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Innovation with lagoon sediments for soil conservation and sustainable intensification in the Ecuadorian Andes. †

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Abstract: Agricultural production outlines the constant antagonism between the quest to achieve the highest yields and the need to preserve the physical / chemical properties of soils. The constantly increasing global demand for food prompts producers to apply more agrochemicals in order to increase their production, generating soil degradation, which is a costly and complex issue to solve. Based on this context, we targeted a variety of objectives such as a) to evaluate the effectiveness of lagoon sediments in soil recovery, b) to analyze the effect of sediment on the yield of the coriander crop, c) and, to determine soil reclamation costs. The experiment was developed in the province of Imbabura, located in northern Ecuador. For this we occupied a surface area per plot of 3 m² and used a completely randomized block experimental design. Four doses of sediment were applied, being mixed with soil. The benefits of the use of lagoon sediments are evidenced in the nutritional quality of the soil after its application, determined by the physical and chemical analysis that reveals an increase of 3.9 ppm of the initial N, even after vegetative consumption. Similarly behaved a best C.E. of 0.85 mS/cm, which promote a higher crop yield compared to the control treatment, becoming an innovative alternative for soil recovery. This activity allowed to reconcile the intensive agriculture with soil conservation.

Keywords: lagoon sediments; soil conservation; intensification; sustainability

1. Introduction

The inadequate management of the soil as a direct consequence of anthropic use, results in its deterioration, based on the responsibility of agriculture, forestry and livestock [1]. Due to the use of agrochemicals, the excessive use of agricultural machinery, the empirical application of synthetic fertilizers, and above all the agronomic ignorance of the crops, cause constant physical, chemical and microbiological degradation in the soil. In Ecuador it constitutes the greatest environmental problem, since 48% of the surface of the national territory presents soil erosion [2]. Being the cause of this reality the vast majority of crops, and coriander is no exception, due to its constant, fast and high consumption of soil nutrients, this crop is considered by farmers to be a soil deteriorator, being ideal for the current research [3].

Therefore, the use of lacustrine material from the Colta lagoon in the province of Chimborazo is proposed as an alternative organic fertilizer, which does not act negatively on the rhizosphere and allows to sustain an agro-environmentally clean agriculture. Through the agro-industrial processes to which the sediment is subjected, heavy metals and pathogens are eliminated, allowing their application in deteriorated soils. This allows to improve the nutritional quality and soil structure and to promote sustainable agriculture [4].

2. Materials and methods.

The present research was conducted in the La Victoria sector of the city of Ibarra, in northern Ecuador, at 2,100 meters above sea level, in a sandy loam type soil and a predominantly semi-deciduous forest, within a shrub ecosystem in the north of the valleys (Fig. 1).

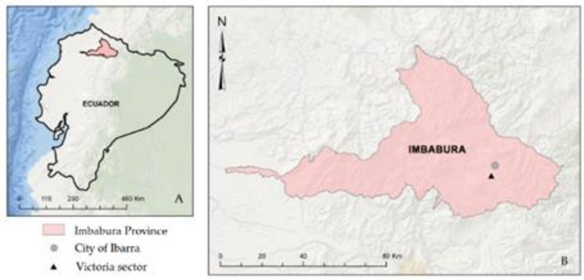

Figure 1. Left, position of Ecuador and within the Province of Imbabura, and right, the La Victoria sector and the city of Ibarra within the Province.

The condition of the soil was determined through the initial physical-chemical analysis of the soil, in order to determine macro and micro nutrients, organic matter, electrical conductivity and soil pH. The samples were taken in a diagonal pattern in relation to the study area [5]. The research has as a study factor the compost (fertilizer) based on dredged sediments from the Colta lagoon, which were applied in five different treatments (Table 1).

Table 1. Percentage of treatments applied during the current study.

Code	Compost (%)	Characteristics
T1	100	100% of the compost and 0% of the soil.
T2	75	75% of the compost and 25% of the soil
T3	50	50% of the compost and 50% of the soil
T4	25	25% of the compost and 75% of the soil
T5	0	0% of the compost and 100% of the soil (core)

The most adequate dosage of compost in the crops promotes the ideal development of the crop. Therefore, based on the recommendation to apply 50% of fertilizer to crops [6]. This reference is considered and the alternative of administering doses with 25% less than the starting point as well as doses with 75% and 100% fertilizer.

