ardoin et al., 2020).

Effective Communication

The conflict situation related to the harvesting of wood and foliage in the area of Besowo Gadungan Nature Reserve requires a solution based on effective communication. Good communication will help clarify rules, reduce uncertainty, and build mutual understanding between farmers and the authorities of Cagar Alam. Therefore, efforts are needed from the authorities of Besowo Gadungan Nature Reserve to be more proactive in organizing regular meetings and dialogue forums with farmers to create more effective and mutually beneficial communication. Efforts to improve effective and mutually beneficial communication between the authorities of Besowo Gadungan Nature Reserve and farmers require several strategic steps. Firstly, the authorities of Besowo Gadungan Nature Reserve can hold regular meetings with farmers, either in person or through online platforms, to discuss current issues and seek solutions together. Additionally, open dialogue forums can be created to allow farmers to directly express their input, concerns, and ideas to the authorities of Besowo Gadungan Nature Reserve. The use of technology such as online platforms can facilitate meeting arrangements if meeting in person is not possible. Furthermore, the preparation of agendas for subsequent meetings and the recording of discussion outcomes and agreements reached are also important steps to ensure focus and smooth discussion and provide reference for further follow-up actions(LeBlanc & Nosik, 2019). Amin (2017) states that communication, as a solution to conflict, requires the presence of dominant elements that are always involved in every communication interaction regardless of location, the identities of the parties involved, or the level of relationship. Through this approach, it is hoped that a more conducive communication environment can be created and potential conflicts minimized. The authorities of Besowo Gadungan Nature Reserve need to realize the importance of involving farmers in the decision-making process regarding the conservation area to produce fair and sustainable solutions.

Factors Causing Conflict

Limakrisna (2011) states that the factors causing conflicts involve dual roles, competition in obtaining resources, unresolved previous conflicts, as well as differences in goals, perceptions, understandings, and values among the parties involved. This indicates that the views and interpretations of both parties regarding the extraction of natural resources vary, leading to tension and potential conflicts between them. The differing understandings between farmers and the conservation area management occur because they have different perspectives regarding the extraction of wood and foliage

in the area of Besowo Gadungan Nature Reserve. Farmers view the extraction of wood and foliage as a source of materials for their farming activities, such as animal feed and livestock pens. On the other hand, the management of Besowo Gadungan Nature Reserve sees this extraction as a threat to the environmental conservation and ecosystem within the area. Additionally, there is ambiguity in the rules and regulations concerning the extraction of forest resources in the conservation area. Farmers feel that the lack of understanding about the applicable regulations and restrictions can trigger conflicts. The involvement of farmers in the policy-making process and the creation of more transparent rules are key to addressing these differing perceptions(Blomkamp et al., 2018).

Another contributing factor to the conflict is the lack of communication and coordination between farmers and the authorities of Besowo Gadungan Nature Reserve. According to Isparwoto (2012), insufficient communication can lead to potential conflicts; a shortage in information exchange and understanding can create misunderstandings and disagreements among the involved parties, thus increasing the risk of conflict. The lack of regular meetings or dialogue forums limits the understanding between the parties, making it difficult to reach mutual agreements. Muqdamien (2020) suggests that both parties have the potential to reach a mutually beneficial agreement, which would have a positive impact on their relationship. Therefore, increasing the intensity of communication and dialogue should be prioritized in building a better relationship to address the factors contributing to conflict. It requires joint efforts between farmers and the authorities of Besowo Gadungan Nature Reserve. Processes such as aligning perceptions, formulating clearer rules, and enhancing communication can be strategic steps to alleviate tension and promote the sustainability of farming activities and environmental conservation.

Impact of Conflict

Muqdamien (2020) states that conflict creates an atmosphere of tension and uncertainty, damaging the collaboration that should occur for the sustainability of both parties. Conflict also negatively impacts the preservation of Besowo Gadungan Nature Reserve. The harvesting of forest resources, such as wood and foliage, by farmers can threaten the biodiversity and ecosystems within the conservation area. Conflict hampers the achievement of conservation goals and the preservation of nature.

The economic and social impacts are also felt by farmers due to this conflict. The potential for sanctions or restrictions on the harvesting of forest resources creates economic pressure. Social tensions between farmers and the conservation authorities can affect psychological well-being and have negative consequences for the sustainability of farming livelihoods.

Conflict can create instability in resource supply for farmers. Restrictions or bans on the harvesting of wood and foliage can adversely affect farming efforts in terms of meeting livestock feed needs. Difficulty in accessing these resources can impact livestock productivity and threaten their business sustainability. However, the

prohibition on the harvesting of leaves and wood by Besowo Gadungan Nature Reserve is a standing regulation. This rule aims to preserve Besowo Gadungan Nature Reserve. Therefore, conflicts that arise should be addressed with an approach that considers conservation interests while understanding the needs and challenges faced by farmers. Fair and sustainable solutions can be found through dialogue, cooperation, and the development of strategies involving both parties.

Addressing the impacts of conflict also requires cooperation between farmers and stakeholders in Besowo Gadungan Nature Reserve. Active involvement from both parties in seeking mutually beneficial solutions will be crucial. Therefore, dialogues and meetings between farmers and stakeholders are necessary to achieve mutual understanding and formulate concrete actions in addressing the impacts of the conflict.

Community Building Strategies for Managing Potential Conflict

Hyde, et al. (2007) defines community building as a series of practices aimed at creating or enhancing a sense of togetherness among individuals or groups within a specific area or with shared needs or interests. Brien (2007) argues that integrated strategies of community building and conflict resolution play a crucial role in addressing potential conflicts. Research findings from the Focus Group Discussion (FGD) conducted on May 10, 2023, and interviews with farmers and stakeholders indicate that community building strategies can be an effective solution in managing potential conflicts between farmers and the Besowo Gadungan Nature Reserve. The first step in designing a community building strategy is to understand the needs, interests, and expectations of both parties. With a strong understanding, the community building strategy can be designed to reflect shared values and norms that are acceptable to all parties.

Lazarus, et al. (2016) demonstrate that the approach of community building strategies can be implemented in various ways, including a deep understanding of the benefits and goals of community building efforts. Community building strategies focus on fostering a positive sense of community among farmers and stakeholders, including the Besowo Gadungan Nature Reserve. The community building strategy emphasizes the importance of involving all relevant parties in the decision-making process (Brien, 2007). Participation mechanisms should be designed to create space for all parties to contribute and communicate openly. At the same time, it is important to build mutual trust between farmers and the Besowo Gadungan Nature Reserve. The importance of holding regular meetings between farmers and stakeholders also creates opportunities to discuss developments, policy changes, or issues that arise directly. These meetings can foster a sense of unity and enhance shared understanding of the challenges and opportunities faced by both parties.

The formation of working groups or committees involving farmers and stakeholders is a key point in the community building strategy. Yudarwati (2004) explains that working groups can provide a platform for discussion, information sharing, and formulation of joint policies that can accommodate the needs of both parties. Thus, collaboration between farmers and stakeholders can be enhanced, opening the way for more effective problem-solving.

Benefits and Goals of Community Building Strategy

This research explores several benefits and targets expected from the implementation of Community Building Strategy (CBS) in identifying and managing potential conflicts between farmers and stakeholders in the Besowo Gadungan Nature Reserve. Antorini and Muñiz (2013) state that the benefits of community building include enhancing communication and collaboration among members or groups by fostering better relationships, which can lead to open and effective communication between both parties. The main benefit of CBS is evident in the effort to establish a sense of community. Hall and Panarese (2016) emphasize that the benefits of community building also include creating a sense of ownership and strong relationships among community members. More than just enhancing social interaction, the strength of a close-knit community can be a primary source for information exchange and assistance. Mcmillan and Chavis (1986) explain that a sense of community involves a feeling of ownership among members, recognizing each other's importance within the group, and having a shared belief that members' needs will be met through collective commitment. Formng a sense of community involves building solidarity, which is expected to increase the involvement and participation of farmers and stakeholders in environmental conservation efforts.

Identified benefits include improved communication and mutual understanding, aligning with the initial targets of CBS. This positive response provides a strong foundation to proceed to the implementation phase of CBS with confidence that this strategy has significant potential in managing conflicts in the Besowo Gadungan Nature Reserve. Additionally, CBS aims to strengthen social relationships among farmers and stakeholders. Through community-building activities, better communication, and increased trust, it is expected that relationships between individuals and groups can become more harmonious, creating a supportive environment. This aligns with Kusworo's (2019) statement that the participation process is designed to provide opportunities for members to engage in planning discussions from the outset. The importance of enhancing interaction and information exchange also becomes the focus of CBS. By facilitating more efficient information exchange, CBS can reduce misunderstandings between parties, find platforms for open discussion, and optimize collaborative potential.

The targets of CBS are to foster unity and shared understanding among farmers and stakeholders. This aligns with Kusworo's (2019) statement that by building trust, strengthening relationships, and providing opportunities for individuals to provide advice or suggestions, conflicts can be resolved by all involved parties. The positive response from respondents indicates that CBS is considered a relevant approach and is expected to make a positive contribution to strained relationships. The strategic targets of CBS include forming a sense of community, active participation in decision-making related to natural resource management, improving communication, and creating a harmonious environment. CBS is directed at involving all parties in the decision-making process, easing tensions through regular meetings, and creating an

open communication environment. Thus, the benefits and targets of CBS are expected to provide a strong foundation for managing potential conflicts and strengthening relationships between farmers and stakeholders in the Besowo Gadungan Nature Reserve.

Community Building Strategy Mechanism

This research explores concrete steps proposed to implement the Community Building Strategy (CBS) in the context of managing potential conflicts between farmers and stakeholders in the Besowo Gadungan Nature Reserve. The results of interviews with farmers and stakeholders yielded positive responses regarding the mechanisms of CBS. The positive response from respondents indicates that CBS mechanisms are considered relevant and aligned with their needs and expectations in managing potential conflicts. Community building mechanisms serve as an essential foundation in executing the community building strategy by bringing community members together, fostering positive relationships, and enhancing social interactions (Lazarus, et al., 2016). The CBS mechanisms offered include the formation of a sense of community, active involvement in decision-making, and the improvement of communication and regular meetings. The positive response from respondents reflects their understanding of these values in addressing conflicts. Although not yet implemented, these mechanisms are considered appropriate steps and are expected to have a positive impact when applied.

One of the key mechanisms of CBS is the formation of a sense of community by making efforts to foster unity among farmers and stakeholders, thus creating a sense of ownership over decisions related to natural resource management in the Besowo Gadungan Nature Reserve. Through activities such as training or social events, individuals and groups are expected to feel actively involved in building solidarity. Furthermore, CBS proposes active participation in decision-making as a crucial mechanism. Reed (2008) shows the importance of stakeholder participation in managing community environments. Farmers and stakeholders are invited to be directly involved in the decision-making process related to natural resource management. This active involvement is believed to increase accountability, reduce uncertainty, and create more sustainable decisions.

Improving communication is also a focus of CBS mechanisms. Through the use of communication tools such as suggestion boxes or online platforms, efficient exchange of ideas and grievances is expected to occur. This mechanism opens up space for open discussions, helps alleviate tension, and builds shared understanding. Additionally, CBS emphasizes the importance of regular meetings as a mechanism to strengthen interactions between farmers and stakeholders. These meetings can serve as platforms to convey information, discuss current issues, and build closer relationships between farmers and stakeholders(Zikargae et al., 2022). Thus, the proposed CBS mechanisms in this study include the formation of a sense of community, active participation, improved communication, and regular meetings. These mechanisms are expected to

serve as concrete guidelines in implementing CBS to manage potential conflicts in the Besowo Gadungan Nature Reserve.

Development of Participation Mechanisms

The development of participation mechanisms begins with identifying the involved parties, including farmers, stakeholders, and various related groups. Through interviews and discussions, the appropriate level of participation for each group is determined by identifying the involved parties such as farmers, the community, conservationists, and authorities to ensure balanced representation in decision-making processes related to natural resource management. This aligns with Atkinson and Willis (2006) emphasizing the importance of building robust community forums and community development strategies for management. The next step in developing participation mechanisms is designing platforms or forums that support interaction and collaboration among relevant parties, including creating discussion spaces, organizing regular meetings, or even establishing joint working groups. This aims to provide facilities that facilitate contributions and active participation from all parties. Reed (2008) demonstrates the importance of stakeholder participation in managing a community environment. The development of participation mechanisms in CBS aims to increase the active involvement of farmers and stakeholders in decision-making related to natural resource management in the Besowo Gadungan Nature Reserve. Interview results show that respondents gave positive responses to the participation concept proposed in CBS. This positive response reflects the respondents' understanding and awareness of the importance of participation in managing conflicts. Although not yet implemented, participation mechanisms in CBS are considered relevant steps and are expected to make a positive contribution to the sustainability of farming practices and environmental conservation in the Besowo Gadungan Nature Reserve. Additionally clear and transparent participation guidelines need to be developed. These guidelines include decision-making processes, rights and obligations of each party, and conflict resolution mechanisms if needed. The development of these guidelines aims to create a fair and organized participatory environment. The importance of training and capacity building is also part of the development of participation mechanisms(Chauhan et al., 2022). Involved parties need to be empowered with the necessary knowledge and skills to participate effectively, including communication training, collaboration skills, and in-depth understanding. By detailing these aspects, the development of participation mechanisms in CBS is expected to create a strong basis for engaging all relevant parties in decision-making related to natural resource management in the Besowo Gadungan Nature Reserve.

Building Trusting Relationships

Building trust begins with identifying potential barriers to trust formation. These factors involve aspects such as perceptual differences, regulatory ambiguity, and past conflict history. By identifying these factors, specific steps can be designed to

address any emerging barriers. Tampubolon (2020) emphasizes the importance of open and honest communication as the primary focus in building trust relationships, encouraging involved parties to share information transparently, including plans, objectives, and policies that may affect them, to create deeper understanding and more effective collaboration. Hyde and Chavis (2007) suggest that community building involves a series of steps and activities aimed at strengthening social bonds and active participation within the community. Furthermore, building trust relationships also involves concrete steps such as developing a shared understanding of cultural differences and values that may influence perceptions. Syamaun (2019) identifies cultural differences that can affect perceptions, including differences in communication styles, thought patterns, daily habits, and values upheld by each culture.

Rumahuru and Gaspersz (2021) highlight the importance of building trust relationships within groups and communities during conflicts. Efforts to build trust relationships in SCB are aimed at creating a strong foundation for effective cooperation between farmers and stakeholders. Although not yet implemented, the positive responses found in interviews indicate that respondents recognize the importance of building trust relationships as a critical step in addressing existing conflicts. The positive response from respondents reflects the understanding and acceptance of the importance of trust by both farmers and stakeholders in the context of conflict management efforts. Although currently in the offering stage, trust-building is expected to provide a strong foundation for further implementation of SCB. Thus, building trust relationships in SCB aims to create a strong basis for positive and collaborative interactions between farmers and stakeholders. Building trust relationships involves efforts to enhance positive and collaborative interactions between farmers with economic interests and stakeholders with environmental conservation interests, including activities such as open dialogue, transparent information sharing, and building shared understanding of the needs and objectives of each party. These efforts are expected to help reduce tension, enhance cooperation, and achieve sustainability in natural resource management in the Besowo Gadungan Nature Reserve.

CONCLUSIONS

The potential for conflict between livestock farmers and stakeholders in the Besowo Gadungan Nature Reserve has been analyzed during the research by identifying causative factors such as lack of communication, differences in perception, and unclear regulations. A conflict management strategy through a community building approach is proposed as a proactive solution. Concrete steps include fostering a sense of community, active involvement in decision-making, continuous communication, and regular meetings. Communication tools such as suggestion boxes or online platforms are proposed to facilitate the efficient exchange of ideas and complaints with the aim of easing tensions and creating a harmonious environment between livestock farmers and stakeholders. The implementation of the community building

strategy is expected to effectively manage potential conflicts, create a balance in the use of natural resources, and strengthen relationships between livestock farmers and stakeholders in the Besowo Gadungan Nature Reserve

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PRODUCERS' PERSPECTIVES OF MODERN SHEEP BREEDS IN SAUDI ARABIA

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ABSTRACT

Sheep (*Ovis aries* L.) farming significantly contributes to food security and is a source of revenue for small-scale breeders in Saudi Arabia. The present study aims to investigate breeders' practices and perceptions on rearing of modern sheep breeds along with their preferences regarding modern farm management. For this purpose, 360 breeders were selected at random, and their responses were collected on a pretested paper-based questionnaire, with 154 breeders agreeing to share information. It was found that most breeders received veterinary extension services and seemed very satisfied. Moreover, the majority of breeders did not receive financial support from the government. Independent *t*-test analysis revealed that the education level significantly influenced breeders' perceptions of modern sheep breeds. Furthermore, age, veterinary extension services, and financial support from the government significantly influenced their preferences regarding modern farm management. The study suggests that veterinary extension programs, through the active involvement of the livestock department and other stakeholders, should be implemented to promote modern sheep breeds and farm management. In addition, the government should facilitate the adoption of these modern sheep farm technologies by enhancing their availability on the market and affordability to breeders.

Keywords: farm management, *Ovis aries* L., perceptions.

INTRODUCTION

The rapid increase in global population has incited food insecurity for future generations. Livestock contributes significantly food security and the incomes of small-scale breeders in many nations, including Saudi Arabia (SA), which holds approximately 26 million individuals of camels, cattle, sheep, and goats, out of which 92 % are sheep and goats. More than 60 % of the sheep and goats are managed by small- and medium-scale breeders for meat and milk production. SA has implemented commercial-scale modes of production for dairy and poultry farms. However, sheep

are generally produced by traditional methods due to adverse agro-climatic conditions (FAO, 2023b).

The International Fund for Agriculture and Development (IFAD) loan and grant projects have proven that livestock can play a key role in poverty reduction in rural areas (Rota and Sidahmed, 2010). Rearing sheep and agriculture together assures availability, access, and quality of food (Seifman and Katz, 2016; Aldosari, 2018). SA fulfills 30 % of its food demands through livestock. Rearing of animals, including sheep, provides direct employment to 250 million people and has been a great source of sustaining Saudi sociocultural heritage (MEWA, 2021).

The Awassi sheep are conventionally shepherded by desert nomads and villagers. Sheep are primarily raised for milk and meat production, and Awassi sheep are sold at high prices due to their fat tail. Moreover, rural residents traditionally make several crafts with their wool (Aldosari, 2018). As of 2021, 12 million individuals of sheep and goats were raised in SA under organic projects. It dropped from the total of 16.07 million individuals of sheep and goats that were raised in 2017 (Puri-Mirza, 2024). The identified causes of low production included limited pasture access, high animal feed costs, traditional farm practices, and climate change. With a huge potential to increase livestock production with the existing inventory of livestock individuals, climate change has been a major challenge, leading to constrained growth of this sector within the country. The use of modern sheep breeds in farming may compensate for the production deficit.

The Sustainable Rural Agricultural Development (SRAD) program (2019–2025) was jointly started by the Ministry of the Environment, Water, and Agriculture (MEWA) and the Food and Agriculture Organization (FAO) within the context of Vision 2030. The program aimed to achieve Sustainable Development Goals (SDGs) by the transformation of animal husbandry (MEWA, 2021). Modern breeding systems and management were introduced in the country to improve technical skills and output. MEWA provided advanced energy and water supply, electric ID, weighing and drafting, head lockers, handling units, feeding technologies, trough and watering, facilities and fences, surveillance, cooling technologies, information technologies, 3D images, and automatic farm cleaning systems. In terms of breeding systems, they acquired photoperiods and hormonal oestrous synchronization, which are widely used in seasonal sheep breeds. These methods are associated with artificial insemination and embryo transfer techniques, in addition to improving meat quality (MEWA, 2021).

Notably, sheep meat is among the top preferred foods among Saudi citizens, followed by camel meat. Because of the low production of sheep meat, SA imports mutton from other countries. According to Business Monitor International (BMI), in 2013, 7584 Mg of mutton were imported from Australia, projecting an increase of 65 % for the same year (BMI, 2016). Moreover, the Observatory of Economic Complexity (OEC) reported that SA imported $2.88 million USD in sheep and goats, ranking as the second largest importer (OEC, 2022). SA imports primarily from Jordan ($118 million), Romania

($80.7 million), Kuwait ($46.1 million), Spain ($32.9 million), and Georgia ($5.62 million) to meet domestic demand.

