DOI: 10.5965/223811712232023367

Revista de Ciências Agroveterinárias 22 (3): 2023
Universidade do Estado de Santa Catarina

Preparation and evaluation of a liquid fertilizer from lactic fermentation of weeds

Preparo e avaliação de um fertilizante líquido a partir da fermentação lática de plantas daninhas

Elizabeth Bereníce Chihuan Dominguez* (ORCID 0000-0002-2962-4170), Juan Gabriel Juscamaita Morales (ORCID 0000-0002-2198-0461), Jorge Luis Tejada (ORCID 0000-0002-2102-1578), Edgar Huamani Ticllahuanaco (ORCID 0000-0002-2863-6209)

Universidad Nacional Agraria La Molina, Lima, Peru. * Author for correspondence: 20130009@lamolina.edu.pe

Submission: 02/02/2023 | Acceptance: 02/05/2023

ABSTRACT

A total of twenty mixtures of weed, B-Lac and molasses were prepared in order to evaluate an accelerated liquid fertilizer (ALF) based on these plants. A mixture of 85% weed: water (1:1), 10% molasses and 5% B-Lac showed the best characteristics and was reproduced at a pilot scale. ALF was applied to lettuce using the following treatments: one foliar application per week of 10 mL L^{-1} (FA1), two foliar applications per week of 10 mL L^{-1} (FA2), one drench application of 50 mL L^{-1} every week (DA1), a drench application of 50 mL L^{-1} every two weeks (DA2) and a control without application (CWA). The variables evaluated were total yield, commercial yield, fresh weight, height, head diameter, percentage of dry matter and the concentration of foliar nitrogen, phosphorus, and potassium. The mixtures in the laboratory and pilot phase were evaluated in a completely randomized design. The field phase was assessed in a completely randomized block design with five treatments and four replications. No significant differences were found between the treatments, except in the percentage of dry matter and potassium content, where FA2 showed the best results (2.35% and 541 mg $plant^{-1}$, respectively). The highest total yield (26.4 t ha^{-1}) and commercial (24.11 t ha^{-1}) were achieved with DA2; however, the nutritional content was lower than that in the other treatments. Using homolactic fermentation it was possible to recycle weeds and produce ALF, which has potential as a biofertilizer according to its chemical characterization and effects shown on lettuce cultivation.

KEYWORDS: organic fertilizer; lactic acid bacteria; biofertilizer; weeds; dry matter; nutrient recycling.

RESUMO

Foram preparadas vinte misturas de ervas daninhas, B-Lac e melaço para avaliar um fertilizante líquido acelerado (ALF) baseado nessas plantas. Uma mistura de 85% erva:água (1:1), 10% melaço e 5% B-Lac apresentou as melhores características e foi reproduzida em escala piloto. A ALF foi aplicada à alface utilizando os seguintes tratamentos: uma aplicação foliar por semana de 10 mL L^{-1} (AF1), duas aplicações foliares por semana de 10 mL L^{-1} (AF2), uma aplicação via drench de 50 mL L^{-1} a cada semana (AD1), uma aplicação via drench de 50 mL L^{-1} a cada duas semanas (AD2) e um controle sem aplicação (CSA). As variáveis avaliadas foram produtividade total, produtividade comercial, massa fresca, altura, diâmetro da cabeça, porcentagem de matéria seca e concentração foliar de nitrogênio, fósforo e potássio. As misturas na fase de laboratório e piloto foram avaliadas em delineamentos inteiramente casualizados. A fase de campo foi avaliada em blocos casualizados com cinco tratamentos e quatro repetições. Não foram encontradas diferenças significativas entre os tratamentos, exceto no percentual de matéria seca e no teor de potássio, onde o AF2 apresentou os melhores resultados (2,35% e 541 mg $planta^{-1}$, respectivamente). As maiores produtividades total (26,4 t ha^{-1}) e comercial (24,11 t ha^{-1}) foram obtidas com AD2; no entanto, o teor nutricional foi inferior aos demais tratamentos. Utilizando a fermentação homolática foi possível reciclar as ervas daninhas e produzir FLA, que tem potencial como biofertilizante de acordo com sua caracterização química e efeitos demonstrados no cultivo de alface.