The research is based on the statistical model of Completely Random Block Design (CRBD), consisting of 15 experimental units distributed in four treatments with a control and three repetitions of each treatment. Each experimental unit presented an area of 3.00 m^2 with 3 m in length and 1 m in width.

2.1. Evaluation of phenological variables.

Days to germination and days to harvest: This variable was determined based on the visualization of emerging plants, from their sowing, until the moment when 90% of germinated plants are observed in each experimental unit [7]. On the other hand, the days to harvest were established based on the recommended phenological characteristics, such as leaves with intense green coloration and an average height of 0.44 m [8-10].

Stem height: In order to determine this variable, a vernier and a tape measure were required, which allows the measurement from the root neck to the end of the main stem. Hereby, data collection was conducted from day 20 of the crop every 10 days, until accomplish 70 days. The choice of plants to be registered was chosen by means of the elimination criterion by edge effect [8].

Crop yield: This variable was determined by means of an analytical balance in which the mass of each experimental unit was recorded, to later determine the number of bundles for each unit, and finally extrapolate them to a production per hectare [9].

Soil evaluation: In order to determine the quality and state of the soil, the pre-sowing physical-chemical analyzes were compared with the post-harvest soil analyzes. This allowed to observe the effects of the fertilizer at the beginning and at the end of the investigation [11].

***Economic analysis:* Based on the International Corn and Wheat Center (CIMMYT) [12], the economic analysis was performed, considering the cost of inputs [3], in order to determine the cost of soil recovery with each treatment.**

3. Results and Discussion.

3.1. Days to germination and days to harvest.

The percentage of compost present in treatment T4 (25% compost and 75% soil), and treatment T1 (100% compost and 0% soil), allowed the seeds to germinate in (11 days avg.) (Table 2). This reaffirmed that the use of sediments promotes a prompt emergence thanks to the structural improvement of the soil required in this stage [6,13]. Similarly, the sediment as compost allowed to improve the harvest time (57 days avg.), with the T3 treatment (50% compost and 50% soil), due to the nutritional value provided by the compost [8,10] (Table 3).

Table 2. Average days of germination and Tukey test at 5%.

Code	Compost (%)	Average (days)	Range
T4	25	11	A
T1	100	11	A
T5	0	13	AB
T2	75	13	AB
T3	50	15	B

Table 3. Average days to harvest and 5% Tukey test.

Code	Compost (%)	Average (days)	Range
T3	50	57	A
T4	25	62	AB
T2	75	71	B
T5	0	73	BC
T1	100	76	C

3.2. Stem height.

The results obtained by the T3 treatments (50% compost and 50% soil), reflect the highest height obtained at 70 days, with (51.47 cm avg), exceeding its average height [9,10] (Table 4). Agreeing that the addition of 50% sediment-based compost promotes growth, thanks to the provision of nutrients for the plant in the development stage [6, 11].

Table 4. Average stem height and Tukey's test at 5%.

Code	Compost (%)	Height						Range
		day 20 (cm)	day 30 (cm)	day 40 (cm)	day 50 (cm)	day 60 (cm)	day 70 (cm)	
T3	50	7.70	8.66	19.12	32.51	46.79	51.47	A
T4	25	9.05	10.06	16.95	28.81	43.21	47.53	AB
T2	75	7.09	7.85	15.24	25.90	38.86	42.75	AB
T5	0	6.70	7.40	13.92	23.67	35.50	39.05	B
T1	100	7.00	7.70	14.06	23.90	33.99	37.39	B

3.3. Yield.

In Table 5 it was observed that the T3 treatment (50% of compost and 50% of soil), was characterized as the best, since it reached (156.94 g plant -1 avg.), which, when extrapolating towards a production in 1 ha with 200,000 plants, the average and adjusted yield are of about 31,388 kg ha-1 and 23,541 kg ha-1 respectively. This allows to obtain 79,800 bundles of 295 g each in a production equivalent to 1 ha . Coinciding with the sediment-based compost, due to its nutritional load [14] and structural improvement in the soil, it concedes the best development of the plants [15], increasing their yield [16,17].

Table 5. Average yield and Tukey test at 5%.