Mutton imports from other countries increase the economic burden on SA. The only way to increase sheep production is to raise modern sheep breeds and implement modern sheep farm management that allows for the long-term sustainability of sheep populations well-suited for the challenging climate of SA. Sheep breeders raise sheep on traditional farms, but large-scale production of modern sheep breeds has not been achieved. Before raising modern sheep breeds in modern sheep farms, it is critical to understand breeders' perceptions of modern sheep breeds and their preferences for modern sheep farm management. Therefore, the current study aims to assess breeders' perceptions of modern sheep breeds, as well as their preferences for modern sheep farm management. Surprisingly, no studies have been conducted to measure these variables. Based on the findings, long-term strategic plans can be developed.

Differences in sheep breeders' perceptions of modern sheep breeds and their preferences for modern sheep farm management were measured in Dawadmi Governorate, SA, based on socioeconomic characteristics. Thus, the hypothesis was proposed as follows: H1: Age, education, breeders' experiences, veterinary extension services, and financial support affect sheep breeders' perceptions of modern sheep breeds; H2: Age, education, breeders' experiences, veterinary extension services, and financial support influence sheep breeders' preferences for modern sheep farm management.

MATERIALS AND METHODS

Study area

This study was conducted in the Dawadmi Governorate, which is located to the northwest of the Riyadh region. This governorate shares its borders with Shaqra and Murat Governorates to the east, Afif Governorate to the west, and Al-Rass Governorate (administratively affiliated with Al-Qassim region) to the north. To the south, it is bordered by Unaizah Governorate, Al-Mithnab Governorate, and Al-Bukayriyah Governorate, all of which are administratively part of the Qassim region. It covers approximately 28 000 km^2 and is ranked fifth among the governorates in the region in terms of area (Gomaa *et al.*, 2023).

Research sample

Out of 5690 sheep breeders who received health cards from the Ministry of Environment, Water, and Agriculture (MEWA) in Dawadmi Governorate (FAO, 2024), 360 were selected using a simple random sampling technique. The sample size calculator was used to determine the sample size (confidence interval, 95 %; margin of error, 5 %; population proportion, 50 %; and population size, 5690). A questionnaire was distributed among sheep breeders, in their local language, at various centers of

the Dawadmi Governorate. They were informed about the objectives of the study and assured that the data would be utilized for research purposes. Out of 360 questionnaires sent, 154 (around 43 %) were returned by the respondents in complete. After the completion of the pilot test, the final survey was conducted in Dawadmi governorate. The data were collected over a 12-week period from February until the end of April 2022.

Research instrument

The questionnaire was reviewed by a group of researchers of the College of Food and Agriculture Sciences at King Saud University. The questionnaire contained five sections. Demographic details were included in the first section. Questions about age, education, sheep farming experiences, sheep breeds, and financial support from the government and the veterinary extension services were measured using a nominal scale (0 = no; 1 = yes). The breeders' age (1 = young; 2 = older), education (1 = school education; 2 = higher education), and experience (1 = low; 2 = high) were computed as new nominal variables using their raw scores. Respondents aged 18 to 38 years were classified as young, while those aged 38.1 to 89 years were classified as older. Respondents with primary, secondary, and intermediate education were classified as having a low level of education, whereas those with college and university education were classified as having a high level of education. Respondents with 2–15 years of sheep farming experience were classified as having a low level of experience, whereas those with 16 or more years of sheep farming experience were classified as having a high level of experience.

The second section measured the sheep farming methods (1 = traditional method; 2 = semi-traditional method; 3 = modern method) and how breeders managed sheep breeds (1 = managed by workers; 2 = managed by specialized technicians; 3 = managed by the owner). The third section included questions on breeders' perceptions of modern sheep breeds using a five-point Likert scale (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). The fourth section contained questions about breeders' satisfaction with veterinary extension services, which were also measured using a five-point Likert scale (1 = very dissatisfied; 2 = dissatisfied; 3 = slightly satisfied; 4 = satisfied; 5 = very satisfied). The last section of the questionnaire covered questions about the breeders' preferences regarding modern farm management. This variable was also measured using a five-point Likert scale (1 = strongly unpreferred; 2 = unpreferred; 3 = neutral; 4 = preferred; 5 = strongly preferred) (Joshi *et al.,* 2015).

Data analysis

Both descriptive and inferential statistics were used for summarizing and analyzing the collected data. The demographic characteristics of the respondents, sheep farming methods, and sheep farming management were summarized using frequencies and percentages. To determine differences in the breeders' perceptions of modern sheep breeds and their preferences regarding modern farm management due to their

personal demographics, parametric statistics were used. For the nominal variables with two categories (age, education level, farming experience, veterinary extension services, and financial support from the government), the independent *t*-test was used. The statistical package for social sciences (IBM SPSS, version 28.0) was used for running the data analysis.

RESULTS AND DISCUSSION

More than three-fifths of the breeders were old, while less than two-fifths of them were young (in the age bracket of 18–38 years). Around three-fifths of the breeders had higher education. More than two-fifths of them had school-level qualifications. More than three-fourths of the respondents earned less than 10 000 SR per month, while less than one-fourth earned more than 10 000 SR to less than 15 000 SR. A large number of breeders had low experience in sheep farming (2–15 years), and more than one-fourth had high experience. The majority of breeders were employed in the government sector, whereas less than 10 % were employed in the private sector, students, or employed in other sectors. More than one-tenth of the breeders were retired and jobless.

Regarding sheep breeds, more than one-fourth of the breeders raised Najdi, and around two-fifths raised Naimi, whereas more than three-fifths of the breeders raised Awassi. Less than 10 % of the breeders raised other breeds. Around three-fifths of the breeders received veterinary extension services. Around one-fourth of the breeders received financial support from the government (Table 1).

Less than three-fourths of the breeders adopted traditional and semi-traditional methods for sheep breeding methods, while more than one-fourth adopted modern sheep breeding methods. A large number of the farms were managed by owners. One-fourth of the farms were managed by workers. A smaller number of the farms were managed by specialized technicians. The findings of the study revealed that most of the breeders operated their farms themselves and followed traditional farm practices (Table 2).

Breeders' responses were arranged in descending order according to the average score for each statement. The average score ranged from a maximum of 4.28 to a minimum of 3.94. More than 80 % of breeders believed that using modern breeds is part of agriculture, that herds of modern breeds are easy to manage, that modern breeds improved production efficacy, and that modern breeding improved herd health. More than three-fourths were convinced that modern breeding helps to the preservation of feed safety, that modern breeds are better than traditional technologies, and that modern breeds are adapted to climate change. More than 70 % of breeders believe that modern breeds are more efficient, increase income, have lower mortality rates, and reduce feed costs. Around 67 % of breeders were convinced that the percentage of twins increased with modern breeding (Table 3).

Table 1. Frequency and percentage of socioeconomic characteristics of sheep breeders, sheep breeds, veterinary extension services, and financial support evaluated in the Dawadmi Governorate, Saudi Arabia (n = 154).

Variables	n	Percentage
	Age	
18 to 38 years	54	35.1
39 to 89 years	100	64.9
	Education	
School education	64	41.6
Higher education	90	58.4
	Monthly income	
Less than 5000 SR	63	40.9
5000 to less than 10 000 SR	55	35.7
10 000 to less than 15 000 SR	30	19.5
15 000 SR or more	6	3.9
	Farming experience	
Low experience	110	71.4
High experience	44	28.6
	Profession	
Government	99	64.3
Private	12	7.8
Retired	19	12.3
Student	3	1.9
No job	18	11.7
Others	3	1.9
	Breeds of sheep	
	Najdi	
No	106	68.8
Yes	48	31.2
	Naimi	
No	95	61.7
Yes	59	38.3
	Awassi	
No	51	33.1
Yes	103	66.9
	Others	
No	140	90.9
Yes	14	9.1
	Received veterinary extension services	
No	64	41.6
Yes	90	58.4
	Financial support from the government	
No	108	70.1
Yes	46	29.9

n: sample size.

Table 2. Frequency and adoption percentage of sheep breeding methods and farm management among sheep breeders evaluated in the Dawadmi Governorate, Saudi Arabia (n = 154).

Variables	n	Percentage
Methods of sheep breeding		
Traditional methods	68	44.2
Semi-traditional methods	44	28.6
Modern methods	42	27.3
Management of sheep farming		
Managed by workers	39	25.3
Managed by specialized technician	8	5.2
Managed by the owner	107	69.5

n: sample size.

Table 3. Percentage, mean, and standard deviation (SD) of sheep breeders' perceptions on modern breeds in the Dawadmi Governorate, Saudi Arabia (n = 154).

Items	Strongly disagree %	Disagree %	Neutral %	Agree %	Strongly agree %	Mean	SD
Using modern breeds is part of agriculture	0.6	3.9	14.3	29.2	51.9	4.28	0.89
The herds of modern breeds are easy to manage	2.6	4.5	11.0	28.6	53.2	4.25	1.00
Modern breeds improve production efficacy	1.3	3.9	13.6	32.5	48.7	4.23	0.92
Modern breeding improves herd health	3.9	3.2	12.3	32.5	48.1	4.18	1.03
Modern breeding helps to maintain feed safety	3.9	3.2	15.6	29.2	48.1	4.14	1.05
Modern breeds are better than traditional technologies	2.6	4.5	16.9	27.9	48.1	4.14	1.02
Modern breeds are more efficient	0.6	7.1	19.5	24.0	48.7	4.13	1.00
Modern breeds are adapted to climate change	1.9	7.1	13.6	31.2	46.1	4.12	1.02
Modern breeding improves income	1.3	7.8	16.9	35.7	38.3	4.02	0.99
Mortality rate is lower with modern breeding	3.9	4.5	18.8	32.5	40.3	4.01	1.06
Modern breeding reduces feed cost	3.9	3.9	20.8	30.5	40.9	4.01	1.06
Percentage of twins is increased with modern breeding	2.6	4.5	26.0	29.9	37.0	3.94	1.02

More than three-fifths of breeders agreed with the statement that modern sheep breeding is more profitable and desirable. More than one fourth of the breeders were neutral, and less than 5 % of the breeders disagreed with modern sheep and goat breeding (Table 4).

For successful sheep breeding, a vibrant linkage with veterinary services is mandatory. In this regard, more than one-fourth of the breeders were very satisfied with the veterinary extension services (Table 5). These findings differ from those of Jain *et al*. (2016), who found that the majority of the breeders were not highly satisfied with the veterinary extension services delivered by the State Department of Animal Husbandry

Table 4. Percentage of overall breeders' perceptions of modern sheep breeds in the Dawadmi Governorate, Saudi Arabia.

Perception level	%
Negative	4.5
Neutral	29.2
Positive	66.2

Table 5. Percentage of breeders' satisfaction level regarding veterinary extension services in the Dawadmi Governorate, Saudi Arabia.

Satisfaction level	%
Very dissatisfied	15.6
Dissatisfied	14.3
Slightly satisfied	18.8
Satisfied	16.9
Very satisfied	34.4

(SDAH) in Rajasthan, India. The high satisfaction level of the breeders in the study area might be the consequence of regular contact with extension offices. Kassem *et al*. (2021) reported that regular contact with extension offices improved satisfaction. Apart from personal attributes, economic advantages gained from the veterinary extension services could be a major determinant for satisfaction (Elias *et al*., 2016). Sheep farming gives direct financial profits and social protection during poor harvest years (Getachew *et al*., 2010).

There are various attributes of modern farm management, starting from fodder selection to market selection, which significantly affect the choice of a breed, its rearing, and market targeting. In this research, the average score ranged from a maximum of 4.24 to a minimum of 3.82. More than four-fifths of breeders preferred to work with veterinarians to manage a herd and preferred modern breeding methods, whereas less than four-fifths preferred balanced diets and implementing instructions provided by the National Livestock Improvement Program. More than three-fifths of the breeders preferred modern technologies to manage their farms (Table 6).

Around half of the respondents preferred modern sheep farm management, whereas more than two-fifths were neutral and less than 10 % did not prefer modern sheep farm management (Table 7). The high preference for modern sheep breeds might be due to the high education among breeders. It is understandable that higher education improves understanding of complex information. Educated breeders might have received innovative information through training, workshops, and extension

Table 6. Percentage, mean, and standard deviation (SD) of breeders' preferences regarding modern sheep farm management in the Dawadmi Governorate, Saudi Arabia.

Items	Strongly unpreferred %	Unpreferred %	Neutral %	Preferred %	Strongly preferred %	Mean	SD
I work with veterinarians to manage the herds	0.6	3.9	13.6	34.4	47.4	4.24	0.87
I prefer modern breeding methods	0.00	4.5	13.6	36.4	45.5	4.23	0.85
I prefer balanced diets	0.00	4.5	16.2	36.4	42.9	4.18	0.86
I implement instructions provided by the National Livestock Improvement Program	0.00	6.5	19.5	28.6	45.5	4.13	0.94
I prefer modern technologies to manage my farm	3.2	9.1	26.6	24.7	36.4	3.82	1.12

Table 7. Overall breeders' preferences towards modern sheep farm management in the Dawadmi Governorate, Saudi Arabia.

Preference level	%
Unpreferred	9.1
Neutral	44.8
Preferred	46.1

programs that probably improved their perception of modern sheep breeds (Noor and Dola, 2011; Thakur *et al*., 2019).

There were significant differences in the breeders' perception of sheep breeds based on their level of education (t = -3.11; p < 0.05). Highly educated breeders had a more positive perception of modern sheep breeds than less educated breeders; the difference in the means represented a medium effect (Cohen's d = 0.5). Regarding breeders' preference towards modern sheep farm management, there were significant differences based on their age (t = 2.05; p < 0.05), veterinary extension services (t = -3.30; p < 0.05), and financial support from the government (t = -2.37; p < 0.05). Older breeders preferred modern sheep farm management practices more than young breeders; the difference in the means represented a small effect (Cohen's d = 0.35). The breeders who received veterinary extension services showed a higher preference towards modern sheep farm management than those who did not; however, the effect was medium (Cohen's d = 0.52). The breeders who received financial support from the government showed a high preference towards modern sheep farm management as compared to those who did not receive any financial support. The computed effect was also small (Cohen's d = 0.45) (Table 8).

Table 8. Differences in sheep breeders' perceptions of modern sheep breeds and their preferences regarding modern sheep farm management according to age, education, breeders' experiences, veterinary extension services, and financial support in the Dawadmi Governorate, Saudi Arabia.

	Breeders' perceptions of modern sheep breeds				Breeders' preference for modern sheep farm management			
Variables	Mean	SD	*t*	Sig(2-tailed)	Mean	SD	*t*	Sig(2-tailed)
				Age				
18–38 years (n = 54)	4.25	0.74	1.51	0.13	4.28	0.62	2.05	0.04
39–89 years (n = 100)	4.05	0.80			4.03	0.77		Cohen's d = 0.35
				Education				
School education (n = 64)	3.89	0.85	-3.11	0.00	4.05	0.76	-0.88	0.37
Higher education (n = 90)	4.28	0.69		Cohen's d = 0.50	4.16	0.77		
				Breeders' experience				
Low experience (n = 110)	4.16	0.72	1.21	0.22	4.15	0.69	0.87	0.38
High experience (n = 44)	4.00	0.93			4.03	0.83		
				Veterinary extension services				
No (n = 64)	3.99	0.80	-1.69	0.09	3.89	0.79	-3.30	0.00
Yes (n = 90)	4.21	0.76			4.27	0.64		Cohen's d= 0.52
				Financial support				
No (n = 108)	4.08	0.81	-0.76	0.44	4.02	0.76	-2.37	0.01
Yes (n = 46)	4.19	0.70			4.33	0.60		Cohen's d= 0.45

SD: standard deviation; *t*: *t* student test.

The findings of this study revealed that the socio-economic characteristics have a significant relationship with breeders' perceptions of modern sheep breeds and their preference towards modern farm management. Inferential analysis revealed significant differences in the perceptions of modern sheep breeds. Education levels also showed significant differences, as highly educated breeders had positive perceptions, likely demonstrating dedication and preference for learning about modern sheep breeds to achieve sustainable production (Martín-Collado *et al*., 2021).

Previous findings revealed that educated breeders in SA improved the survival rate of sheep flocks by adopting modern breeds (Ali *et al*., 2020). Haile *et al*. (2020) reported that the breeders' perceptions can be improved through repeated training and awareness programs. For instance, MEWA and FAO cooperation formulated the Sustainable Rural Agricultural Development (SRAD) program (2019–2025), focusing on improving incomes in the livestock sector. The challenge of low productivity was addressed by

promoting modern breeding technologies and advanced farm management practices among small-scale livestock herders. Farm demonstrations were arranged to educate participants in terms of sustainable farm productivity, safe and low-cost animal feed, organized milk and wool processing infrastructures, enhanced marketing networks, farm management, and management of local breed resources (FAO, 2023a). MEWA has organized a visit of international experts to SA and signed an agreement in order to promote modern livestock breeds, modern farm management, productivity, and food security (FAO, 2022).

Positive perceptions of modern sheep breeds might be a consequence of the breeders' participation in the training and farm demonstrations. Toma *et al*. (2018) argued that the provision of appropriate educational or relevant information transfer could influence breeders' perceptions and intent to adopt. According to researchers' observations, educated breeders hold deep understandings of the advantages of modern breeds. Breeders stated that modern breeds contained genetic diversity, which improved disease resistance and allowed for the sustainability of sheep populations well suited to the challenging climate conditions of the study area. Caihong (2023) reported similar advantages of modern breeds. Furthermore, educated farmers in the study area believed that the higher perception of modern breeding is an output of modern knowledge gained from various educational programs arranged by the veterinary extension department.

Results revealed that older breeders preferred modern sheep farm management. It is understandable that they may have extensive experience, and it is reasonable to assume that they will achieve good results with modern farm management. Holmøy *et al*. (2012) reported that experienced breeders hold a high understanding of the socio-economic advantages of modern sheep farm management. Lianou and Fthenakis (2021) found an association between experience and farm management. Moreover, Martín-Collado *et al*. (2021) confirmed that experience is one of the major factors that increase preferences for modern sheep farm practices. Older farmers have more experience and may be better able to learn advanced information about modern farm management. It is reasonable to expect older breeders to be responsible for their own livelihoods and income.

Sheep farming provides direct cash profits and social security during bad crop years (Getachew *et al*., 2010). According to researchers' observations, older sheep breeders seemed interested in modern sheep farm management because of its socio-economic and cultural values. They stated that modern sheep farm management improved their annual incomes and enabled them to meet their socio-economic needs, whereas young breeders seemed less interested in sheep farming and preferred to get jobs away from rural areas. Similar observations were recorded by Papadopoulos (2006), who found that modern sheep farm management increased farm productivity and incomes. Breeders' agreement with the advantages of modern farm management also was validated by Simões *et al*. (2021), who found that the understanding of modern farm management is the key to achieving sustainable sheep production in the future,

allowing breeders to understand and implement high-yielding techniques, nutrition, reproductive patterns, genetic improvements, and modern reproductive techniques (Simões *et al*., 2021).

The findings of this study also point out that breeders who received veterinary extension services preferred modern sheep farm management, implying that they are aware of its advantages. This is consistent with Asaduzzaman *et al*. (2021), who reported that veterinary extension services provide information about disease and causes of mortality. Poor veterinary extension services discourage modern sheep breeding, farm management, and production. MEWA and other stakeholders are working together to strengthen the capacity of small-scale livestock breeders through learning processes (FAO, 2023a).

The veterinary extension services in SA established farm demonstrations and presented the advantages of modern farm management in terms of sustainable productivity. Moreover, these services benefit breeders in terms of safe animal food, reduced feeding costs, feed imports, organized milk and wool processing infrastructure, enhanced marketing networks, a functional digital livestock information management system, conservation and utilization of local animal genetic resources, attainment of animal food self-sufficiency, and movement towards one-health. The unique animal genetic resources, socio-cultural dimensions, and increasing demand offer investment opportunities and can be the keystone of resilient and sustainable livestock development in SA (FAO, 2023b).