PALAVRAS-CHAVE: adubo orgánico; bactérias láticas; biofertilizante; plantas daninhas; matéria seca; reciclagem de nutrientes.

INTRODUCTION

Agriculture generates a large amount of organic waste from different activities, such as pruning debris, stubble, and weeding. However, in recent years, interest in recycling these has increased. Amendments with non-toxic organic residues are necessary to improve the fertility and characteristics of the soils, as well as to increase crop productivity. But for this, adequate treatment is required to eliminate compounds that may have harmful effects (BADDI et al. 2016).

Weeds are undesirable plants that coexist, deteriorate the quality of crops, and interfere with agricultural activities. They can cause serious losses in agricultural production (MAQSOOD et al. 2020). However, because of their highly extractive nature, they can be a potential source of nutrients that could be returned to the soil and reused by crops (LINDSEY et al. 2013, SAKONNAKHON et al. 2006). For example, DE MATOS et al. (2018) found that *Nicandra physalodes* has a low C/N ratio, low levels of cellulose, hemicellulose and lignin, in addition to high concentration of nutrients. Therefore, its residues can decompose quickly and serve in the recycling of soil nutrients.

Plant recycling opens the possibility of reducing agricultural practices that generate pollution. At the same time, it may allow recovery of nutrients through composting techniques, vermiculture, biol production, etc. (ODEPA 2015). Composting is an accelerated version of the naturally occurring decomposition processes in the soil where much of the degradable organic carbon in the waste is converted to carbon dioxide (CO_2). On the other hand, biol is a liquid organic fertilizer that originates from decomposition of organic materials in the absence of oxygen. It is a digested source of animal and vegetable waste (REYES 2017). These processes can take approximately 1 to 4 months depending on the environmental conditions in which they are produced, hence new alternatives are constantly pursued.

There is scientific literature on the use of organic waste to produce solid fertilizers or amendments. The development of accelerated liquid fertilizers from waste originated in fishing, dairy and livestock industries has also been investigated, however, there is little information on the production of liquid organic fertilizers made with weeds (BADDI et al. 2016).

The present work proposes that the use of vegetable residues from weeds will allow the elaboration of an accelerated liquid fertilizer with good characteristics to use as a biofertilizer. It will allow the nutrients captured from the soil by the weeds to be recycled. Thus, the objectives of the present study were to recycle weed residues, characterize an accelerated liquid fertilizer created from these plants and evaluate it in the cultivation of lettuce.

MATERIAL AND METHODS

Location of the study

Laboratory and pilot phases were carried out in the Laboratory of Environmental Biotechnology - Bioremediation of the National Agrarian University La Molina (UNALM) in October and December 2018, respectively. Subsequently, the field phase was carried out in a field adjacent to the soil laboratory at UNALM, located in the province of Lima, Lima region, district of La Molina (12° 04’ 58" S latitude and 76° 56’ 51" W longitude). with an altitude of 238 meters above sea level. This was done from May to July 2019 with average temperatures between 12.3 and 28.20 °C and an average relative humidity of 83.93%.

Laboratory Phase

Weeds were collected from various fields at UNALM where corn, quinoa, cauliflower, watermelon, and sweet potato were previously grown. The weeds were cut at ground level and in large quantities: *Chenopodium mural* (25%), *Chenopodium album* (20%), *Nicandra physalodes* (20%) and *Sorghum halepense* (15%). Other species were collected in less quantities were *Lycopersicon pimpinellifolium* (10%), *Bidens pilosa* (5%) and *Ipomoea* sp. (5%).

Twenty-one kg of weeds were weighed and processed in an industrial blender, adding water in a 1:1 ratio (weeds: water). Molasses is a source of carbohydrates and B-Lac is a conglomerate of lactic acid bacteria of genera *Lactobacillus*, *Streptococcus* and *Bifidobacterium* (GARCÍA 2008). Prior to preparing the mixtures, the pH of the raw materials was measured, then a mix of 20 weeds, B-Lac and molasses was prepared, establishing the treatments as shown in Table 1. The mixtures were placed in 1 L polypropylene containers and the initial pH and percentage of titratable acidity were measured. Then, each mixture was covered with a polyethylene bag to generate anaerobic conditions. The treatments were stored for five days at room temperature (ranging from 11.9 °C to 30.3 °C with an average of 17.49 °C). On the days 0, 1, 2, 3, 4 and 5 after preparation, the pH was measured with a Hanna HI9025 potentiometer, and the percentage of titratable acidity followed a standardized method 942.15 of the AOAC (1998). On the fifth day the mixtures were pressed manually to separate liquid and solid fractions. Then, the liquid fraction was compared using the following criteria that determine an optimal liquid fertilizer: pH less than or close to 4, lack of strong smells, no presence of bubble formation and the absence of molds or yeasts (PERALTA et al. 2016).