Code	Compost (%)	Average yield (g plant-1)	Range
T3	50	156.94	A
T4	25	145.12	AB
T2	75	130.28	B
T1	100	113.73	BC
T5	0	96.25	C

3.4. Soil evaluation.

Treatment T1 (100% compost and 0% soil), presented the best results, as it demonstrated less nutritional wear after harvest. Treatments T2 (75% compost and 25% soil), T3 (50% compost and 50% soil) and T4 (25% compost and 75% soil), similarly presented good results, with wear balanced nutritional and nutritional stability at the end of the study (Table 6, Table 7). Nutritional stability and positive structural modification were verified [15], stabilizing the sandy loam soil to loamy soil [18], allowing greater retention of moisture and oxygenation of the soil [11] [19], balancing the EC at 0.85 mS cm-1 [20], also at the end of the study.

Table 6. Physical-chemical analysis of the soil prior sowing.

Code	N	P	K	Ca	Mg	S	Fe	B	Zn	Cu	Mn	E.C.[1] mS cm^{-1}	pH	M.O. (%)
	(mg kg^{-1})		(meq $100ml^{-1}$)			(mg kg^{-1})								

[1] Electric conductivity (E.C) = Ability of the soil to conduct electrical current and take advantage of salts through this conduction [20].

T1	57.92	28.2	1.64	60.58	7.83	132.67	155.28	0.35	2.86	13.57	31.51	1.61	7.42	7.43
T2	70.15	32.3	1.21	49.19	6.95	119.22	105.51	0.25	3.7	8.62	26.32	1	7.45	5.98
T3	23.41	32.24	1.09	46.68	7.19	79.8	103.08	0.31	3.68	7.06	15.56	1.15	7.48	5.54
T4	14.71	46.97	0.87	41.76	5.97	40.13	135.82	0.33	12.6	10.23	41.41	0.92	7.34	3.19
T5	48.06	43.28	0.66	41.23	5.25	19.16	121.79	0.85	3.86	11.83	27.04	0.44	7.22	2.53

Table 7. Post-harvest soil physical-chemical analysis.

Code	N	P	K	Ca	Mg	S	Fe	B	Zn	Cu	Mn	E.C. mS cm^{-1}	pH	M.O. (%)
	(mg kg^{-1})		(meq 100ml^{-1})			(mg kg^{-1})								
T1	37.3	35.27	0.83	17.3	6.1	42.65	163.51	0.25	2.61	7.93	38.0	0.75	7.43	6.97
T2	34.7	42.03	0.83	15.9	5.66	22.03	117.07	0.34	5.45	9.67	35.3	0.71	7.39	5.07
T3	27.3	47.81	0.8	12.9	5.81	12.79	155.58	0.26	6.97	10.7	29.2	0.85	7.32	3.83
T4	41	58.1	0.72	11.4	5.05	27.48	173.8	0.25	5.31	7.53	39	0.74	7.3	3.77
T5	26	35.43	0.59	8.43	3.81	9.71	166.18	0.41	4.92	7.85	31.7	0.38	7.17	2.05

3.5. Economic analysis.

Table 8. Economic analysis of the research.

	Code				
	T1	T2	T3	T4	T5
Average yield (kg ha-1)	22 746	26 056	31 388	29 024	23 890
Adjusted yield (kg ha-1)	17 059.5	19 542	23 541	21 768	14 437.5
Price ($ stranded of 295g-1)	0.25	0.25	0.25	0.25	0.25
Gross profit from the field (S ha-1)	14 457.2	16 561	19 950	18 447.46	12 235.1
Compost cost ($/ha/ciclo)	6 388.67	4 791.89	3 192.00	1 596.78	0
Production cost ($ ha-1)	3 866.63	3 866.63	3 866.63	3 866.63	3 866.63
Net profit ($ ha-1)	4 201.90	7 902.50	12 891.37	12 984.05	8 368.54
Benefit / Cost (B C-1)	1.41	1.91	2.83	3.38	3.16

The benefit / cost ratio has an index greater than one (B C-1> 1), in each of the results. On the other hand, treatment T4 (25% compost and 75% soil), presented higher profitability, with a value of $ 3.38, which reflects that for each monetary unit that is invested, the invested is recovered and a profit of $ 2.38 was realized (Table 8). However, the T3 treatment at the end of the study adheres to the main objective of the research, improving the characteristics of the soil and production. Therefore, it would be considered the best treatment at the end of the study.

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