Previous research also indicates that veterinary extension services can shift breeders' preferences from traditional to modern sheep farm management (Aman *et al*., 2019; Martín-Collado *et al*., 2021; Dabiah *et al*., 2023; Muddassir and Alotaibi, 2023). The veterinary extension department educates breeders on scientific animal husbandry practices, modern breeds, and farm management (Jena *et al*., 2019). Veterinary extension services in SA consolidated modern farm management and improved farm production. MEWA and FAO jointly provide required materials, medicines, vaccines, and small equipment to achieve sustainable modern sheep breeds (UNSA, 2022). In response to the underuse of modern sheep farm management practices, the SRAD program established farm demonstrations to enhance productivity through natural resource management and promote diversification and incomes for smallholders, including sheep breeders, with a focus on rural youth and women (FAO, 2024).

Results also explain the significance of external financial support in the success of modern sheep breeding. It is clear from the findings that breeders who received financial support from the government preferred modern farm management. Financial support enables them to purchase modern farm tools to accomplish sustainable productivity. In turn, it might change breeders' preferences regarding modern sheep farm management, such as the adoption of modern breeds and management techniques to achieve desirable outcomes. According to the researchers' observations, breeders sought financial support to gain more benefits. Moreover, breeders in the study area stated that they could establish modern sheep farms and improve production if they

received financial support from the government. Similar findings were reported by Aldosari (2018).

There are increasing concerns of the Saudi government towards modern sheep farm management. In previous decades, the government has formulated several policies to support sheep breeders. The modern sheep farming system was among the supported sectors, in which breeders received financial support to increase farm production, upgrade traditional farm management, and subsidize feed prices (Ameen *et al*., 2019). These findings are consistent with those of Vaintrub *et al*. (2021), who revealed that financial support for sheep breeding and modern farm management is crucial. The lack of support hinders extensive breeding and reduces preference for modern sheep farm management. Similarly, Bartolini and Viaggi (2012) found that financial support for sheep breeders increased farmers' interest in modern farm management. As a result, financial support for sheep breeders in the study area is expected to increase breeders' preference for modern sheep farm management.

CONCLUSIONS

Modern sheep breeds and farm management have significant value for breeders, especially those whose income partially or totally depends on livestock rearing and marketing. The education level of breeders showed a significant relationship with their perceptions of modern sheep breeds. Moreover, age, veterinary extension services, and financial support had a significant impact on their attitudes toward modern sheep farm management. It is critical that the government create a framework to inform breeders about modern sheep breeds and farm management and that the veterinary extension department develop a capacity-building program to strengthen modern sheep breeds in remote areas where sheep farming is the primary source of income for breeders.

Breeders' participation in raising modern sheep breeds can be encouraged by providing improved veterinary extension services that help breeders develop their skills. Moreover, the extension department should arrange programs, workshops, and training sessions to improve commercial sheep farming. Commercial benefits may encourage breeders to learn and implement modern breeding systems and farm management. The findings of this study may not be relevant for breeders in other geographical regions; therefore, a similar study should be conducted in other sheep and goat farming regions in Saudi Arabia.

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Agrociencia

EFFECT OF SUBSTRATE WATER CONSUMPTION AND FERTILIZATION LEVELS IN THE YIELD OF STRAWBERRY (*Fragaria x ananassa* Duch.)

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ABSTRACT

Few greenhouse studies have been carried out to evaluate the effect of substrate water consumption before the application of nutrient solutions with different electrical conductivity (EC) values. The objective of this study was to evaluate the effect of two levels of substrate water consumption for moisture replenishment and three EC values of the Steiner solution on the yield and fruit quality of a strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). A randomized block split-plot design with four replicates was used. The bigger plot consisted of the water consumption assessment at levels of 350 and 700 mL, which corresponded to 11.29 and 24.19 %, respectively, of the water volume contained in the saturated substrate (after free drainage). In the smaller plot, three EC levels of the Steiner solution (0.5, 0.75, and 1 dS m^{-1}) were evaluated for a total of six treatments. The main factors analysis showed that yield (g $plant^{-1}$), fruit per plant, fruit weight, degrees Brix, and vitamin C content were higher at the 700 mL intake and the ECs of 0.5 and 0.75 dS m^{-1}. The interaction between factor levels revealed that all response variables were higher for the 700 mL consumption and the EC of 0.5 and 0.75 dS m^{-1} and lower for the EC of 1 dS m^{-1}. On the other hand, for the 350 mL consumption, a decreasing trend of the same response variables was observed as the EC increased. In addition, the combination of 700 mL water consumption and the EC of 0.75 dS m^{-1} resulted in the highest values of these variables.

Keywords: Steiner solution, electrical conductivity, water stress.

INTRODUCTION

Strawberries (*Fragaria x ananassa* Duch.) have a large demand in Mexico and in many developed countries (Romero-Romano *et al*., 2012) due to the crop's high content of micronutrients and antioxidants such as vitamin C and folic acid (Aguilar-Tlatelpa *et al*., 2019; Arriaga-López *et al*., 2023). In 2021, Mexico recorded a production of

442 150.81 Mg on a surface of 10 149.47 ha, with an average yield of 43.56 Mg ha^{-1}. The states with the largest strawberry production in the country are Michoacán, Baja California, and Guanajuato (SIAP, 2022). The countries with the biggest production are China, the United States, Mexico, Turkey, and Egypt, representing 70 % of the worldwide production. Mexico is third in the production and export of strawberries (Ramírez-Padrón *et al*., 2020; FAO, 2022).

For better phytosanitary control, nutrient application, and water use, strawberries and diverse horticultural plants are grown in greenhouses in containers with substrate (Aydi *et al*., 2023; Nakro *et al*., 2023). Substrates are materials composed of one or more combinations of different sources, such as coconut fiber, stone wool, peat, perlite, vermiculite, tezontle, and others. The physical and chemical properties of the materials used vary broadly, and their characterization is important in determining the capacity of the substrate to store and release water and nutrients (Gruda, 2019). Organic substrates such as peat have the highest cationic exchange capacity values (90 to 140 cmol kg^{-1}), while inorganic compounds such as perlite have lower values (25 to 35 cmol kg^{-1}) (Silber, 2019).

Substrates must be highly water-retentive and available for plant roots, with an adequate porosity that allows a suitable air and water supply for their growth (Bhat and Hussain, 2023). Because some substrates are inert, nutrients must be applied in the precise amounts and proportions that the plants need (Guan *et al*., 2023). Regarding this, Steiner (1961) developed a procedure to formulate a nutrient solution for crops, considering the relation of ions, pH, and electrical conductivity (EC).

Earlier studies show that the growth and yield of strawberry crops depend on the pH and EC of the Steiner solution (Preciado-Rangel *et al*., 2020; Hernández-Valencia *et al*., 2022). High EC values can reduce the rate of CO_2 intake and the transpiration rate of the plants due to the high absorption of Na^+ and Cl^-, which causes an imbalance in the availability of nutrients (Wu and Kubota, 2008). Studies carried out by González-Jiménez *et al*. (2020) on strawberry cv. Festival showed that when the EC of the Steiner solution is equal to or greater than 2.7 dS m^{-1}, the foliar concentration of P and Mg is reduced by up to 50 %, but the vitamin C content increases up to 34 %.

For optimal growth and yield, it is necessary to supply the required amount of water at the right time so plants can maintain a high transpiration rate that dissipates the solar radiation they absorb (Ramos-Tamayo *et al*., 2023, Márquez-Zambrano *et al*., 2023). When the water availability of the substrate decreases, so does the transpiration rate. If water stress becomes severe, the opening of the stomata decreases, affecting the entry of CO_2 to the leaves and reducing the rate of photosynthesis (Fischer *et al*., 2022; Maldonado-Peralta *et al*., 2022). On the other hand, when a very high humidity rate is maintained, oxygen availability for plants can be affected, thus also affecting growth and yield. Based on the sensitivity of the crop to water and oxygen deficits in the root zone, an adequate range of substrate humidity fluctuations must be maintained for the optimum development of the plants.

Few studies at a greenhouse level have evaluated the combined effect of different water consumption levels of the substrate before irrigating with different EC values of the nutrient solution. Therefore, under the hypothesis that the combined effect of the water consumption level of the substrate and the electrical conductivity of the Steiner solution affects the yield and quality of fruits in a strawberry crop, this study aimed to evaluate the effect of two water consumption levels for the replacement of humidity and three EC levels of the Steiner solution on fruit yield and quality.

MATERIALS AND METHODS

The study was carried out in the 2022 summer-fall cycle in a chapel-style greenhouse (16 m wide, 24 m deep, and 9 m high) covered with a diffused, high-density polyethylene (0.94 g cm^{-3}, 80 % diffusivity) with one zenithal and several lateral windows. The greenhouse is located in the facilities of the Antonio Narro Autonomous Agrarian University, in Buenavista, Saltillo, Mexico (25° 23′ 42″ N and 100° 59′ 57″ W, at an altitude of 1745 m).

In this study, strawberry plants (*Fragaria x ananassa* Duch.) cv. Albion were used. This cultivar grows on short and long photoperiod days, producing fruits with good quality and size. Fruits are easy to gather and have an extended shelf life. They are resistant to adverse weather conditions and diseases such as anthracnose, *Vercillium*, and *Phytophthora*, and pests such as the spider mite (*Tetranychus* sp.) (Eurosemillas, 2019).

A total of 24 polyvinyl chloride (PVC) containers (NMX-E-199/1), 19.4 cm inside diameter and 20 cm tall, were used for the plant establishment and growth. At one end of each container, a double layer of plastic mesh with a diameter of 1 mm was placed, on which filter paper (80 g m^{-2}) was fixed. The containers were used as weighing lysimeters; therefore, all of them were adjusted to the same weight (950 g) with small metallic discs.

Each container was filled with 800 g (dry weight) of a composite substrate (based on volume) consisting of 70 % *Sphagnum* peat (Premier brand, Pro-Mix, Inc., Quebec, Canada) and 30 % perlite with a bulk density of 0.09 g cm^{-3} (Termolita, S.A.P.I. de C.V., Monterrey, Mexico), which reached a height of a 17 cm container, equivalent to a substrate volume of 5.025 L. The average dry weight of the container and the substrate was 1750 g. The highest level of water retention of the substrate in the container (saturated substrate, after free drainage) was 3100 mL, equivalent to 616.9 mL of water per liter of the substrate.

Treatments and statistical evaluation

A randomized block design arranged in divided plots with four replicates was used to evaluate the effect of the substrate's water consumption before irrigation and the EC of the nutrient solution (Steiner). The largest plot was used for the substrate water consumption evaluation with levels of 350 and 700 mL, which corresponded to 11.29

and 24.19 % of the volume of water contained in the saturated substrate. The smallest plot consisted of three EC levels of the Steiner solution (0.5, 0.75, and 1 dS m^{-1}), for a total of six treatments. The experimental unit was one plant per repetition of each treatment. Multiple treatment means were compared using Tukey's test ($p \leq 0.05$).

Transplanting, irrigation, and fertilization

The strawberry seedlings were transplanted on June 9, 2022, in PVC containers with peat and perlite substrate (70 and 30 % v/v). Irrigation was applied by sub-irrigation (capillary rise), placing the containers inside plastic boxes. The nutrient solution was added to the boxes up to a height of 20 cm so that the solution entered the container from the bottom and reached the surface through the capillary rise. This way, the water (with the nutrient solution) fills the porous space of the substrate. Once the substrate becomes saturated, the nutrient solution contained in the box and the excesses drained out of the containers were recovered in bottles using valves connected to the bottom of the boxes for reuse and to avoid wasting water and nutrients and polluting the environment.

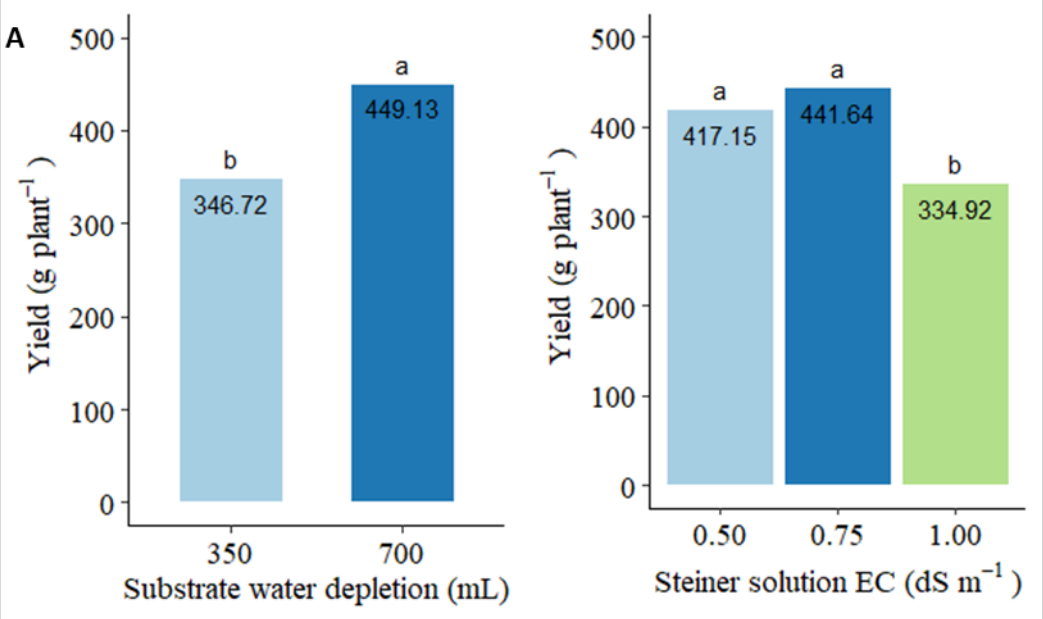
Steiner nutrient solutions with ECs of 0.5, 0.75, and 1 dS m^{-1} and pH levels of 6 to 6.5 were used, with 98 % sulfuric acid added for adjustment. To eliminate the concentration of salts in the substrate and avoid modifications to the nutrient solution, every time the EC of the corresponding treatment increased by 0.2 dS m^{-1}, the substrate was washed using distilled water. The weight for irrigation to be applied was determined by the difference between the weight of the container and saturated substrate (4850 g) and the consumption of water of the corresponding treatment (350 and 700 mL), using a digital scale with a capacity of 10 kg and a precision of 1 g.

Response variables

Harvests were carried out on different dates based on the degree of maturity of the fruit. The first cut was on August 15, 2002, and finished on September 17, 2022. In each cut, the number of fruits per plant was obtained. At the end of the harvest, the total number of fruits per plant was determined, along with their corresponding weight (of all cuts performed). The fruits harvested in each cut were weighed using a digital precision scale. Soluble solids were measured using a refractometer (Spectrum Technologies, 2801, USA). The vitamin C content of the fruits from the different treatments was determined using the methodology described by Padayatt *et al*. (2001).

RESULTS AND DISCUSSION

For the different EC levels of the Steiner solution, yield (g $plant^{-1}$) was 29.54 % higher in plants with a consumption of 700 mL of water for the application of irrigation from the saturated substrate compared to a consumption of 350 mL (Tukey, $p \leq 0.05$) (Figure 1A), which indicates that maintaining an elevated water level in the substrate affects root function and reduces yield. For any level of water consumption in the substrate,



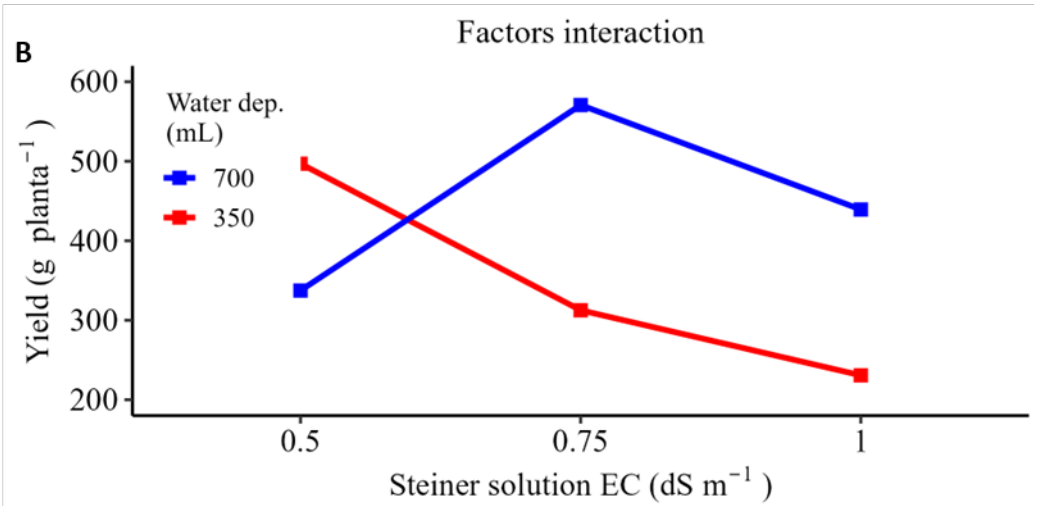


Figure 1. Effect of substrate water consumption for irrigation and electrical conductivity (EC, dS m^{-1}) of the Steiner solution on yield (g plant^{-1}) of the strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). A: Effect of the main factors; B: effect of the interaction of the factor's levels.

yield was equivalent in EC levels of 0.75 and 0.5 dS m^{-1}, and these, in turn, were higher than that observed at 1 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 1A). The yield was 31.84 % higher at an EC of 0.75 dS m^{-1} than that obtained at 1 dS m^{-1}, indicating that plant yield decreases at high EC levels of the Steiner solution.

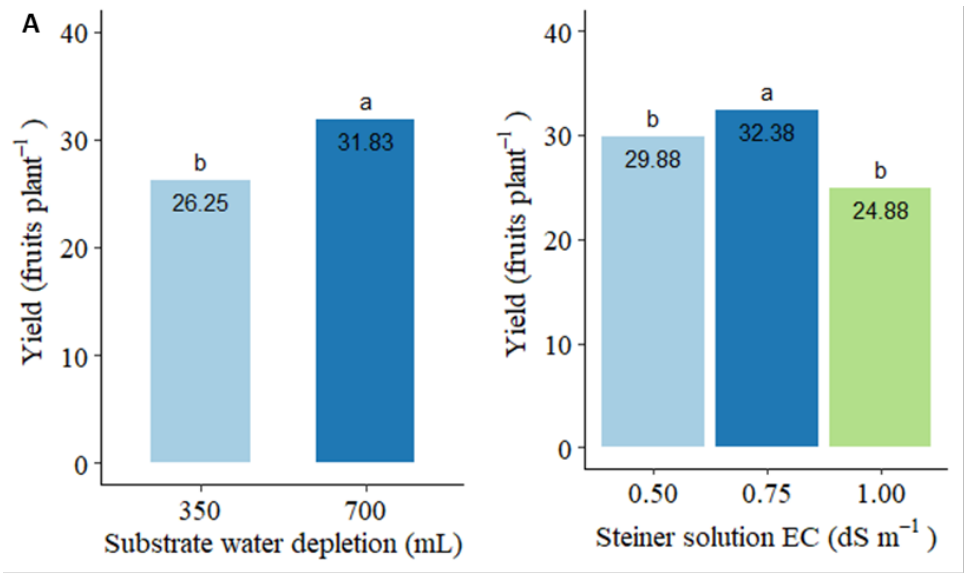
The interaction between the water consumption of the substrate and the EC of the Steiner solution showed that, for the consumption of 700 mL of water by the substrate, the highest yield appeared at 0.75 dS m^{-1} and decreased towards 0.5 and 1 dS m^{-1} (Figure 1B). For the consumption of 350 mL, yield decreased with the increase in the value of EC in the solution. The highest yield (570.72 g $plant^{-1}$) corresponded to the combination of 700 mL and 0.75 dS m^{-1}, and it was 1.47 times higher than the combination of 350 mL and 1 dS m^{-1} (Tukey, $p \leq 0.05$). This result shows that the substrate's high humidity and the Steiner solution's EC affect the plant yield.