Table 1. Composition of the mixtures generated with weeds, molasses and B-Lac and evaluated in the laboratory.

Treatment	Weed 1:1 (%)	Molasses (%)	B-Lac (%)
T1	100	0	0
T2	95	5	0
T3	90	10	0
T4	85	15	0
T5	80	20	0
T6	95	0	5
T7	90	5	5
T8	85	10	5
T9	80	15	5
T10	75	20	5
T11	90	0	10
T12	85	5	10
T13	80	10	10
T14	75	15	10
T15	70	20	10
T16	85	0	15
T17	80	5	15
T18	75	10	15
T19	70	15	15
T20	65	20	15

The statistical design used was a completely randomized design with three replications. The results that showed significant differences in the analysis of variance were subjected to a Tukey mean comparison test ($p<0.05$) using InfoStat, a Statistical Software program (Infostat, Cordoba, Argentina). In addition, a cost-benefit analysis for each mixture was done considering the lowest-cost treatment and the one that makes best use of the raw material.

Pilot Phase

Only the treatment selected in the laboratory phase was prepared to be used at a pilot trial. In the pilot phase, 42 kg of weeds were used to prepare the accelerated liquid fertilizer (ALF) through homolactic fermentation for 30 days in a 150 L capacity plastic container. This work was done at room temperature (which fluctuated from 13.3 °C to 28.3 °C, with an average of 20.9 °C). The methodology used to assess pH and titratable acidity was the same as that used in the laboratory stage.

After the homolactic fermentation, the mixture was pressed to separate the liquid fraction from the solid. In the liquid fraction (ALF) the following was estimated: pH, electrical conductivity, total solids, organic matter, N, P, K, Ca, Mg, Na, Fe, Cu, Zn, Mn, B, Pb, Cd, Cr, the ratio carbon-nitrogen, and the content of microorganisms. Because there are no parameters to determine the C/N ratio in liquid organic fertilizers, the compost data was taken as a reference.

An ALF phytotoxicity test was performed for lettuce seeds (*Lactuca sativa*) cv. Lollo. The tests were done in Petri dishes at different concentrations of ALF (0, 0.01, 0.1, 1, 10 and 100% v/v), following the methodology of SOBRERO & RONCO (2004). The six treatments arranged in a completely randomized design with three replications were evaluated. Before applications, pH and EC were determined in the dilutions. Filter paper and 20 lettuce seeds were placed in each Petri dish, which were then moistened with 4 mL of the corresponding dilution and placed in the dark for 120 hours. At the end of the period, the number of germinated seeds and the length of the radicle were determined which served to calculate the germination index (GI), the relative germination percentage (RGP) and the relative radicle growth (RRG) using the following formulas (TIQUIA 2000):

$$RGP = \frac{Number\ of\ germinated\ seeds\ in\ the\ extract}{Number\ of\ germinated\ seeds\ in\ the\ control} * 100$$

$$RRG = \frac{Length\ of\ radicle\ in\ the\ extract}{Length\ of\ radicle\ in\ the\ control} * 100$$

$$GI = \frac{RGP * RRC}{100}$$

Field Phase

Lettuce plants of the *Iceberg* type cv. Bernardina were transplanted at 0.3 m between plants and 0.8 m between rows in a double row. The length of each experimental unit was 5 m, and it was composed of 3 rows, for an area of 12 m^2 and a total of 100 plants per experimental unit. This is equivalent to a density of 83,000 plants per hectare. The agronomic management used was conventional for lettuce cultivation, with timely applications of pesticides, fertilization, irrigation by gravity and four weeding days in total. Harvest was done by cutting plants at ground level when they reached the appropriate maturity, which was determined by the degree of compaction of the heads. Three weekly harvests were made, starting from the ninth week after transplantation.

The treatments consisted of one foliar application per week of 10 mL L^{-1} of ALF (FA1), two foliar applications per week of 10 mL L^{-1} of ALF (FA2), one drench application of 50 mL L^{-1} of ALF every week (DA1), a drench application of 50 mL L^{-1} of ALF every two weeks (DA2) and a control without application (CWA). The experimental design was a completely randomized block design with five treatments and four replications. Applications were made two weeks after transplanting for a period of six weeks employing a backpack sprayer, equipped with a blue adjustable conical nozzle. The foliar applications were done by completely wetting all the foliage with a volume of 200 L ha^{-1} of solution and for the drench treatments, a volume of 100 L ha^{-1} was applied to the neck of the plant.

The harvest was measured by weighing the heads of lettuce, data that was used to calculate the total and commercial yield (total yield minus the weight of plants with premature flowering, without heads and damage from pests and/or diseases). In addition, head height, equatorial diameter of heads and the percentage of aerial dry matter were measured. For the last measure, between 180 and 200 g of fresh tissue was extracted from one plant per plot and dried in an oven at 70 °C for three days. Nitrogen content was determined using micro Kjeldahl method. Phosphorus and potassium were obtained by adding 7 mL of HNO_3 to a 5 g sample of ground dry matter. Temperature was gradually brought up to 175 °C and digestion was left for approximately two hours until the solution crystallized. Finally, between 10 and 15 mL of boiled distilled water was added, and stirred, to dissolve the ashes. The solution was then filtered and made up to 25 mL, and then the samples were assessed.

The data were subjected to an analysis of variance and the significant results were analyzed in a Duncan multiple comparison test ($p < 0.05$), using InfoStat-Statistical Software program (Infostat, Cordoba, Argentina).

RESULTS AND DISCUSSION

Laboratory phase

The raw materials used in the preparation of the 20 mixtures revealed pH values of 5.34 (1:1 weeds), 4.07 (B-Lac) and 4.93 (molasses). When the mixtures were analyzed, the initial pH ranged between 4.58 and 5.92 (Table 2). Those treatments that included a greater quantity of weeds, showed that they started with a higher pH. Then, a tendency to acidification was observed as the storage time passed, due to the transformation of soluble carbohydrates in molasses into lactic acid caused by lactic acid bacteria (ZHAO et al. 2019). The pH showed decrease until the third day, with values of less than 4 in all treatments, except in the control treatments that did not contain molasses and/or B-Lac (T1, T2, T3, T4, T5, T6, T11 and T16) (Table 2).

It was observed that in treatments T2, T3, T4, T5, T7, T8, T9, T10, T12, T13, T14, T15, T17, T18, T19 and T20, as the pH decreased, the percentage of titratable acidity increased between the second and third day, then it stabilized (data not shown). This means that starting at the third day, the lactic acid bacteria produced lactic acid more slowly, using a source of sugars different than the soluble ones, as reported by CHEN et al. (2017). It is important that a decrease in pH occurs, since when it is less than 4, the accumulation of lactic acid produces an inhibitory effect on pathogenic bacteria such as Gram-negative bacteria by interfering with their cellular metabolism (RIVERA et al. 2017).

The best treatments based on the pH values and percentage of titratable acidity were T8, T9, T10, T13, T14, T15, T18 and T19. An additional criterion considered for choosing the best treatment was the production cost of each mixture, which varied between 0 and 0.57 USD per liter produced in the laboratory phase. It should be noted that this cost would decrease if elaborated on a larger scale. In addition, considering the characteristics of an optimal liquid fertilizer and, because it shows the lowest production cost (0.28 USD per liter) and the best use of residues (weeds), the T8 treatment was selected (85% weeds 1:1, 10% molasses and 5% B-Lac) to be produced in greater quantity (i.e., to be used in a pilot phase).

Table 2. pH values of the mixtures generated with weeds, molasses, and B-Lac for five days.