In this study, the average yield observed was 397 g $plant^{-1}$. In an investigation on drip irrigation with treatments based on moisture replacement at tensions of 15 and 30 kPa in strawberry plants cv. Monterrey and Seascape, Cormier *et al*. (2020) reported yields ranging between 360 and 441 g $plant^{-1}$. For cv. Albion under deficit irrigation with reductions of 15 and 30 % below the reference evapotranspiration, average yields of 260.66 g $plant^{-1}$ were reported (Adak, 2019), which are lower than those obtained in this study.

Ahmed and Gad (2022), in strawberry cv. Festival planted in a perlite and vermicompost substrate with an irrigation level of 100 % of the reference evapotranspiration, obtained a yield of 789.67 g $plant^{-1}$, higher than that obtained in this study. Results indicate that when EC is higher than 0.75 dS m^{-1}, the yield of strawberry cv. Albion decreases. Similar results were reported by Denaxa *et al*. (2022) in cv. Camarosa and Rociera when increasing the EC of the nutrient solution from 0.4 to 4 dS m^{-1}, leading to a yield reduction in each variety of 29.1 and 22.7 %, respectively.

For the different levels of EC of the Steiner solution, yield (fruits per plant) was also higher (21.25 %) for the consumption of 700 mL than the one observed in 350 mL (Tukey, $p \leq 0.05$) (Figure 2A). For both humidity consumption levels by the substrate, the highest yield (fruits per plant) was obtained in the EC of 0.75 dS m^{-1}; its value decreased to 0.5 dS m^{-1}, and it was lower than 1 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 2A). Yield decreased by 30.14 % when EC increased from 0.75 to 1 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 2A).

The interaction between humidity consumption by the substrate and the EC of the Steiner solution displayed a very similar relation to that observed for yield. The highest value (41 fruits per plant) was observed in the consumption of 700 mL and an EC of 0.75 dS m^{-1}, and decreased in the EC of 0.5 and 1 dS m^{-1} (Figure 2B). On the other hand, for the consumption of 350 mL, yield (fruits per plant) decreased with the increase in EC of the Steiner solution. The higher yield (fruits per plant) was obtained in plants with the treatment with 700 mL and an EC of 0.75 dS m^{-1}, and the lowest one, in plants with the treatment with 350 and an EC of 1 dS m^{-1} (Tukey, $p \leq 0.05$).



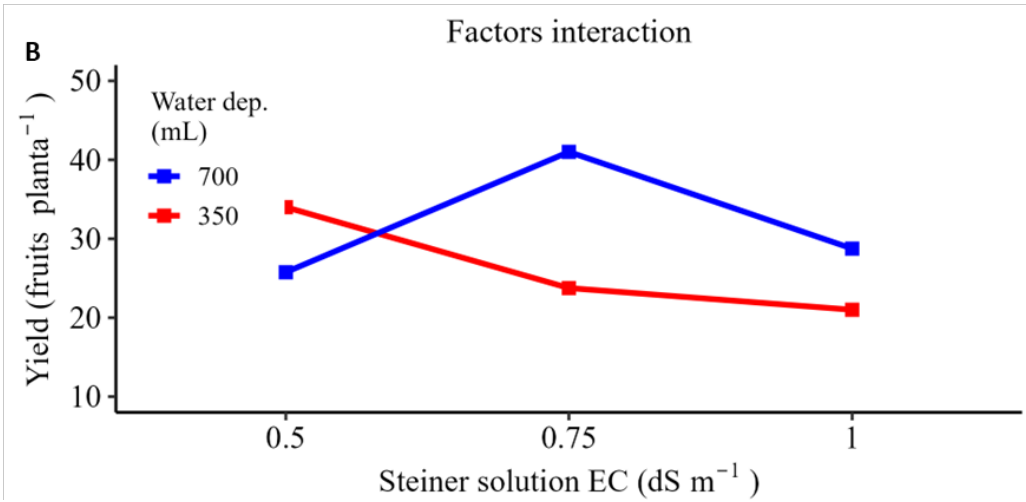


Figure 2. Effect of the substrate water consumption for irrigation and electrical conductivity (EC, dS m^{-1}) of the Steiner solution on yield (fruits plant^{-1}) of the strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). A: Effect of the main factors; B: effect of the interaction of the factor's levels.

These results suggest that high substrate humidity values and the Steiner solution's EC reduce the yield in plants (fruits per plant). However, Ahmed and Gad (2022) showed that the application of irrigation at 100 % of the reference evapotranspiration in strawberry cv. Festival plants had the highest yield (31 fruits per plant), whereas, with irrigation applied at 60 %, lower yields were obtained (17 fruits per plant). This difference is probably due to the level of water stress corresponding to 60 %, being much higher than the one induced with the 700 mL of water consumption by the substrate in this study. The adverse effect of the increase of EC on the number of fruits per plant was also reported by Ferreira *et al*. (2019) on cv. Albion, since the increase in EC from 0.7 to 2.5 dS m^{-1} reduced the number of fruits per plant by 24.7 %.

For the three levels of EC of the Steiner solution, average fruit weight was also greater (14.41 %) for 700 mL than 350 mL (Tukey, $p \leq 0.05$) (Figure 3A). For both levels of substrate water consumption, the fruit weight was greater in the EC of 0.5 dS m^{-1}, decreased to 0.75 dS m^{-1}, and was lower than 1 dS m^{-1} (Figure 3A). Fruit weight decreased by 12.31 % when the EC of the solution increased from 0.5 to 1 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 3A).

Regarding the interaction between substrate water consumption and the EC of the Steiner solution, for 700 mL of consumption, the same change pattern as observed in the variables-response described earlier was found. Fruit weight was greater with an EC of 0.75 dS m^{-1} and lower at 0.5 and 1 dS m^{-1}. For the consumption of 350 mL, fruit weight decreased with the increase of EC (Figure 3B). For the combined effect of water consumption of the substrate and EC of the solution, the highest fruit weight was obtained in plants where the consumption was 700 mL and EC was 0.75 dS m^{-1}, and the lowest, with 350 mL and 1 dS m^{-1} (Tukey, $p \leq 0.05$).

As opposed to the results in this study, earlier work on strawberry plants from different cultivars indicates that the fruit weight is greater at higher irrigation levels (Ameri *et al*., 2012; Perin *et al*., 2019; Ahmed and Gad, 2022), which may be due to the fact that, with the consumption of 700 mL of the humidity by the substrate, no greater stress was produced, whereas with 350 mL, an oxygen deficit could have been induced in the roots area due to the high frequency of irrigation. On the other hand, despite irrigation at 100 % of the reference evapotranspiration in other studies, the irrigation frequency was not very high.

In this study, the average fruit weight decreased as the EC of the solution increased (for 350 mL of substrate water consumption). The greatest weight was obtained with the combined effect of 700 mL and an EC of 0.75 dS m^{-1}, whereas the lowest was obtained with the combination of 350 mL and 1 dS m^{-1} (Figure 3C). Garriga *et al*. (2017) also reported reductions in fruit weight of the cv. Camarosa due to the increase in saline stress.

For the three EC levels of the Steiner solution, the degrees Brix of the juice of the fruits were 8.73 % higher in the consumption of 700 mL compared to those observed with 350 mL (Tukey, $p \leq 0.05$) (Figure 4A). For both levels of substrate water consumption, the degrees Brix were greater for the EC of 0.75 dS m^{-1}, being 11.55 % higher than those with 0.5 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 4A).

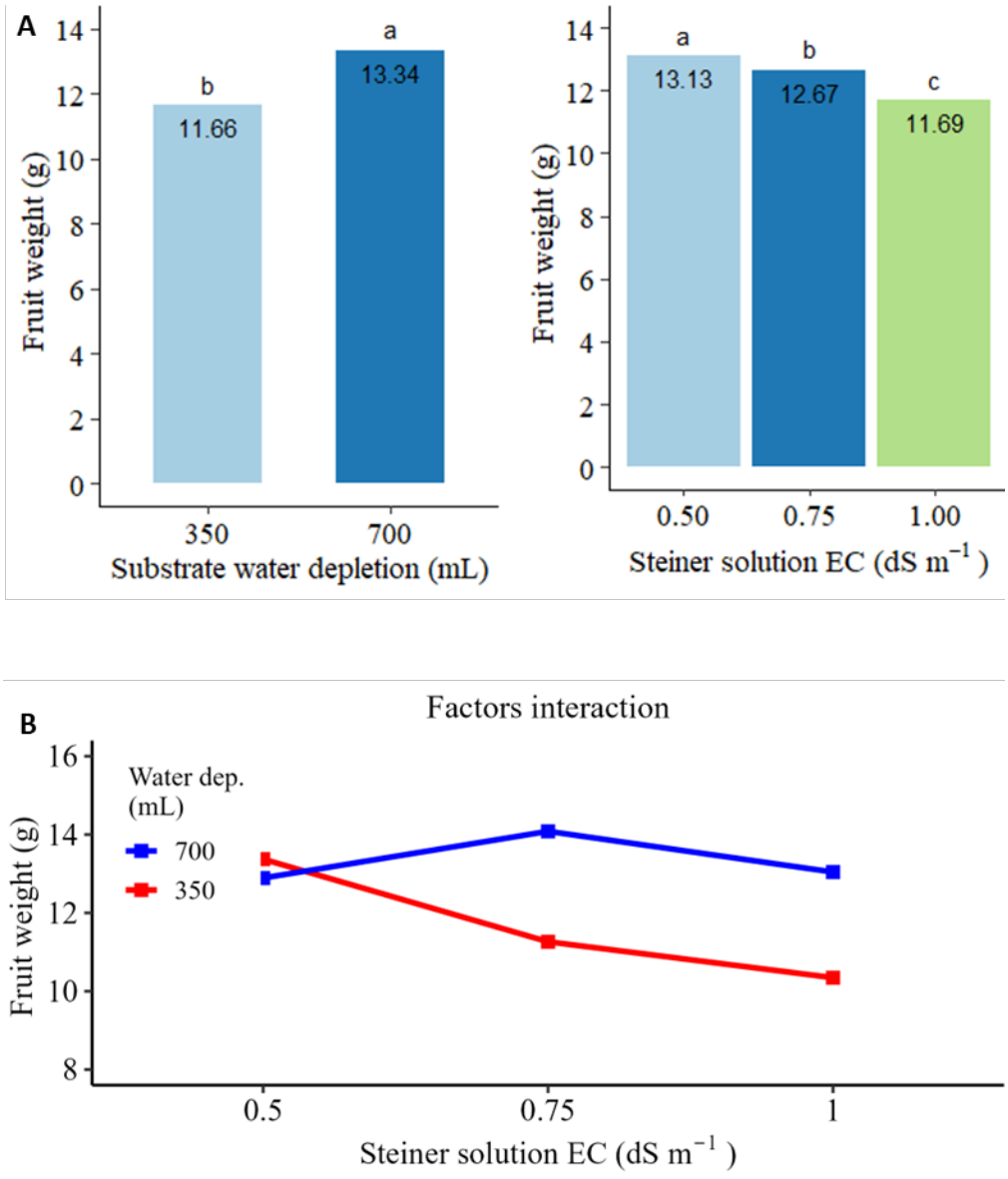


Figure 3. Effect of the substrate water consumption for irrigation and electrical conductivity (EC, dS m^{-1}) of the Steiner solution on the average fruit weight (g) of the strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). A: Effect of the main factors; B: effect of the interaction of the factor's levels.

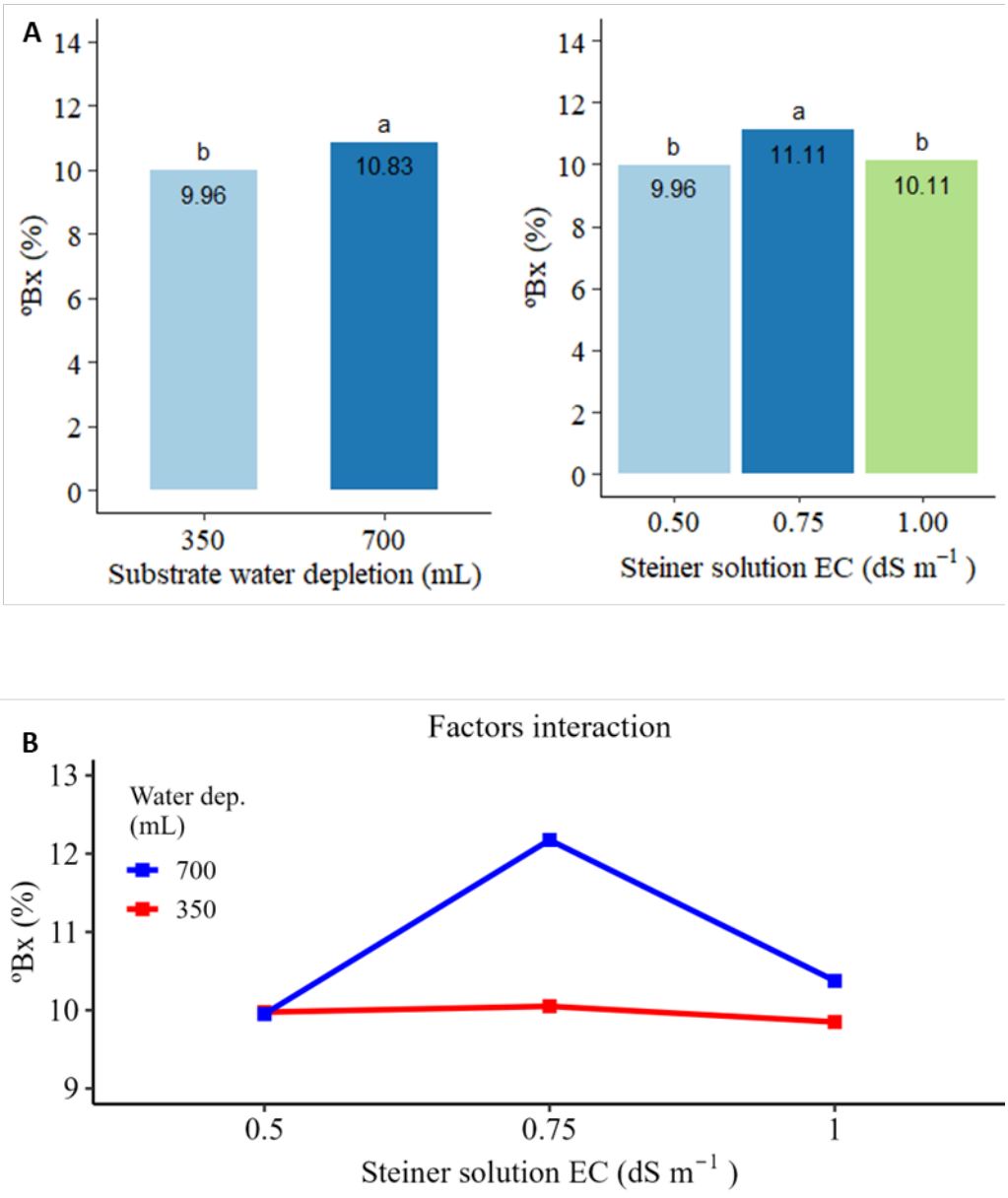


Figure 4. Effect of the substrate water consumption for irrigation and electrical conductivity (EC, dS m^{-1}) of the Steiner solution on the degrees Brix of the juice of fruits (%) of the strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). A: Effect of the main factors; B: effect of the interaction of the factor's levels.

The interaction between substrate water consumption and the EC of the solution indicates that the highest value of degrees Brix takes place in the consumption of 700 mL while being noticeably lower at 0.5 and 1 dS m^{-1}. For the consumption of 350 mL, the values of degrees Brix were very similar in all EC levels of the nutrient solution (Figure 4B). This indicates that maintaining moderate EC and substrate moisture levels favors the increase in degrees Brix, whereas higher values for humidity of the substrate and EC of the solution reduce degrees Brix. For the combined effect of the substrate water consumption and the EC of the nutrient solution, the highest value for degrees Brix was obtained in plants with a consumption of 700 mL and an EC of 0.75 dS m^{-1}, whereas the lowest was obtained for 350 mL and an EC of 1 dS m^{-1} (Tukey, $p \leq 0.05$).

Other studies indicate that salinity has a positive effect on the concentrations of total soluble solids (degrees Brix), organic acids, and sugars, which are compounds that contribute to improving the aroma and flavor of many fruits (Kader, 2008; Rouphael *et al.*, 2018). The optimum value for degrees Brix for red fruits ranges between 6 and 9 %. The average of degrees Brix observed in this study was 10.4 %, a slightly higher value than the optimum (Hancock, 1999). For strawberry cv. Festival, the highest values of degrees Brix were obtained with higher irrigation levels (Ahmed and Gad, 2022). Ferreira *et al*. (2019) found no significant effects of different EC levels on degrees Brix in cv. Albion. The increase in the concentration of sodium chloride in the nutrient solution increased the degrees Brix and total acids in strawberry plants cv. Elsanta, Korona, and Camarosa (Saied *et al*., 2005; Keutgen and Pawelzik, 2007; Galli *et al*., 2016). However, other studies report that degrees Brix and total acids do not change with the increase in salinity of irrigation water (Keutgen and Pawelzik, 2007; Khayyat *et al*., 2007; Jamalian *et al*., 2008).

For the three EC levels of the Steiner solution, the vitamin C content in fruits was also greater (22.56 %) in the substrate water consumption of 700 mL compared to 350 mL (Tukey, $p \leq 0.05$) (Figure 5A). For both levels of substrate water consumption, the vitamin C content was higher and equal for EC of 0.5 and 0.75 dS m^{-1} and lower at 1 dS m^{-1} (Tukey, $p \leq 0.05$) (Figure 5A). This result indicates that plants under slight water stress, when irrigated at 700 mL of substrate moisture consumption, increase the vitamin C content of the fruits in combination with a moderate EC value of the Steiner solution.