Treatment *	pH					
	Day 0	Day 1	Day 2	Day 3	Day 4	Day 5
T1	5.92	5.41	5.04	5.11	5.36	5.65
T2	5.64	5.27	4.06	4.11	3.97	4.00
T3	5.50	5.36	4.17	4.15	4.09	4.06
T4	5.28	5.26	4.47	4.22	4.07	3.96
T5	5.21	5.16	5.03	4.25	4.09	4.05
T6	5.61	4.48	4.77	5.06	4.98	5.08
T7	5.25	4.31	3.73	3.75	3.70	3.77
T8	5.10	4.64	3.82	3.78	3.83	3.80
T9	5.04	4.77	3.93	3.89	3.88	3.82
T10	5.02	4.85	4.02	3.96	3.92	3.82
T11	4.97	4.17	4.29	4.41	4.40	4.28
T12	4.93	4.31	3.75	3.75	3.66	3.56
T13	4.91	4.51	3.85	3.81	3.73	3.77
T14	4.92	4.71	3.96	3.90	3.85	3.80
T15	4.89	4.72	4.11	3.97	3.86	3.75
T16	4.68	4.26	4.11	4.24	4.30	4.26
T17	4.76	4.41	3.82	3.78	3.76	3.78
T18	4.78	4.54	3.90	3.84	3.82	3.69
T19	4.79	4.58	3.98	3.92	3.92	3.87
T20	4.58	4.30	3.83	3.90	3.90	3.85

*Treatments generated with percentages of weeds 1:1, molasses, and B-Lac, respectively. T1: 100-0-0, T2: 95-5-0, T3: 90-10-0, T4: 85-15-0, T5: 80-20-0, T6: 95-0-5, T7: 90-5-5, T8: 85-10-5, T9: 80-15-5, T10: 75-20-5, T11: 90-0-10, T12: 85-5-10, T13: 80-10-10, T14: 75-15-10, T15: 70-20-10, T16: 85-0-15, T17: 80-5-15, T18: 75-10-15, T19: 70-15-15, T20: 65-20-15.

Pilot Phase

From a total of 100 L of the mixture: 85% weeds 1:1, 10% molasses and 5% B-Lac, a total of 68 L of ALF was obtained, which exhibited a density of 1.043 g mL^{-1} and a C/N ratio of 61.06, indicating a high availability of carbon and low availability of nitrogen (BRUST 2019). Likewise, pH values of ALF at this phase were lower than the values observed in the laboratory, probably due to higher temperatures experienced at the pilot phase. The pH was observed to drop from 5.00 on day 0 to 3.84 on day 3, then it slowly dropped to reach 3.75 on day 5. Then it was stabilized (Figure 1). On the other hand, percentages of titratable acidity showed an increase from 0.72 on day 0 to 2.20 on day 3. From that day on, a slow increase was observed up to 2.68 on day 5, where a new increase took place, up to 3.56 on day 10, from where it stabilized (Figure 1).

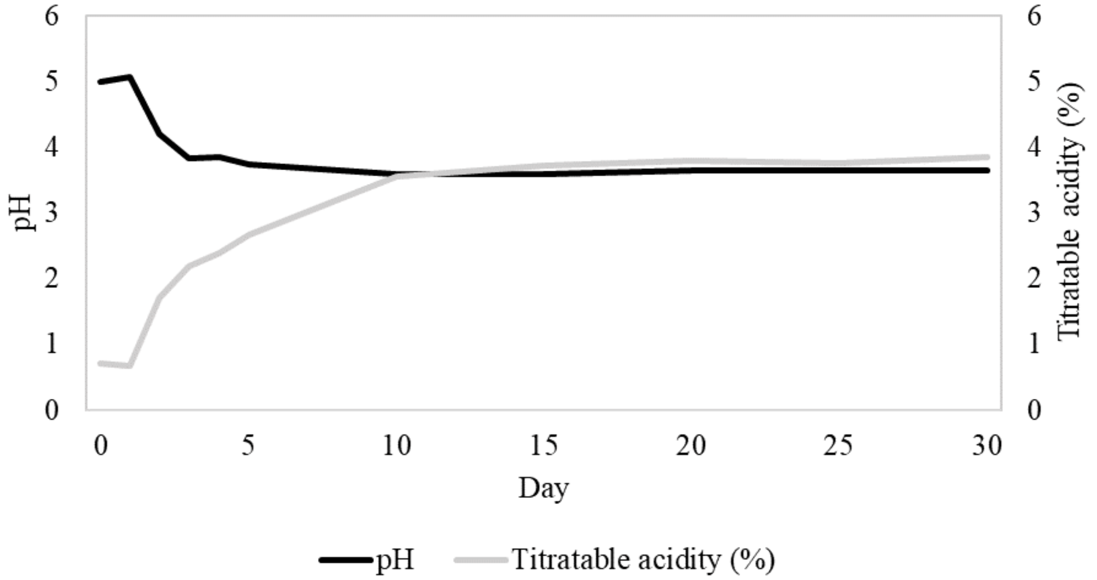

Figure 1. Data on pH and titratable acidity for the accelerated liquid fertilizer during the pilot phase.

Regarding the chemical analysis of ALF, the nitrogen content was similar to other biofertilizers (Table 3), however, it was lower compared to those that included raw sources from animals because of the nitrogen contained in excreta. The low phosphorus content in ALF may be explained by the fact that under acidic conditions, iron favors the precipitation of highly insoluble iron phosphates (CALLEJAS et al. 2018), for which phosphorus remains immobilized in the solid part. In addition, phosphorus is slowly released from organic fertilizers (MNTHAMBALA et al. 2022), unlike potassium which is rapidly recycled from organic waste (ANDREWS et al. 2021). In relation to other organic fertilizers of plant origin, the content of calcium, magnesium, zinc, and manganese is higher, while the iron values are similar to those found in ALF (Table 3).

Table 3. Chemical characterization of liquid accelerated weed fertilizer (ALF) and other organic fertilizers.

Parameters	TO	Papabiol (1)	Biofert hot pepper (2)	Biofert .(3)	Alpa-biol (4)
pH	3.46	3.67	3.69	3.72	3.83
EC (dS m^{-1})	27.20	24.1	20.1	18.5	23.40
solids total (g L^{-1})	115.96	147.2	137.4	111.38	177.88
MO in solution (g L^{-1})	86.10	117.3	115.4	87.48	137.02
Total N (mg L^{-1})	2114.0	2688	2716.0	3640	3696
Total P (mg L^{-1})	164.06	275.52	259.59	1165.32	658.10
Total K (mg L^{-1})	4212.50	5316.7	8040.0	4440	8700
Ca (mg L^{-1})	2488.75	1316.7	836.0	2695	3335
Total mg (mg L^{-1})	875.00	750	556.0	855	12500
Total Na (mg L^{-1})	757.50	450	214.0	970	590
Total Fe (mg L^{-1})	30.65	38.8	19.24	152.3	280.45
Total Cu (mg L^{-1})	0.68	1.53	1.48	5.9	2.40
Total Zn (mg L^{-1})	20.25	4.12	1.94	36.25	11.65
Mn (mg L^{-1})	8.23	3.48	2.6	17.2	71.80
Total B (mg L^{-1})	2.68	6.01	3.87	2.49	7.80

(1) Liquid fertilizer from discarded potatoes (MEZA 2014).
(2) Biofertilizer from processing residues of "*rocoto"* hot pepper (*Capsicum pubescens)* (RICSE 2013).
(3) Biofertilizer from barley bagasse, cattle excreta and cheese whey (BUCHELLI 2014).
(4) Accelerated liquid fertilizer from alpaca feces and bovine whey (QUIÑONES 2016).

The chemical analysis indicated the presence of lead (0.93 mg L^{-1}), cadmium (0.32 mg L^{-1}) and chromium (0.66 mg L^{-1}), however these values did not exceed the maximum limits established (MINISTERIO DE LA PRESIDENCIA ESPAÑA 2013), consequently they do not represent a risk of contamination, so their use as a fertilizer is appropriate.

The microbiological analysis showed an absence of total coliforms, fecal coliforms, and *Escherichia coli* (Table 4), because of the low pH in ALF (3.46) that generated an unfavorable environment for these pathogens. Another factor was the abundance of lactic acid bacteria (LAB) that produce growth inhibitors for *Fusarium* or *Bacillus cereus* in fermented foods (Table 4). In addition, LAB makes bacteriocins, hydrogen peroxide and low-molecular weight fatty acids, some of which act as inhibitors in the growth of pathogenic Gram-positive and Gram-negative bacteria (RIVERA et al. 2017).