The highest vitamin C content in the fruits was obtained with the consumption of 700 mL and an EC of 0.75 dS m^{-1}, and its concentration decreased (for the same substrate water content) with an EC of 0.5 and 1 dS m^{-1}. For the consumption of 350 mL, vitamin C content decreased with the increase of the EC of the nutrient solution (Figure 5B). For the combined effect of water consumption and EC, the highest vitamin C content was obtained in plants with a consumption of 700 mL and an EC of 0.75 dS m^{-1} and with a consumption of 700 mL and an EC of 0.5 dS m^{-1}, making these greater than the

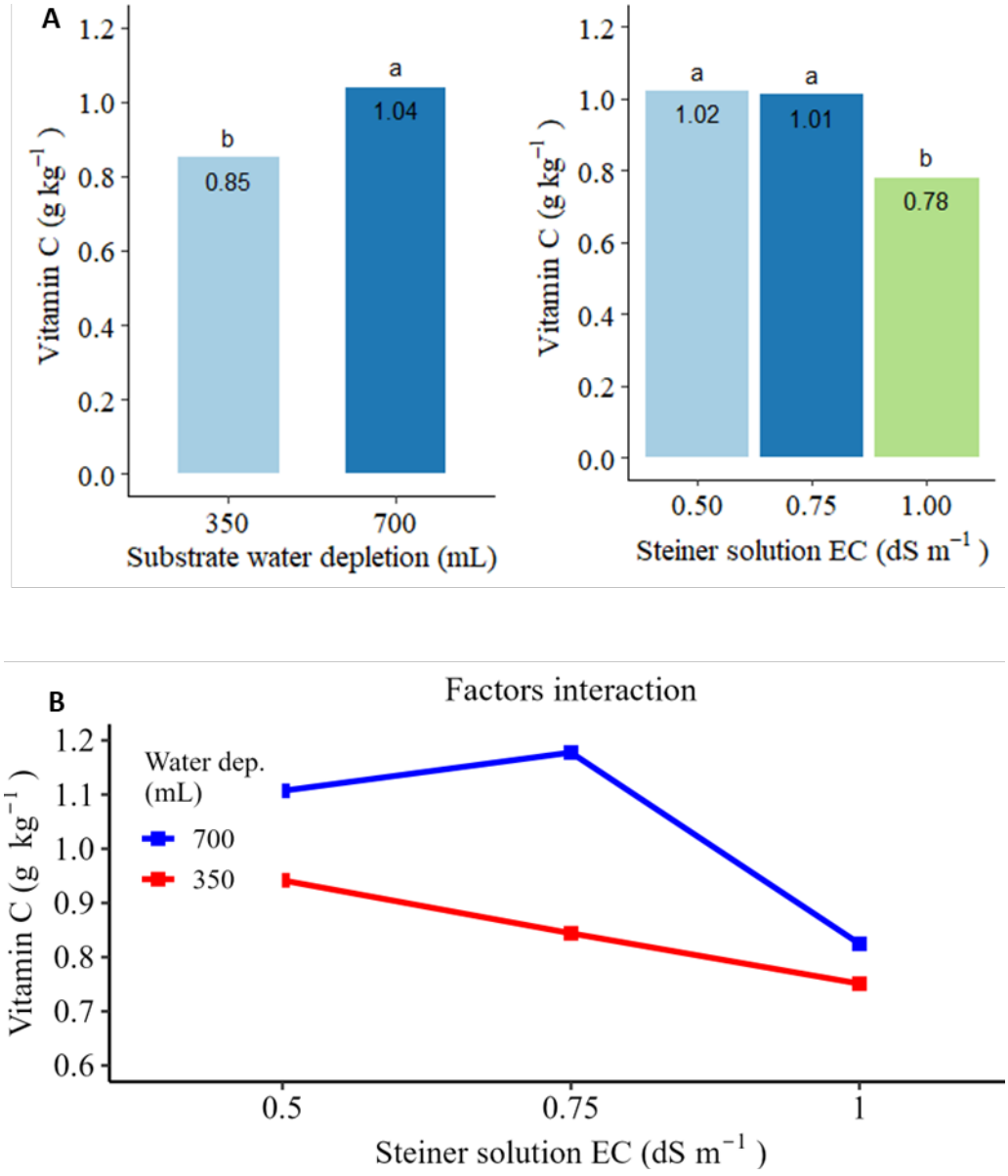


Figure 5. Effect of the substrate water consumption for irrigation and electrical conductivity (EC, dS m^{-1}) of the Steiner solution on the content of vitamin C of the juice of fruits (g kg^{-1}) of the strawberry crop (*Fragaria x ananassa* Duch. cv. Albion). Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). A: Effect of the main factors; B: effect of the interaction of the factor's levels.

rest of the treatments (Tukey, $p \leq 0.05$).

Water deficit may interrupt metabolic processes in strawberries, including the biosynthesis of vitamin C. Ascorbic acid is synthesized in plants using enzyme reactions that require adequate water availability (Fenech *et al*., 2019). A study by Medyouni *et al*. (2021) shows that water deficit increases the total content of carotenoids and vitamin C in tomato fruits (*Solanum lycopersicum* L.), but reduces the levels of soluble sugar and organic acids. However, Ahmed and Gad (2022) found a maximum and minimum value for vitamin C contents in strawberries of 0.782 and 0.708 g kg^{-1} with the highest and lowest levels of irrigation, respectively. These values are lower than the average observed for this study (0.941 g kg^{-1}). When the EC of the nutrient solution increases from 0.75 to 1 dS m^{-1}, the vitamin C content decreases. Similar results were observed by Hernández-Valencia *et al*. (2022) in strawberry cv. Camino Real when the vitamin C content decreased from 0.615 to 0.562 g kg^{-1} when increasing the EC of the nutrient solution from 1.4 to 1.7 dS m^{-1}.

CONCLUSIONS

For the three levels of electrical conductivity (EC) of the Steiner solution evaluated (0.5, 0.75, and 1 dS m^{-1}), yield (g $plant^{-1}$ and fruits $plant^{-1}$), fruit weight, degrees Brix, and vitamin C content were higher with a substrate water consumption of 700 mL (24.19 % of the saturated substrate volume consumption) than with 350 mL (11.29 % of the saturated substrate volume consumption). For both water consumption levels, the highest values for the variables were obtained with EC values of 0.5 and 0.75 dS m^{-1}. The interaction between substrate water consumption and the EC of the Steiner solution showed that the highest values for the same response variables were obtained with a consumption of 700 mL of substrate water and an EC of 0.75. With a consumption of 350 mL of substrate water, the variables mentioned were lower and generally decreased as the EC value of the solution increased.

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Agrociencia

EFFECTS OF *Eucalyptus* PLANTATIONS ON THE PHYSICAL AND CHEMICAL PROPERTIES OF SOIL IN FLOODPLAINS OF THE EASTERN REGION OF PARAGUAY

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ABSTRACT

The floodplains of the eastern region of Paraguay have soils with a shallow water table that causes flooding in months of heavy rainfall (August to December). The soils, predominantly Ultisols with gleyic properties, display high contents of soil organic matter (SOM) and an acidic pH. These environments are being transformed into *Eucalyptus camaldulensis* Dehnh. plantations, primarily for energy purposes. The aim of this study was to evaluate the chemical and physical properties of soils in eucalyptus plantations established on the native lowland grasslands. For this purpose, three chronosequences were selected, consisting of native grasslands and eucalyptus plantations aged between 2 and 8 years. In each system, the chemical and physical properties were determined at depth increments (0–5, 5–10, 10–20, and 20–40 cm). Each soil sample in the plots included six repetitions for both chemical and physical analyses. In the first years of eucalyptus planting, soil organic carbon (SOC) decreased by 50 % due to the intensive tillage carried out in the first years to establish the eucalyptus plantations. SOC concentrations recovered over time, although they did not reach the levels observed in the native grasslands. Soils with eucalyptus plantations displayed a higher bulk density (up to 1.35 g cm^{-3}), greater acidity (pH value of 4), and a decrease in phosphorous (P) and exchangeable bases (up to 30 %) in comparison with natural grasslands. It is concluded that, in order to prevent the degradation of the chemical and physical properties of the soil in natural grasslands, it is necessary to plan practices that include land-use changes with native forest species and reconsider the practice of transforming these natural systems.

Keywords: *Andropogon lateralis* Nees, *Paspalum notatum* Flüggé, hydromorphic soils, forestry, drainage.

INTRODUCTION

On a global scale, floodplains characteristically display soils with high carbon (C) and store approximately 12 % of the worldwide reserves (Hussain *et al.*, 2020; Keller *et al.*,

2021). In addition, they play a relevant part in biodiversity and the regulation of the water cycle and greenhouse gases (Sutfin *et al.,* 2016). A total of 40 % of the eastern region of Paraguay is covered by lowlands found in the Humid Chaco ecoregion (Ávila-Torres *et al*., 2018). This landscape is represented by wide prairies covered in natural grasslands, dominated by *Andropogon lateralis* Nees and *Paspalum notatum* Flüggé, and is used for extensive cattle farming. These environments are affected by floods from the Paraguay and Paraná rivers, which are known for their extensive biodiversity and enormous environmental benefits, such as C reserves in soils or water flow regulation.

Soil organic material (SOM) reserves in the floodplains are greater than in forest or agricultural soils of the highlands of the same regions (Encina-Rojas *et al.,* 2023). The organic C reserves are determined by the contribution of organic remains derived from the high density and number of roots, which is typical of the natural grasslands of this type of ecosystem (Tonucci *et al.,* 2017). These properties are similar to the prairies in the floodplains of the Paraná River, near the province of Corrientes, Argentina (Navarro and Kurtz, 2019).

Native grasslands are currently being transformed into eucalyptus plantations, which implies an intensive intervention of the soil, altering some ecosystem functions such as the water cycle and the recycling of nutrients (González-Sosa *et al.,* 2024). There are studies that show that the degradation of these natural grasslands could contribute to altering the hydrology and mineralization of the large SOM reserves, increasing the emission of greenhouse gases and reducing biodiversity (Habel *et al.,* 2013; Keller *et al.,* 2021). Studies on South American grasslands indicate that eucalyptus causes reductions in water levels and the net flow of underground waters (Christina *et al.,* 2017). Vic *et al.* (2005) evaluated the water cycle in the Argentinean pampas before and after forestation and found the eucalyptus reduced the water level during dry periods due to the high evapotranspiration.

Eucalyptus spp. are the forest species that have integrated most efficiently in tropical climates. Due to their speedy growth, they extract important nutrients in short growth cycles (Santana *et al.,* 2008; Pulito *et al.,* 2015; Rocha *et al.,* 2019). Studies carried out by Laclau *et al.* (2010) in native grasslands in Brazil showed that Ca, Mg, and K concentrations in the soil decreased with the establishment of eucalyptus, generating acidity and altering the dynamics and availability of phosphorous (Boulmane *et al.,* 2017).

In floodplains with native grasslands in Paraguay, eucalyptus plantations are swiftly growing. Therefore, the aim of this investigation was to evaluate the medium- and long-term impacts of these plantations on the chemical and physical properties of the soil. This data will help determine the impacts of the eucalyptus plantations on these ecosystems to develop sustainable management strategies for landscape planning and to propose practices to preserve soil properties.

METHODOLOGY

Location and characteristics of the area of study

The investigation was carried out in the eastern region of Paraguay, located in a floodplain of the Tebicuary River, an affluent of the Paraguay River. The study area is located in three districts of the Department of Caaguazú: Coronel Oviedo, San José, and RI 3 Corrales (Figure 1), in the Atlantic Forest of the Alto Paraná ecoregion and the Selva Central in the Upper Paraná basin (Ávila-Torres *et al.*, 2018). The region has a subtropical climate (Köppen's classification) with a mean annual rainfall of 1700 mm, a mean annual temperature of 26 °C, and an average altitude of 200 m.

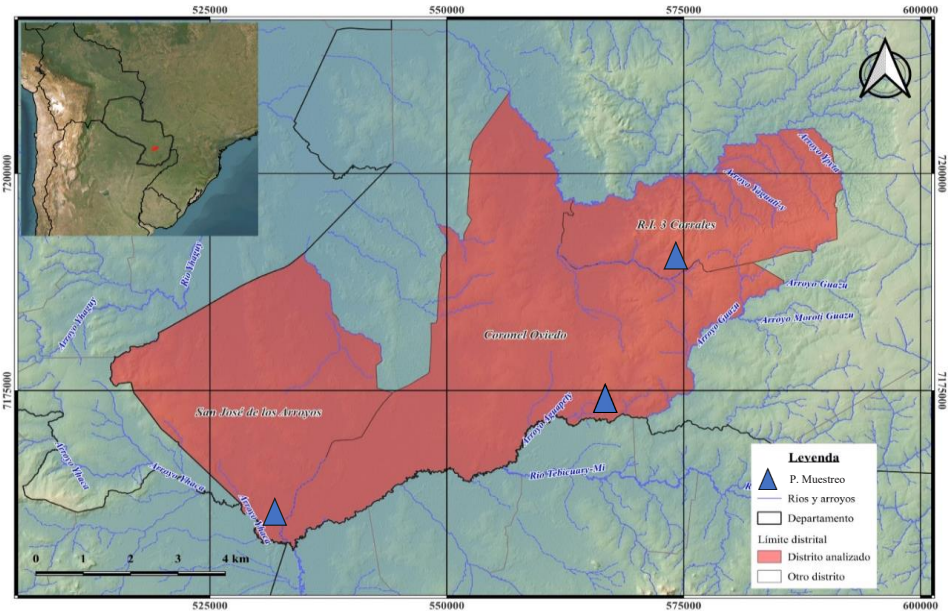

Figure 1. Location of the evaluated plots in the Department of Caaguazú, eastern Paraguay.

Eucalyptus establishment in floodplains

The main purpose of eucalyptus plantations is to generate biomass for energy and paper production. Establishing eucalyptus plantations in these lowlands generally requires intensive tillage, typically using a moldboard plow and subsoiler to improve rooting and accelerate drainage during months of high rainfall. The forest species used was cloned *Eucalyptus camaldulensis* Dehnh., which is planted at a density of 625 plants ha^{-1} (4 m between rows and 4 m between plants). During the planting process, a single base fertilization is used with 60 kg ha^{-1} of phosphorous oxide (P_2O_5) using triple superphosphate. Eucalyptus grows 3 to 5 m in height in its first year, reaching 20 m by the age of 8 years.

Experimental design and sampling

In the selected plots, eucalyptus plantation systems of varying ages (2 to 8 years) were identified on the same natural grassland that served as a reference control (Table 1). The plantations covered surfaces between 50 and 350 ha. In the adjacent areas to the plantations, natural grasslands were found. The sample units were the natural grasslands and the eucalyptus plantations established as chrono-sequences: a- (Coronel Oviedo): 2, 4, 6, and 8 years, b- (San José): 4, 6, and 8 years, and c- (RI 3 Corrales): 8 years.

Table 1. Evaluated native grassland and eucalyptus plantation (*Eucalyptus camaldulensis* Dehnh.) plots evaluated on the Tebicuary River floodplains in eastern Paraguay.

Location	Plot #	Years of plantation
Coronel Oviedo	NG	
	E2	2
	E4	4
	E6	6
	E8	8
San José	NG	
	E4	4
	E6	6
	E8	8
RI 3 Corrales	NG	
	E8	8

NG: natural grassland; E: eucalyptus (2, 4, 6, or 8 years of growth).

In the central zone of each plot, both in the grasslands and the eucalyptus plantations, sampling points were selected. Pits were opened, and samples were taken from depths of 0–5, 5–10, 10–20, and 20–40 cm. Six independent samples were extracted, made up of 12 samples each, for chemical analyses and the measurement of apparent density. Soil samples were stored in plastic bags, labeled, and taken to the laboratory, where they were dried in the open, sieved at 2 mm, and homogenized before chemical analysis.

Analysis of the soil properties

The pH was measured using H_2O and $CaCl_2$ 0.01 M in a 1:2 soil-solution ratio. The C content was determined through humid combustion (Walkley and Black method). The exchangeable Al was extracted with KCl 1 M, and the total N (Nt) was extracted with the Kjeldahl method. The carbon-nitrogen ratio (C/N) was also calculated. The exchangeable Ca, K, and Mg were obtained using ammonium acetate (1 M, pH 7) and determined by atomic absorption spectrophotometry (AAS). Available Fe, Cu, Mn,

and Zn were extracted with Mehlich solution and determined by AAS. Extractable P was measured using the molybdenum blue method, and soluble B in hot water was determined with the azomethine-H method. The distribution of the particle size (clay <2 μm, lime from 2 to 50 μm, and sand >50 mm) in a single layer (0–5 cm) was also determined. The apparent density was calculated from the weight of the soil at 100 °C and the volume of the sampling cylinder.

Statistical analyses

Average values, standard deviations, and variation coefficients were determined for each variable, and the data were subsequently analyzed using an analysis of variance (ANOVA). The means of the treatments were compared using Tukey's test, and Pearson's correlation was also carried out. For the Principal Components Analysis (PCA), Bartlett's test was first carried out, and once it became significant, the PCA was performed between the natural grassland and the eucalyptus plantation ages using the SAS statistical package (2009).

RESULTS AND DISCUSSION

Soil organic carbon, total nitrogen, and C/N ratio

The soils displayed soil organic carbon (SOC) concentrations between 2 and 3.6 % in plots repopulated with *E. camaldulensis*. These values were reduced substantially in comparison with the natural grasslands (Table 2). After the soil was prepared, SOC concentrations decreased by approximately 50 % until the depth of approximately 40 cm (Table 2, Figure 2). Ramos-Hernández and Martínez-Sánchez (2020) evaluated the C capture of native grasslands in southeastern Mexico, where they found that the *Paspalum* spp. species provide larger amounts of C in comparison to other grass species. Viglizzo *et al.* (2019) mention that the grasses in lower areas of South America capture large amounts of C in comparison to other species and that this could be compensating for greenhouse gas emissions from livestock production.

Total nitrogen (Nt) concentrations (Table 2) followed the same tendency as C, with a correlation (Table 3) of 0.99 ($p < 0.001$). However, unlike C, Nt showed no recovery through the years in eucalyptus plantations. The C/N ratio in natural grasslands was 9:14 (Table 2), whereas in all eucalyptus plantations, the ratio increased significantly (greater than 20), despite the lower Nt concentrations.

This study shows that the important C reserves accumulated in the native grasslands decrease with the establishment of intensive eucalyptus plantations. In the first years, the C reserves dwindle by up to 50 %. Another effect recorded was the Nt loss and the subsequent increase of the C:N ratio, which went from 10–12 in the grasslands to 19–25 in the plantations. Despite the effect being partly due to tilling, which dilutes the contents of organic C and N in the surface layer of the soil, it is also feasible that the drainage implemented significantly reduced the level of the water table and,

Table 2. Chemical and physical soil properties in the 0–5 cm-deep layer of natural grasslands and eucalyptus plantations (*Eucalyptus camaldulensis* Dehnh.) in plots evaluated on the Tebicuary River floodplains in eastern Paraguay.

District	Plot	pH		C	Nt	C/N	P	ECEC	Al	K	Ca	Mg	Ad	S	L	Cl
		$CaCl_2$	H_2O	%			mg kg^{-1}	$cmol_c\ kg^{-1}$					g cm^{-3}	%		
Coronel Oviedo	NG	4.6a	5.1a	2a	0.2 a	9b	6.0a	7.3 a	0.1c	0.1a	1.29a	0.44a	0.98a	75a	5a	20a
	E2	4.3b	4.6b	1.2c	0.08 a	15a	3.2b	5.9b	1.2b	0.02c	0.85b	0.26c	1.21b	74a	5a	21a
	E4	4.2b	4.6b	1.4b	0.10 a	14a	2.5b	6.4b	1.4a	0.04c	0.96b	0.35c	1.22b	79a	4a	17a
	E6	3.9c	4.3c	1.5b	0.11 a	14a	3.5b	6.5b	1.6a	0.02c	0.98b	0.38b	1.23b	79a	3a	18a
	E8	3.9c	4.3c	1.6b	0.11 a	15a	3.4b	5.9b	0.1c	0.08b	1.00b	0.41b	1.29b	82a	2a	16a
	p-value	0.001		0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001	0.01	ns	ns	ns
San José	NG	4.3a	4.8a	2.8a	0.19 a	15b	6.28a	8.3a	1.0b	0.09a	0.99a	0.06b	0.89a	74a	5a	21a
	E2	3.7b	4.4b	1.9b	0.09 b	21a	3.05b	7.1b	1.2a	0.02b	0.52c	0.03b	1.19b	79a	4a	17a
	E4	3.9b	4.3b	2.3b	0.11 a	21a	4.30b	7.2b	1.3a	0.06b	0.76c	0.1b	1.21b	78a	5a	17a
	E6	3.9b	4.1b	2.2b	0.12 a	20a	2.91b	7.6b	1.2a	0.06b	0.85b	0.15a	1.23b	78a	5a	17a
	p-value	0.001		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.01	0.01	0.001	ns	ns	ns
RI 3 Corrales	NG	4.0a	4.4a	3.6a	0.25 a	14b	4.62a	7.6b	1.2b	0.12a	1.00a	0.14b	0.92b	73a	5a	22a
	E8	3.8b	4b	3.0b	0.10 a	30a	3.13b	6.7a	1.9a	0.07b	0.87b	0.25a	1.33a	75a	4a	21a
	p-value	0.001		0.001	ns	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	ns	ns	ns

Nt: total nitrogen; ECEC: effective cation exchange capacity; Ad: apparent bulk density; S: sand; L: lime; Cl: clay; NG: natural grassland; E: eucalyptus (2, 4, 6, or 8 years of growth); ns: not significant. Different letters indicate significant differences ($p \leq 0.05$).

consequently, improved soil aeration, leading to an increase in the mineralization of organic material (Pérez-Cruzado *et al.*, 2012; Poeplau *et al.*, 2011).

The reduction of soil organic matter (SOM) in these lowland soils is due in great part to the intensive preparation of the soil for the establishment of eucalyptus. This practice involves the removal and mixing of horizons, reducing the SOM content on the surface. Studies mention that soil scarification reduces SOM by nearly 50 % (Jiménez-Esquilin *et al.*, 2008), and this loss increases with the use of subsoiling and moldboard plowing, which promote erosion and the leaching of organic compounds and nutrients from the soil (Walmsley and Godbold, 2010). Eucalyptus plantations, when combined with other grassland systems to create silvopastoral systems, may improve the concentrations of SOM in the soil profile (Boulmane *et al.*, 2017), although the final evolution of SOM is highly determined by the initial content of the soil (Cook *et al.*, 2016).

The loss of Nt, with the subsequent increase of the C:N ratio, can be attributed to denitrification and even to the leaching of mineral N, which may affect water. This increase in the C:N ratio, along with the strong acidity, may lead to lower N availability for the plants (Pulito *et al.*, 2015). In this regard, some studies have found high C:N ratios in the soil under eucalyptus plantations in comparison to native plant

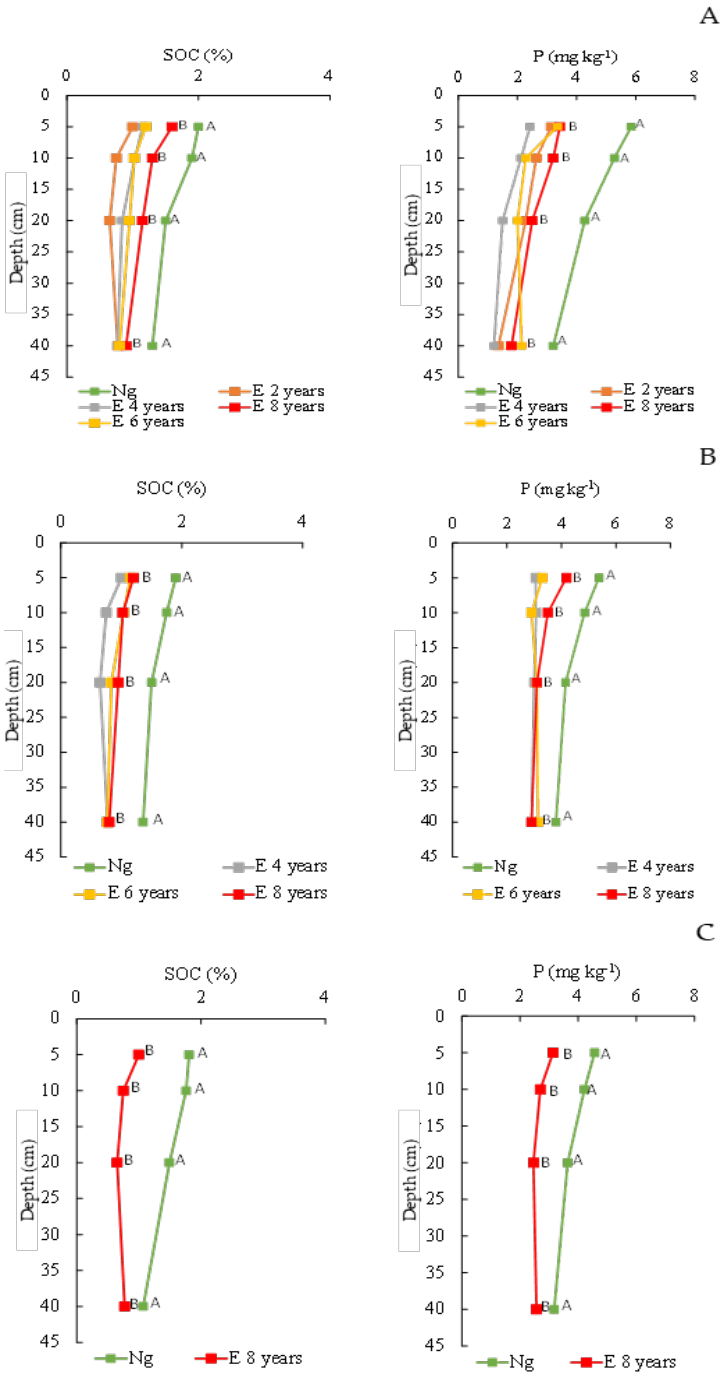

Figure 2. Soil organic carbon (SOC) concentration and available P at different depths, by district, in the natural grasslands and eucalyptus plantation (*Eucalyptus camaldulensis* Dehnh.) plots evaluated on the Tebicuary River floodplains in eastern Paraguay. Different letters indicate significant differences ($p \leq 0.05$).

Table 3. Correlation coefficients between fertility parameters of the natural grasslands and eucalyptus plantations (*Eucalyptus camaldulensis* Dehnh.) in plots evaluated on the Tebicuary River floodplains in eastern Paraguay.

Variable	pH	Al	SOC	Nt	C/N	P	ECEC	K	Ca	Mg	Ad
pH	1										
Al	-0.89	1									
SOC	----	----	1								
Nt	----	----	0.99	1							
C/N	----	0.62	0.33	----	1						
P	-0.82	-0.84	0.79	----	----	1					
ECEC	0.73	----	0.69	----	----	0.75	1				
K	0.75	-0.53	----	----	----	----	----	1			
Ca	0.76	-0.84	----	----	----	0.63	----	0.62	1		
Mg	0.82	-0.87	----	----	----	----	----	----	0.78	1	
Ad	-----	----	-0.80	----	----	----	----	----	----	-----	1

SOC: soil organic carbon; Nt: total nitrogen; ECEC: effective cation exchange capacity; Ad: apparent bulk density.

soil, as well as a lower microbial activity (Lima *et al.,* 2006). This effect is limiting for eucalyptus crops due to a lower availability of N during its cycle and for subsequent plantations (Pulito *et al.,* 2015).

Among the fast-growing forest species, eucalyptus is characterized by a low density of leaves, and as a consequence, lower amounts of organic material are deposited on the surface of the soil (Hemes *et al.,* 2018). Eucalyptus plantations present less C in comparison with natural systems due to the lower contribution of organic compounds and the slow decomposition of biomass (Paul *et al.,* 2002), as well as the lower amount of moisture found in the soil. Studies indicate that foresting with eucalyptus can maintain SOM content (Pulrolnik *et al.,* 2009); however, other studies indicate that these plantations reduce the reserves of SOM in the soil profile due to a lower biomass contribution, providing plant residues with high concentrations of lignin (Hemes *et al.,* 2018).

Apparent bulk density of the soil and texture

In this study, results indicate a greater apparent bulk density in the new eucalyptus plantations (greater than 1.3 g cm^{-3}), in comparison to natural grasses (0.98 g cm^{-3}). The results of the apparent density present a negative correlation (-0.80, $p < 0.01$) with SOC (Table 3); that is, as SOC decreases, soil density increases. The results display high contents of sand (80 %), lime (5 %), and clay (15 %), and no variations with the establishment of the eucalyptus trees. The loss of SOC in the eucalyptus plots results in the increase of apparent soil density, reduction of porosity and water infiltration,

and increase in the surface runoff. The loss of SOC leads to increased soil density and may result in a decrease in root growth, lower SOM fixation, water infiltration, and a reduction in the biological activity of microorganisms (Conte *et al.,* 2011).

Extractable phosphorus

Natural grasslands displayed extractable P concentrations ranging from 2 to 8 mg kg^{-1}, which can be attributed to the natural acidity of these soils. P concentrations fell significantly with the establishment of the eucalyptus plantations, with losses of approximately 30 % at the time of the establishment, and recovered without reaching the original levels at the end of the rotation. In all chronosequences studied (Table 2, Figure 2), P concentrations were lower in the eucalyptus plantation systems, ranging between 2 and 3 mg kg^{-1}. The concentration of available P correlates negatively (Table 3) with acidity ($r = -0.82$, $p < 0.001$); that is, as acidity increases with eucalyptus plantations, P availability decreases. Likewise, P presented a high correlation (Table 3) with SOM ($r = 0.79$, $p < 0.001$). The transformation of natural grasslands to plantation systems generated losses in the reserves of available P at all depths studied (Figure 2) in the first years of planting and up to 8 years without recovering its natural concentration.

Some nutrients, such as P, decrease their availability with the acidity of the soil. Around 80 % of the P in the surface of the soil is considered to be found in its organic form, which is why, when SOM concentrations are reduced, the P extractable is reduced. Pulrolnik *et al.* (2009) and Hemes *et al.* (2018) mention that the biomass of the eucalyptus presents high amounts of polysaccharides and lignin, which hinder its decomposition and the accumulation of SOM, affecting the reserves of P and Nt.

Fast-growing and intensively managed forest species, such as eucalyptus plantations, have high needs for P and are efficient in its absorption and translocation in the plant (Fife *et al.,* 2008). In Brazil, P availability in Oxisols was evaluated in eucalyptus plantations, finding a low availability compared to the natural grasslands (Foltran *et al.,* 2019). Nutrient reduction in eucalyptus plantation soils was reported by several authors (Gonçalves *et al.,* 2020; Rocha *et al.,* 2019), which is why the use of fertilizers and agricultural lime is important to increase the availability of nutrients and the productivity of the plantation systems.

pH, Al, effective cation exchange capacity, and exchangeable nutrients

Natural grasslands displayed a potentially acidic pH (4.8), and the plantation of eucalyptus increased the acidity; at the same time, exchangeable Al increased ($r = -0.89$) in the studied chronosequences (Tables 2 and 3), particularly at the end of the rotation at 8 years. The relation between pH and Ca, Mg, and K presented a high negative correlation (Table 2), indicating that as the acidity increased, the concentration and availability of the studied bases decreased.

In the new eucalyptus plantations, a reduction was observed in the concentrations of exchangeable Ca, Mg, and K (Table 2, Figure 3), as well as a reduction in these when the sampling depth increased up to 40 cm. The effective cation exchange capacity (ECEC)

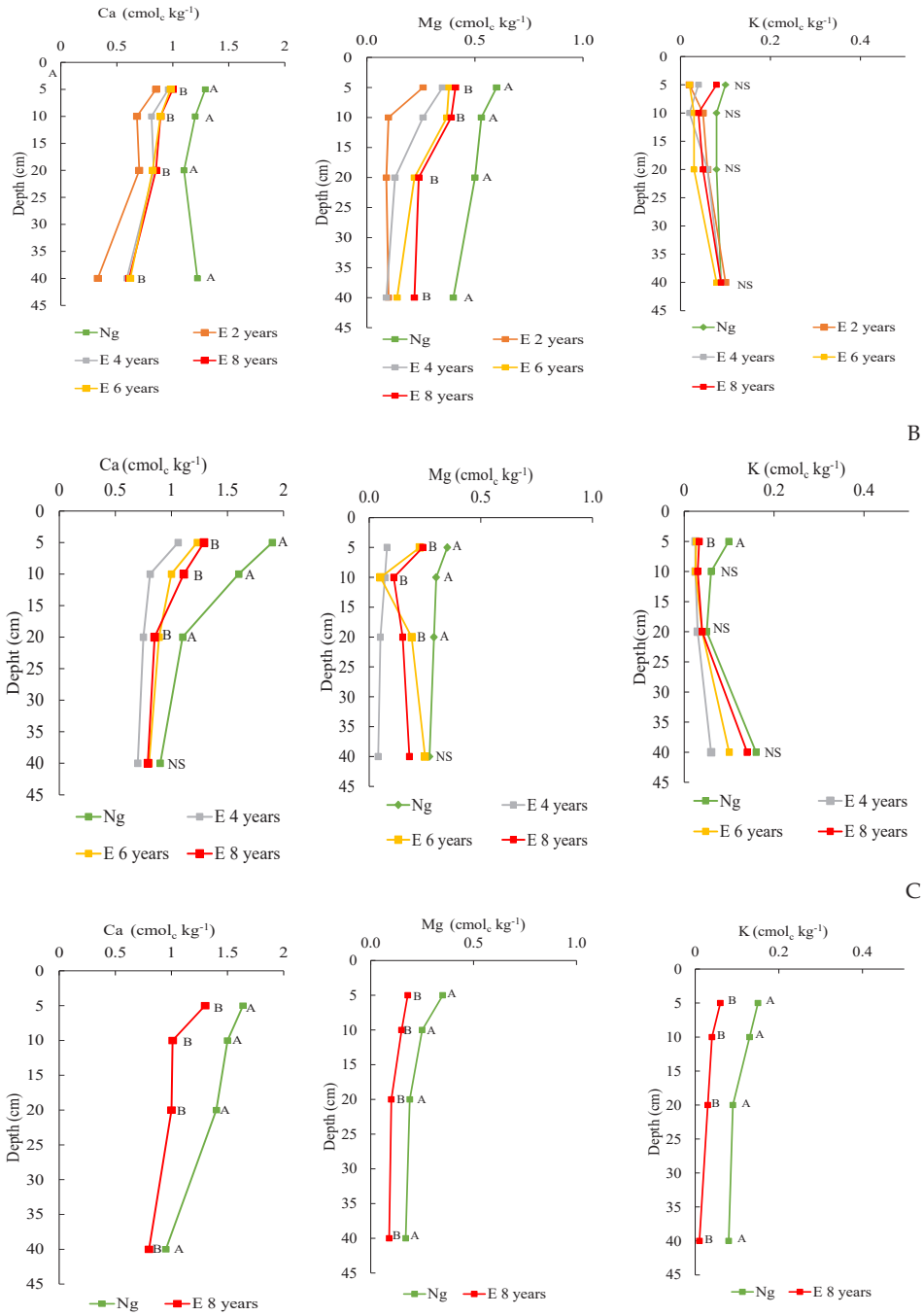

Figure 3. Concentrations of exchange calcium (Ca), magnesium (Mg), and potassium (K) at different soil depths in plots evaluated on the Tebicuary River floodplains in eastern Paraguay. Different letters indicate significant differences ($p \leq 0.05$).

was low (7.5 $cmol_c$ kg^{-1}) in the natural grasslands and decreased in all treatments with eucalyptus.

Studies mention a strong increase in the acidity of the soil has a direct impact on the availability of nutrients and leads to the appearance of toxic elements such as Al (Holland *et al.*, 2017), which is an element that limits the growth of all plant species since it is not an essential element. The evolution of the quality of soils under eucalyptus plantations was evaluated by Rocha *et al.* (2016; 2019), finding a high acidity in the soil and a very low availability of exchangeable bases (Merino *et al.*, 2005; Villalba-Martínez *et al.*, 2022).

Ca absorption is proportional to stem growth and biomass during the cycle of the eucalyptus, while the Mg requirement is greater in the first years (Laclau *et al.*, 2010; Rocha *et al.*, 2016). In successive plantations, K deficiencies reduce the stomatal opening (Laclau *et al.*, 2010), and the abscission of leaves becomes the main strategy for transpiration in moments of water scarcity, which is why one of the consequences of K deficiency in eucalyptus is the loss of leaves. Eucalyptus absorbs large amounts of Ca, Mg, and K at different depths. This extraction is correlated with the growth rate (Cook *et al.*, 2016; Rocha *et al.*, 2016). Consequently, successive eucalyptus plantations lead to reductions in the reserves at critical levels in the soil (Boulmane *et al.*, 2017).

Principal components analysis

The principal components analysis (PCA) corresponding to the three studied chronosequences (Figure 4) shows the distance marked between the natural grasses

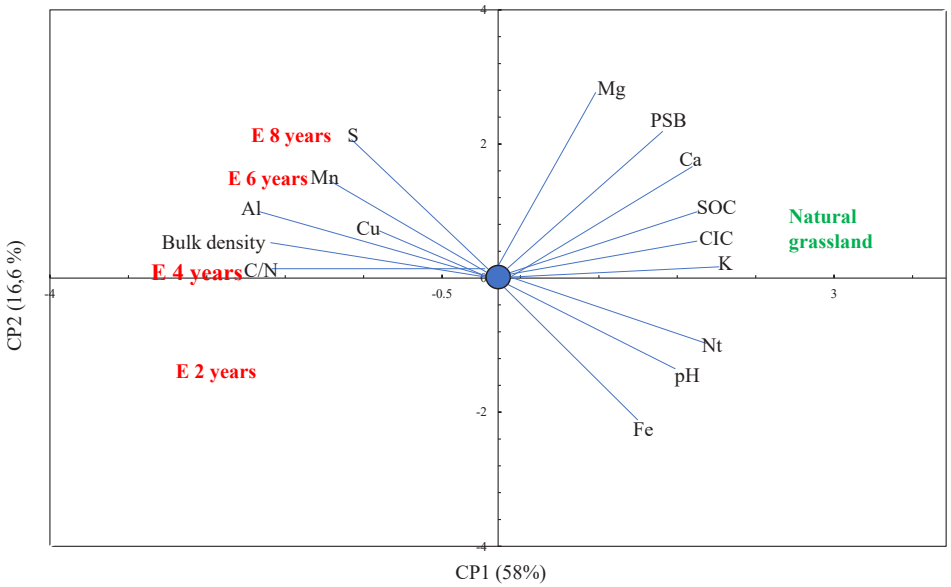

Figure 4. Principal component (CP) analysis of the evaluated natural grasslands and eucalyptus plantations (*Eucalyptus camaldulensis* Dehnh.) in plots evaluated on the Tebicuary River floodplains in eastern Paraguay.

and the eucalyptus plantations. In the plots studied, the natural grassland systems were characterized by a high accumulation of C and available nutrients, whereas the systems with eucalyptus plantations were characterized by the accumulation of Al, an increase in density, and the loss of nutrients.

Just as other intensive cropping systems, eucalyptus plantations require important amounts of nutrients, mainly N, P, K, and Ca. Santana *et al.* (2008) found that the aerial biomass of eucalyptus in southern Brazil contained, in kg ha^{-1}, 483 of N, 37 of P, 301 of K, and 620 of Ca at a standard harvest age of 6.5 years. The highest accumulation of Ca in these plantations was observed in the wood of the trunk, in comparison with the leaves and branches (Leite *et al.,* 2011; Santana *et al.,* 2008). It is therefore highly unlikely that the restitution of nutrients can take place through the contribution of eucalyptus biomass.

CONCLUSIONS

The establishment of eucalyptus plantations on the natural grasslands, which implies tilling and drainage, reduced soil organic carbon (SOC) concentrations. Throughout the 8 years of rotation, a recovery was observed in the SOC reserves, but it was not enough at the end of the cycle to counteract the loss. In the same period, the N and P reserves presented reductions of 50 %, related to the loss of SOC. Acidity was also produced, along with losses of up to 30 % of Ca, Mg, and K. Part of the losses were attributed to the intense nutrient extraction, which is characteristic of intensive eucalyptus plantations. The reduction of extractable P from the soil is due to the greater acidity that affects the mobility of this element, as well as the loss of SOM, which regulates the reserves of organic P in the soil. With the introduction of eucalyptus plantations, a greater apparent bulk density was observed in the soil in comparison with the native grasslands.

Based on the data presented, it is concluded that planning for these new systems is necessary, taking into account land management and soil conservation practices (tillage, fertilization, forestry management) to prevent fragile soils from being degraded and their fertility deteriorated, affecting their quality for future uses.

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Agrociencia

INFRARED SPECTROSCOPY ANALYSIS AND CHEMICAL PROPERTIES OF INCEPTISOLS FOR AGRICULTURAL LAND DEVELOPMENT

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ABSTRACT

The purpose of this study was to explore the properties of Inceptisols (Cambisols) to provide fundamental information for agricultural development. The soil type occupies a significant and vital part of the agricultural land, especially in Kendari City, Indonesia. A total of 30 Inceptisol soil samples on limestone parent material were collected from three locations under tree canopy using vertical profiles to identify the physic and chemical properties. The soil mineral was examined by using X-Ray Diffraction (XRD); clay mineral was determined with Fourier Transform Infrared (FTIR) spectroscopy; chemical elements with X-ray Fluorescence (XRF); total nitrogen content with the Kjeldahl method; and soil magnetic properties with a magnetic susceptibility meter. Total nitrogen in the soil was found to range from 0.106% to 0.597%, soil pH ranged from 5.7 to 6.95, and the sand fraction was determined to be the dominant in all profiles, accounting for 60% to 70%. In contrast, oxides of Si, Al, Fe, Mg, Ti, Ca, S, Na, K, P, Mn, Ni, Co, and Cr were identified in the chemical element content. While the increasing trends of Al, Fe, and Mg with depth were largely attributed to limited leaching and slow rates of weathering, the dominant upward trends of Si across all sites indicated significant soil development in the study area. All sites showed upward trends in magnetic susceptibility, indicating the enrichment of magnetic minerals. Although FTIR spectroscopy successfully identified soil minerals at various depths, the diffraction pattern of the topsoil revealed the silicon oxide quartz (SiO_2) phase. At 80 to 200 cm, montmorillonite absorption bands were prominent, while at 0 to 40 cm (topsoil), kaolinite absorption bands dominated. The transformation of montmorillonite into kaolinite in Inceptisol, driven by high mineralization during soil development and restricted leaching and weathering, has a substantial impact on agricultural development and long-term productivity.

Keywords: Inceptisols, Cambisols, FTIR Spectroscopy, Magnetic Susceptibility.

INTRODUCTION

Recent research highlights the importance of understanding the dominant soil development processes and their impact on agricultural utilization (Kartawisastra,

2013). Inceptisols, as defined by the World Reference Base for Soil Resources (Nachtergaele, 2017) and known as Inceptisols in the US soil taxonomy, are particularly significant in soil age sequences. These soils exhibit an intermediate stage of soil development, as evidenced by the development of a cambic horizon but the absence of an argillic horizon (Khresat, 2005).

Inceptisols typically form in environments where soil-forming processes are somewhat inhibited (Dengiz, 2020). By reflecting the initial modifications made to the parent material by soil formation activities, these soils can be studied to provide insight into the early phases of pedogenic processes (Amara *et al*., 2022). Prevalent in mountainous regions, this soil is primarily driven by climatic factors and their altitudinal variations, which influence pedogenic development (Almquist, 2020). In addition to the parent material, climate, terrain, organisms, and time all have an impact on soil formation (Muslim *et al*., 2021). Found in varied habitats, from frigid climates to very warm, humid, and subhumid regions (Stewart, 2019), and ranging from the Arctic to the tropics (Foss *et al*., 1983), the transformation of Inceptisols likely occurs when one or more factors controlling pedogenic processes change.

Inceptisols are widely distributed across Indonesia, particularly in calcareous landforms, and have significant potential for use as agricultural land (Tufaila *et al*., 2016). They develop on old geological materials, which may result from slow pedogenic processes acting upon these soils, active erosion, or gradual weathering (Eso *et al*., 2019). The mean soil texture is clay loam and sandy loam with acidic to slightly acidic soil reactions, with the topsoil having higher organic carbon than the subsoil. Several techniques are used to characterize soil samples, such as physical descriptors (i.e., color, density gradient, particle size, texture, morphology), chemical analysis (i.e., elemental composition, pH, nitrogen content), and magnetic susceptibility properties. Fourier Transform Infrared (FTIR) spectroscopy is used to find valuable data, as forensic soil characterization is a simple, rapid, and non-destructive technical approach that is capable of distinguishing the principal chemical classes of organic matter through the vibrational characteristics of their structural, chemical bonds. Previous studies have successfully described the composition status of different soil horizons (Cox *et al*., 2000; Margenot *et al*., 2019) and determining crystalline silica in industrial dust samples (Ojima, 2003). Magnetic susceptibility is used to express the magnetic mineral content of the soil and to study soil-forming processes (Jordanova, 2016; Maxbauer *et al*., 2016) and soil erosion (Eso *et al*., 2021).

This study aimed to identify the characteristics of Inceptisols (Cambisols) found in calcareous landforms developed from the limestone parent material. Some physical, chemical, and mineral content features can be used to guide soil management and provide balanced fertilizer recommendations. Based on its characteristics, the soil studied can be used for agriculture land, both seasonal and annual crops.

MATERIALS AND METHODS

Site description and sampling method

Soil samples were collected from three locations. A total of 30 samples, taken from depths ranging from 20 to 200 cm across all profiles (each profile comprising 10 samples), were analyzed for physical, magnetic, chemical element, mineral, and organic components. Seasonal crops grown on the existing land included vegetables, while annual crops consisted of oil palm, durian, nutmeg, cloves, and sugarcane. Profiles 1 and 2 were located in the Abeli District, while Profile 3 was situated in the Puwatu District (Figure 1).

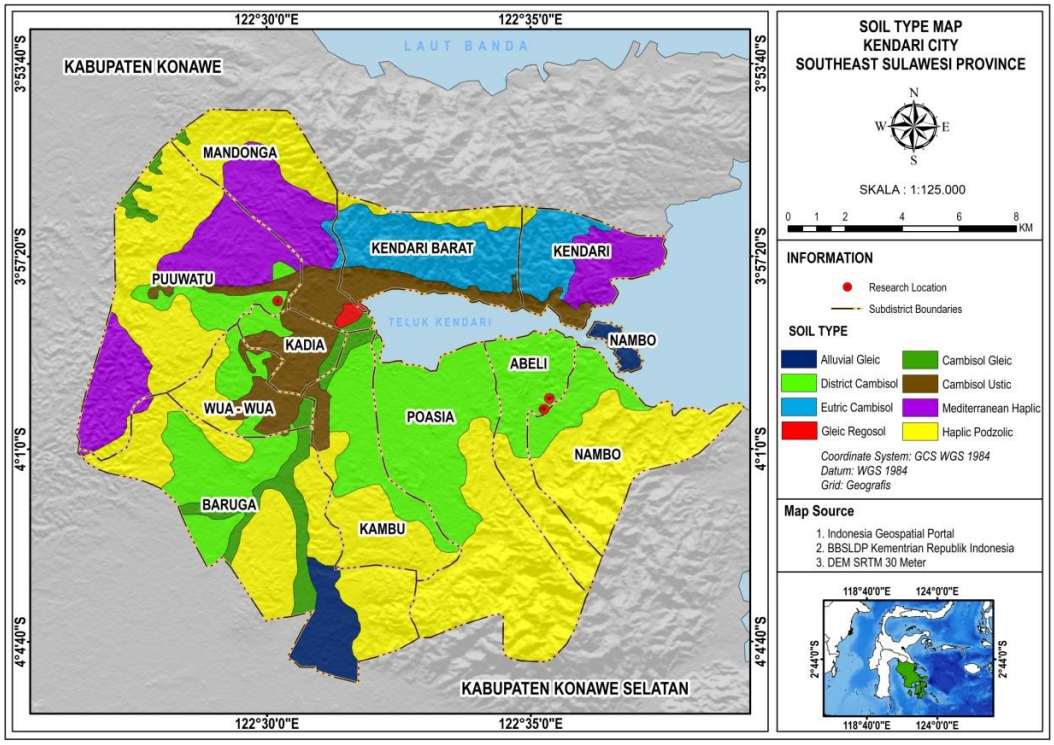

Figure 1. A schematic map of soil types in Kendari City, obtained from the Indonesia Geospatial Portal (http://www.geospatial-indonesia.com), shows the sampling sites in the Abeli and Puwatu districts, marked with rounded red indicators.

Magnetic properties measurement

Analysis of the magnetic properties was conducted at the Earth Physics Laboratory of Halu Oleo University. Magnetic susceptibility was measured at frequencies of 470 Hz and 4700 Hz using a Bartington MS2B susceptibility meter set to a sensitivity of 1.0 (Dearing *et al*., 1996). The mass-specific frequency-dependent susceptibility (c_{FD}) and its percentage (c_{FD} %) were calculated using the following equation

$$\chi_{FD} = \chi_{LF} - \chi_{HF} \quad (1)$$

$$\chi_{FD}\% = \frac{\chi_{LF} - \chi_{HF}}{\chi_{LF}} \times (100)\ \% \quad (2)$$

Here, χ_{LF} and χ_{HF} represent low- and high-frequency susceptibility, respectively. The interpretation of χ_{FD} was used as a proxy to estimate the total concentration of superparamagnetic (SP) grains, following Dearing *et al*. (1996): low χ_{FD} % < 2 %, indicating virtually no SP grains; Medium χ_{FD} % (2–10%) indicating an admixture of SP and coarser non-SP grains or SP grains; High χ_{FD} % (10–14%) indicating predominantly SP grains; and Very high χ_{FD} % (> 14%) indicating rare values or potential contamination.

Soil properties analysis

Major elements were analyzed using X-ray fluorescence (XRF) spectrometry at the Geo Gea Laboratory in Kendari City, Indonesia. Soil samples were air-dried and passed through a 2-mm sieve prior to analysis. Selected soil properties and characteristics were determined according to Soil Survey Staff guidelines (Ditzler and Hempel, 2017), unless stated otherwise. These included pH measurements in water and 1 M KCl using a 1:1 soil-to-solution ratio, and total nitrogen content determined by the Kjeldahl method (Weil and Brady, 2017). Bulk soil fractionation into three particle size fractions (clay, silt, and sand) was performed by wet sieving and sedimentation following Stokes's law (Rossiter, 2011). Reagent blanks were used as quality control samples during the analysis.

Fourier Transform Infrared (FTIR) spectroscopy analysis

In this study, X-ray diffraction (XRD) analysis and Fourier Transform Infrared (FTIR) spectroscopy were employed to characterize the mineral and organic components of soil samples at the Integrated Chemistry Laboratory of Hasanuddin University, South Sulawesi, Indonesia. Samples were crushed into a fine powder using an agate mortar, with grinding time minimized to prevent deformation of the crystal structure and ion exchange. Soil fractions were ground, mixed, and diluted with potassium bromide (0.5–3%), pressed into pellets, and desiccated before analysis. Soil extracts or suspensions were dried onto infrared windows. Since the beam interacts with all areas of the material, the transmission provides a bulk infrared measurement, allowing FTIR spectra of soil minerals and organic components to be obtained

RESULTS AND DISCUSSION

The variation of the magnetic properties of soil

Soil magnetism research is essential for understanding the magnetic characteristics of soil, which plays a key role in explaining plant root development and their function in agricultural productivity. The patterns of magnetic property variation (Figure 2) showed an increasing trend in magnetic susceptibility across all profiles, indicating the enrichment of magnetic minerals. The χLF values for profiles 1, 2, and 3 ranged from 9.59×10^{-8} to 36.22×10^{-8}, 11×10^{-8} to 86.5×10^{-8}, and 17.5×10^{-8} to 97.85×10^{-8} m^3 kg^{-1}, respectively. These values suggest a high concentration of paramagnetic minerals, including olivine, smectite, attapulgite, epidote, and dolomite, which are classified as moderately magnetic ($10–100 \times 10^{-8}$ m^3 kg^{-1}) according to soil categories based on magnetic susceptibility (Quijano *et al*., 2014).

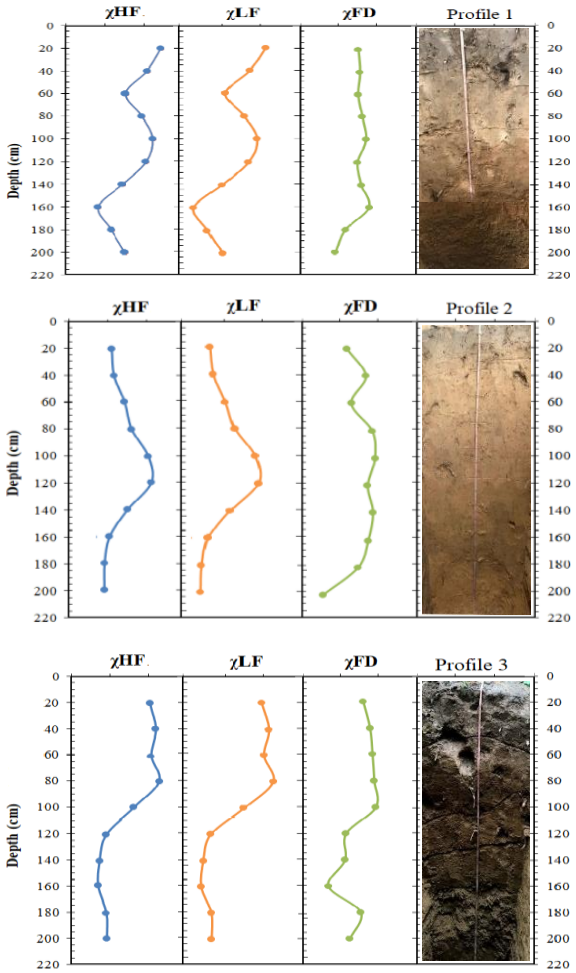

Figure 2. Normalized magnetic susceptibility as a function of depth for profile 1, profile 2 and profile 3.

Profiles 1 and 2 had frequency-dependent susceptibility values ranging from 12.65% to 16.18% and 10.16% to 15.69%, respectively, indicating a high concentration of SP minerals. In contrast, profile 3 exhibited values ranging from 2.04% to 13.97%, with medium values suggesting the presence of SP-enhanced soil minerals (Figure 3)

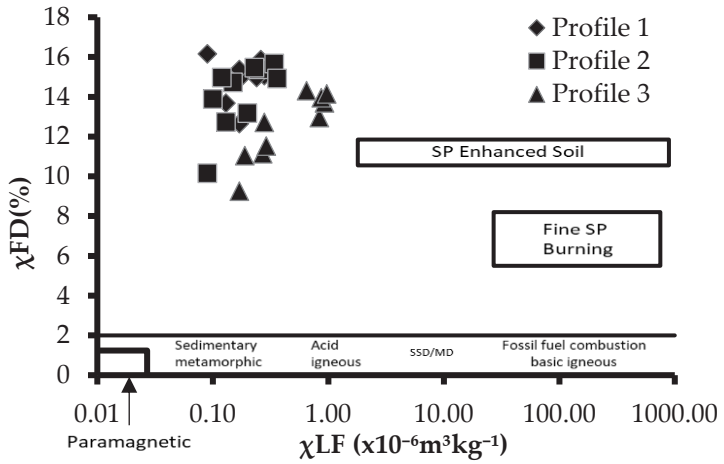

Figure 3. Scattergram of frequency-dependent susceptibility percentage (χFD%) against low-frequency susceptibility (χLF) for three soil vertical profiles, with boxes and labels adapted from Dearing (1999).

Physics and chemical properties of the soil

Inceptisols from these profiles exhibited varying colors depending on land use and mineral content, but were predominantly reddish yellow to dark brown, with hues ranging from 7.5 YR to 10 YR. The value varied from 3 to 7, and chroma ranged from 4 to 8. Soil textures were primarily sand, loamy sand, and sandy loam. The soil reaction (pH) was slightly acidic across all profiles, ranging from 5.5 to 6.5. The mean electrical conductivity was 0.055 dS m^{-1}, with a range from 0.04 to 0.07 dS m^{-1}. The salinity levels were low, and no significant impact on plant growth is expected across all soil profiles (Pooja and Kumar, 2015)

The mechanical composition of all profiles was dominated by the sand fraction (Figure 4), comprising 50–70 % in the different horizons. Silt and clay fractions make a relatively small contribution to the texture and display variations in the lower part of the profile. Although the clay fraction is small in amount, it is relatively enriched in the lower parts of these soils and increases rapidly as it approaches the C horizon. This enrichment is strongly influenced by reduction processes and weak pedogenic clay formation from the primary rock minerals.

Analysis of the chemical elements using the XRF method identified several elements present in all profiles, including oxides of Si, Al, Fe, Mg, Ti, Ca, S, Na, K, P, Mn, Ni, Co, and Cr. These elements exhibit a specific pattern (Figure 5). Si is the most abundant in

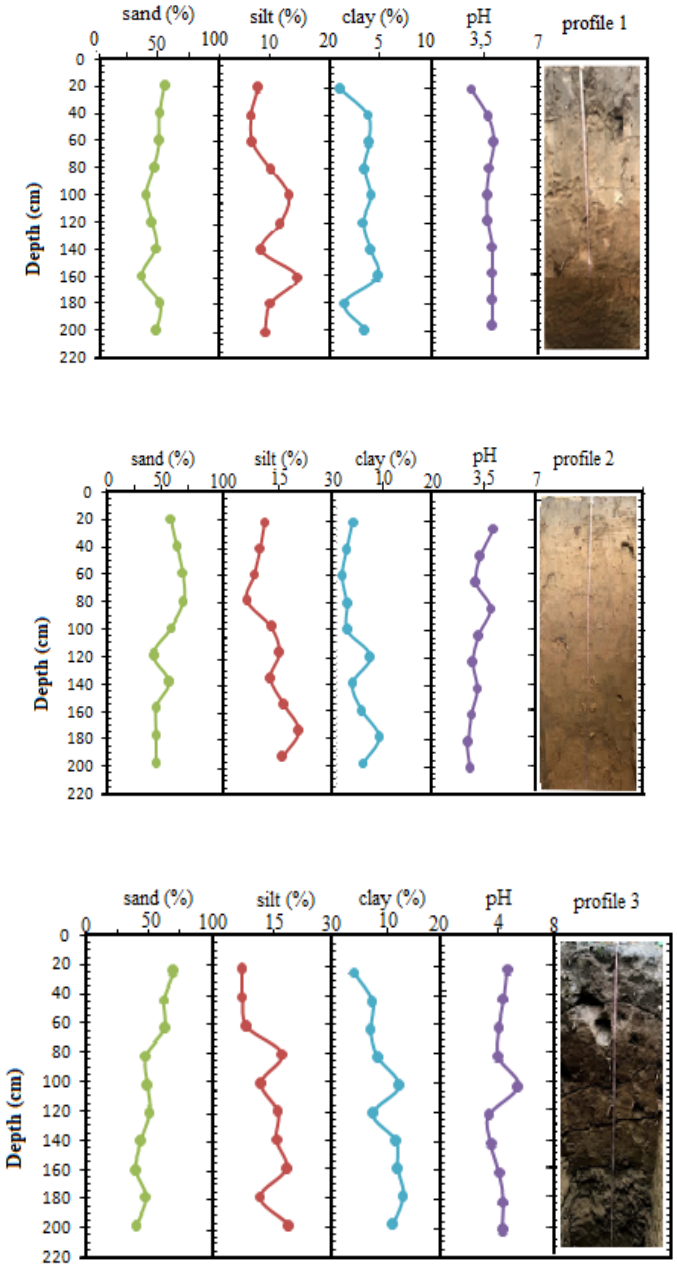

Figure 4. Normalized pH and soil fraction (sand, silt, and clay) as a function of depth for all soil profiles.

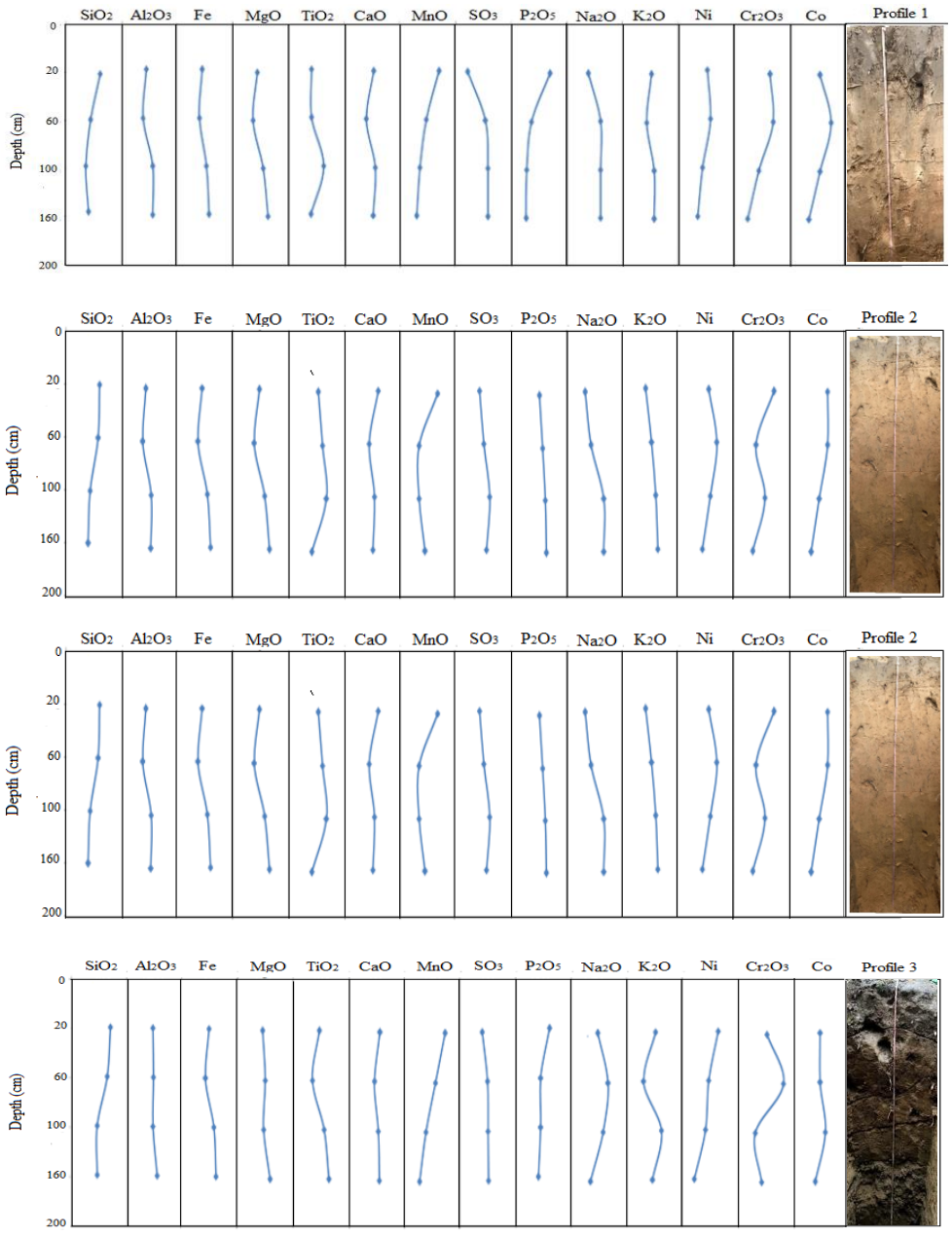

Figure 5. Normalized chemical element content of soil as a function of depth for all soil profiles.

all profiles, ranging from 57.6% to 62.74%, followed by Al (4.1–5.08%), Fe (0.76–1.29%), Mg (0.2–1.15%), Ti (0.198–0.87%), Ca (0.095–0.15%), S (0.04–0.09%), Na (0.01–0.06%), K (0.01–0.043%), P (0.01–0.038%), Mn (0.01–0.038%), and Co, Cr, and Ni, each less than 0.02%. A significant trend was observed when comparing the chemical elements among all soil profiles, showing a unique pattern. Si tends to increase, while Al, Fe, and Mg tend to decrease across all profiles. In contrast, total P and total K, which are critical components of soil fertility, showed a negative trend with depth, indicating higher nutrient availability in the topsoil. Among the various chemical elements found in the soil profiles, the presence of nickel (Ni), chromium (Cr), and cobalt (Co) is particularly significant for soil qualities due to their high magnetic susceptibility and commercial value.

Although associating the variation in magnetic properties with the distribution of chemical elements can be unreliable, the observed patterns may be related to the weathering history of the soils. The results of this comparative characterization demonstrate some distinct differences between the magnetic characteristics and chemical elements in the soil profile. The observed differences are consistent with the hypothesis that the high-Fe soil has experienced more intense weathering resulting from either the higher Fe concentration, the lower magnetic properties, or both. Further work is needed to explain the observed difference between the high-Fe and control soil and to identify specific mechanisms by which altered weathering conditions determine weathering rates.

Total nitrogen and chemical mineral composition of soil

The average total nitrogen of soil ranged from 0.21 to 0.59 % for profile 1, from 0.1 to 0.48 % for profile 2, and from 0.1 to 0.39 % for profile 3 (Figure 6). Total nitrogen levels on topsoil are increasing, meeting the medium criteria for profiles 1 and 2 and the low criteria for profile 3.

The diffraction pattern of the topsoil from all profiles (Figure 7) revealed a 100% silicon oxide (SiO_2) phase with a trigonal (hexagonal axis) crystal system. The peak positions

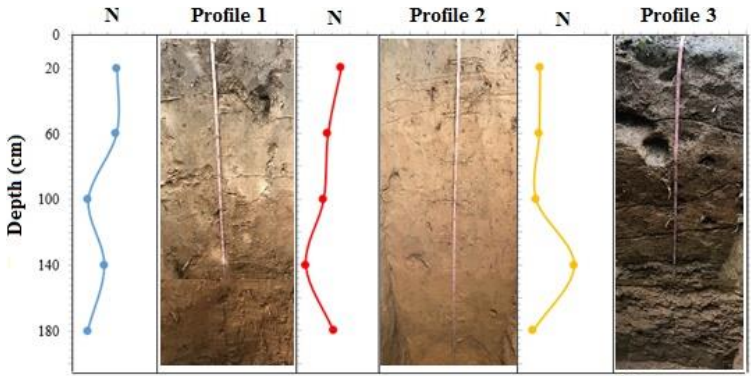

Figure 6. Total nitrogen content in vertical layer of soil horizon for all profiles.

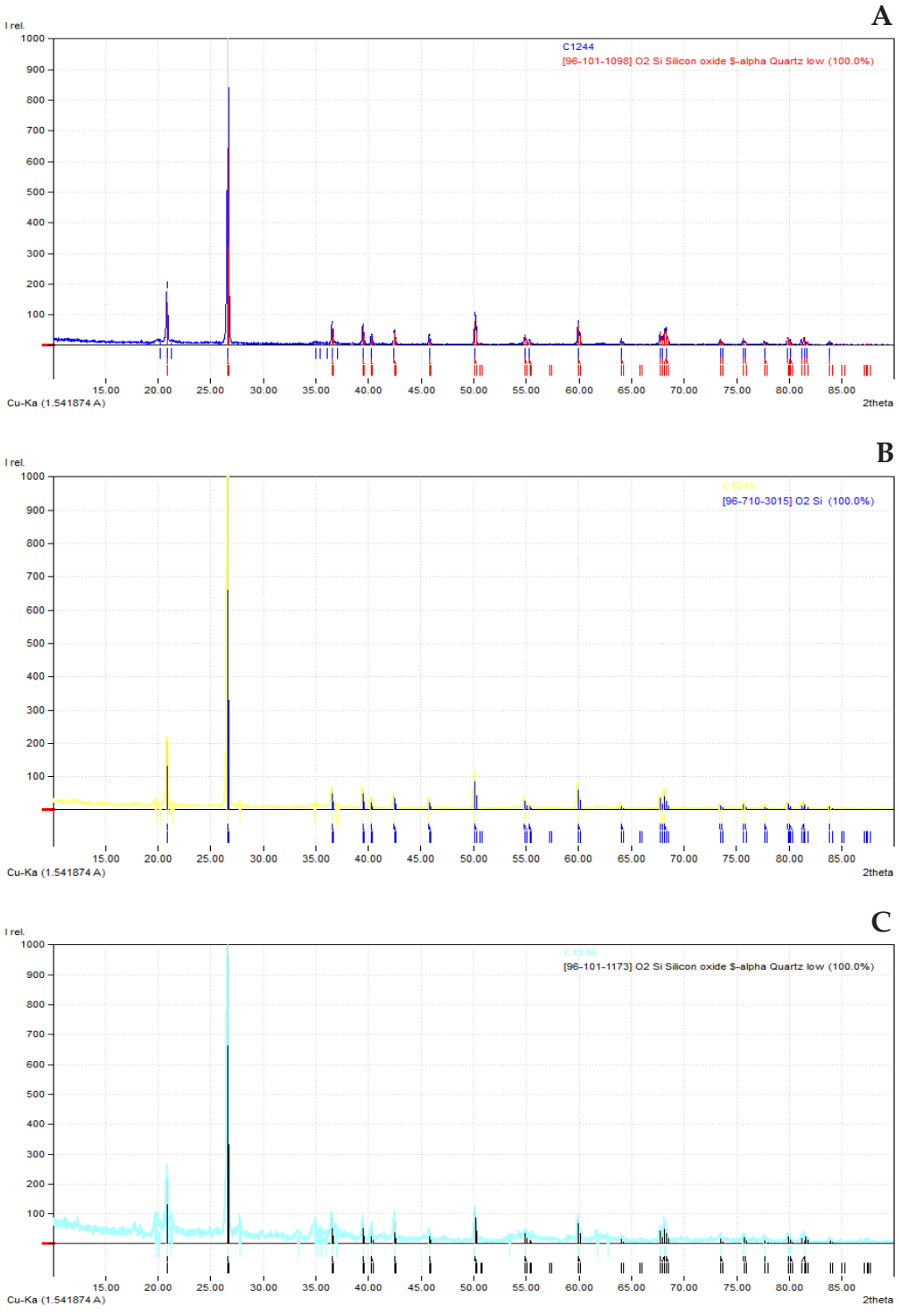

Figure 7. The diffraction pattern of the topsoil: Profile 1 (A), Profile 2 (B), and Profile 3 (C).

in the 2θ angle correspond to low quartz minerals, with the three highest peaks at angles 26.64°, 20.86°, and 50.14°.

FTIR variation

Soil evaluation using FTIR spectroscopy with an infrared spectrum (400–4000 cm^{-1}) (Figure 8) revealed the nature of the frequency groups at three soil sites, showing fluctuations with depth (i.e., 20, 40, 80, 120, 160, and 200 cm, respectively), which were generally governed by fundamental vibrations.

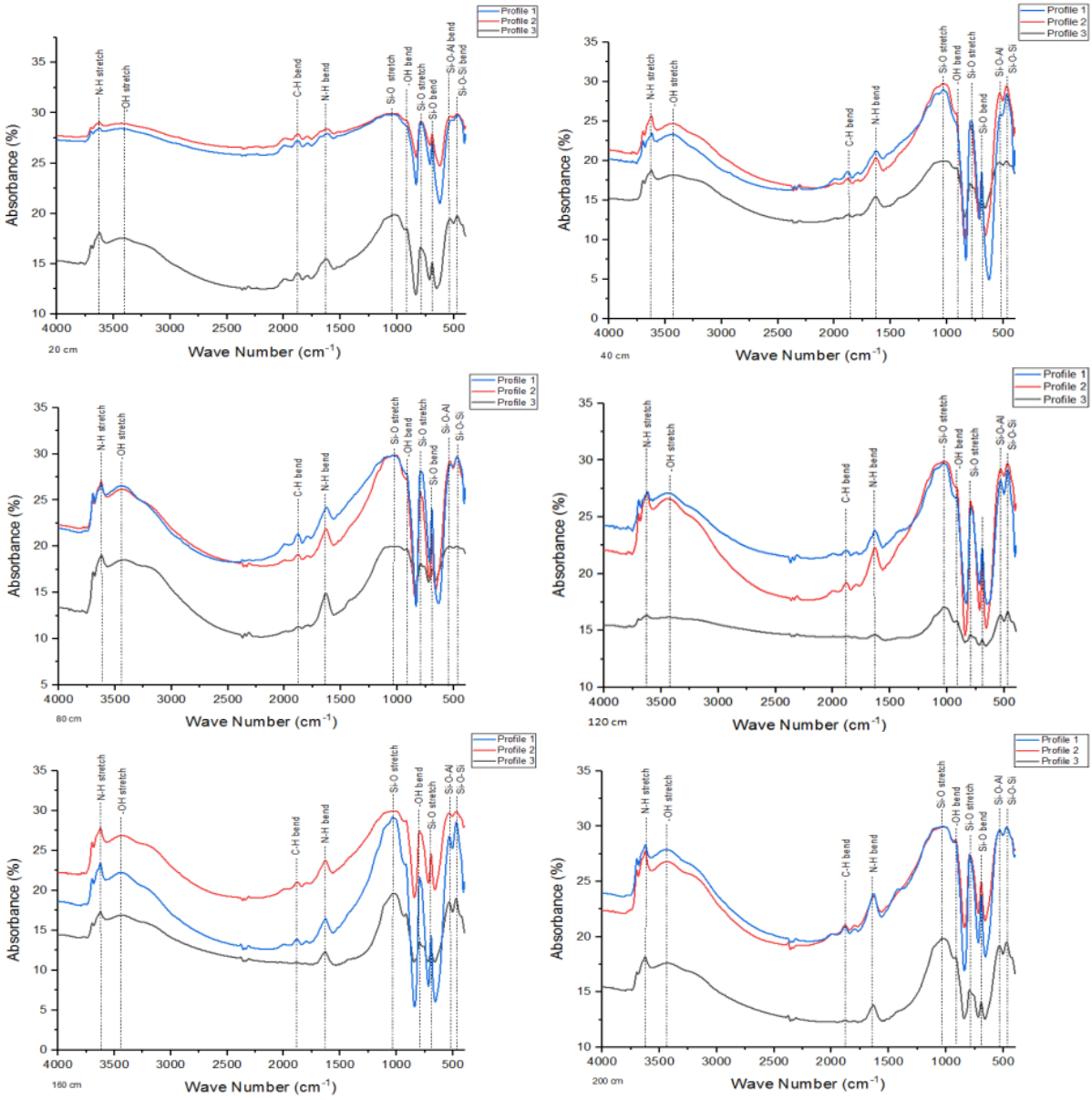

Figure 8. Comparison of Fourier Transform Infrared (FTIR) spectroscopy spectra of topsoil from Abeli District (left) and Puwatu District (right).

Absorbance bands corresponding to organic functional groups indicate an index of soil organic matter (SOM) humification at all profiles, which is higher in topsoil than in subsoil, including alcohols (O-H) stretching in strong board (3420–3440 cm^{-1}), aliphatic primary amines (N-H) (3697–3620 cm^{-1}), amine and cyclic alkenes (1665–1630 cm^{-1}) due to N-H bending, C=C stretching vibration, and aliphatic C-H bending at 1872 cm^{-1}. However, overlapping low absorbance intensity of organic functional groups and dominant absorbance of mineral components, particularly Si-O stretching, occur in the region 1100–800 cm^{-1}, making interpretation difficult on this band.

Soil mineral absorbance bands corresponding to phyllosilicates groups, including hydroxyl (O-H) stretching and bending, occur at 3700–3620 and 920–916 cm^{-1}. Silicate Si-O asymmetric stretching occur at 1090–1030 cm^{-1}, Si-O symmetric stretching at 795–790 cm^{-1}, and Si-O bending at 695–690 cm^{-1}. Specific absorption of the fingerprint region was sensitive enough to distinguish Si-O-Al and Si-O-Si bending, allowing for the identification of the phyllosilicate structural class (Krivoshein *et al*., 2020).

Layer silicates are made up of Al in octahedral coordination with O bonded to one (1:1) or two (2:1) sheets of Si in tetrahedral coordination with oxygen. Structural characterization and phylosilicate identification are based on the absorbance of mineral structural units. The 1:1-layer silicates (Figure 8) show two or more OH stretching bands at depths of 20 and 40 cm across all profiles, whereas the 2:1-layer silicates exhibit a single OH stretching band (3700–3620 cm^{-1}) at depths of 80, 120, 160, and 200 cm, which is attributed to OH coordinated with octahedral cations

IR spectroscopy in the range of O-H stretching vibrations is one of the most accurate methods for identifying phyllosilicates in polymineral mixtures. The primary absorption band spectra from topsoil to 40 cm depth across all profiles show a single OH stretching vibration in the hydroxyl group region (3700–3400 cm^{-1}). A single peak at 3694 and 3620 cm^{-1} can be classified as a 2:1 layer of kaolinite, while a broad absorbance in the Si-O stretching region (1120–950 cm^{-1}) shows peaks at 1114, 1032, 1010, and 936 cm^{-1}

Furthermore, in the 80 to 200 cm depth range, peaks at 3629 and 3620 cm^{-1} are classified as a 1:1 layer silicate, with two OH stretching bands and two broad Si-O stretching absorbances at the 1044 and 918 cm^{-1} peaks. Overall, based on IR spectrum band absorption, the soil mineral type from 80 to 200 cm depth resembles the montmorillonite absorption band, while the topsoil to 40 cm depth corresponds to the kaolinite absorption band (Ojima, 2003).

High levels of Al, Fe, and Mg in the soil, with these patterns increasing with depth (Figure 8), indicated Al_2OH vibration (3620 and 916 cm^{-1}), FeAlOH (890–910 cm^{-1}), and MgAlOH (850 cm^{-1}) in montmorillonite (Madari *et al*., 2006). In contrast, the 1:1 layer silicate attributed to kaolinite is expressed in terms of Si-O absorbance at 1120–950 cm^{-1}. It appears that, using an FTIR analysis approach, variations in clay minerals from montmorillonite to kaolinite in the topsoil throughout the profiles could be explored.

Micro-ATR spectroscopy was used to study the effect of clay swelling on the misorientation and physical breakdown of montmorillonite platelets (Du and Zhou, 2011). The shift from montmorillonite to kaolinite in topsoil affects soil properties, water dynamics, and fertility, all of which are critical for agricultural development. Sustainable land management practices must adapt to these changes, such as adding organic matter to soils (Wilding and Drees, 1983), implementing crop rotation to maintain nutrient-holding capacity, developing irrigation strategies, and selecting crops suited to ensure optimal yield productivity

The abundance of magnetic minerals with upward trends from the bottom of the rock strata supports long-term pedogenic processes (Maxbauer *et al*., 2017). The χ_{LF} values at all profiles ranged from 9.59×10^{-8} to 97.85×10^{-8} $m^3\ kg^{-1}$, indicating a high concentration of paramagnetic minerals such as olivine, smectite, attapulgite, epidote, and dolomite. The average frequency-dependent susceptibility values in all profiles ranged from 12.65% to 16.18%, indicating that bulk superparamagnetic minerals strongly influence weathering through chemical, physical, and environmental factors. The abundance of Si, followed by Al, Ca, Fe, Ti, Na, S, and Mn, can be linked to the weathering history of the soils. Slow weathering rates present substantial challenges to agricultural development due to slow nutrient replenishment and poor water retention.

Total nitrogen values in all sample sites were higher in the topsoil than in the subsoil. It is unclear whether the high nitrogen values in all profiles are driven by anthropogenic or pedogenic processes (de Vries and Posch, 2011). Because nitrate ions and clay-humus particle surfaces are negatively charged, NO_3^- is easily leached with drainage water unless it is taken up by organisms or denitrified. The strong affinity of H^+ ions for negatively charged surfaces can lead to the displacement of cations such as Ca^{2+}, Mg^{2+}, and K^+ from particle exchange surfaces (Margenot *et al*., 2019). The vibrations of relevant atomic groupings vary in frequency to an extent that corresponds to IR bands associated with mineral identification in the sample material

The diffraction pattern of topsoil from the three profiles (Figure 7) was identified as quartz-low (SiO_2), indicating the need to investigate their interference with minerals in the main absorption band (Dewi *et al*., 2018). As a result, Inceptisol topsoil had the highest mineral essential for crop formation as a result of physical change. Clay minerals, such as montmorillonite (high fertility), must be transformed into kaolinite (low fertility) using natural resource management and sustainable farming technologies.

CONCLUSIONS

This study examined the chemical and magnetic properties of Inceptisol soil under tree canopies, along with Fourier Transform Infrared (FTIR) spectroscopy analysis. The analysis revealed a range of chemical element contents, each exhibiting a distinct pattern. The average total nitrogen content of the soil ranged from 0.14% to 0.51%, with values increasing sequentially from the underlying bedrock to the topsoil. The

variation in magnetic susceptibility across all sites showed an upward trend, indicating the enrichment of magnetic minerals and, thus, the prolonged influence of pedogenic processes

IR spectrum band absorption corresponding to organic functional groups serve as an index of soil organic matter humification across all profiles, including alcohol and aliphatic primary amine stretches, as well as amines and cyclic alkenes. Understanding the swelling and physical breakdown of montmorillonite platelets requires collaborative efforts to implement sustainable soil management practices aimed at maintaining soil health and ensuring long-term productivity. Mineral modification using additives can enhance the properties of montmorillonite or stabilize kaolinite soils, thereby supporting long-term agricultural productivity and improved land use.

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