Table 4. Microbiological analysis in accelerated liquid weed fertilizer.

Microorganisms	Quantity
Bacteria count _ lactic acid (CFU mL^{-1})	18×10^6
Yeast count (CFU mL^{-1})	55×10^5
Coliform amount _ total (MPN mL^{-1})	<3*
Coliform amount _ fecal (MPN mL^{-1})	<3*
Amount of *Escherichia coli* (MPN mL^{-1})	<3*

* Absence of microorganisms. CFU: colony forming units, MPN: most probable number.

In the phytotoxicity test, pH increased with increasing dilutions of ALF, while electrical conductivity (EC) decreased from 18.85 dS m^{-1} (100% dilution) to 0.53 dS m^{-1} (0.01% dilution), a value that equals the EC for table water (Table 5).

Table 5. Values of pH and electrical conductivity (EC) for dilutions of the accelerated liquid fertilizer for weeds.

Dilution (%)	pH	EC (dS m^{-1})
100	3.59	18.85
10	3.76	4.36
1	4.46	1,133
0.10	6.63	0.66
0.01	7.07	0.53
0	7.18	0.53

The highest values for RGP (103.57%), RRG (115.98%) and GI (120.12%) were obtained in the 0.01% dilution (Table 6). The absence of phytotoxic substances and the presence of nutrients in that concentration level favored the development of the seedlings. With a 0.10% dilution, the GI slightly exceeded the control, this result was influenced by RRG (Table 6).

Table 6. Relative germination percentage (RGP), relative radicle growth (RRG) and germination index (GI) of lettuce seeds as a function of different dilutions of accelerated liquid weed fertilizer.

Dilution (%)	Number of germinated seeds	RGP (%)	Radicle length (mm)	RRG (%)	GI (%)
100 (pure)	0.0	0.0	0.0	0.0	0.0
10	1.3	7.1	2.8	12.7	0.9
1	18.3	98.2	12.8	57.9	56.9
0.10	17.3	92.9	24.1	108.9	101.1
0.01	19.3	103.6	25.7	116	120.1
0 (control)	18.7	-	22.1	-	-

ZUCCONI et al. (1981) determined the following criteria for an interpretation of germination indices: GI values ≥80% would indicate that there are no phytotoxic substances or that they are in very low concentration, GI ≤ 50% would indicate a strong presence of phytotoxic substances and if 50 < GI < 80, it would be interpreted as a moderate presence of those substances.

In the 1% dilution, a good RGP (98.21%) was observed, however the RRG was low (57.92%), so the GI was 56.88%. That value of RRG would indicate the presence of phytotoxic substances because RRG is a more sensitive variable than RGP since there are phytotoxic metabolites that do not inhibit germination, but they do limit the development of the radicle (VARNERO et al. 2007). Likewise, the low pH (4.46) (Table 5) could be affecting the normal development of the radicle.

Field Phase

The yield fluctuated from 21.5 t ha^{-1} to 26.4 t ha^{-1} (total) and from 20.09 to 24.11 t ha^{-1} (commercial) (Figure 2). Those values were higher than the normal average yield in Peru (11.4 t ha^{-1}) but similar to yields in Metropolitan Lima (21.4 t ha^{-1}) (SIEA 2019). There were no significant differences between treatments, however there was an increasing trend in total and commercial yield when the foliar treatment was applied more frequently, and the drench application was done less frequently. The short vegetative period of the lettuce crop would explain this since organic fertilizers show a slower response in yield (PURBAJANTI 2019). Yield is also indirectly influenced by the effect of organic matter on the physical characteristics of the soil such as aggregate stability and porosity, which improve root growth, rhizosphere and stimulate crop growth (GOSS et al. 2013). which is also a slow process. Increasing the frequency of foliar application or doses increases the yield in various horticultural crops (KOLOTA & OSINSKA 2001).

The yield was slightly higher with drench application compared to foliar application. The highest total and commercial yield was obtained when drench applications were done every two weeks (DA2) (Figure 2). This result could suggest that the ALF could cause a negative effect on the lettuce crop generated by some allelopathic compound present in any one of the weeds used, and that when applied at a higher frequency towards the roots of the crop it causes a negative effect on the yield.

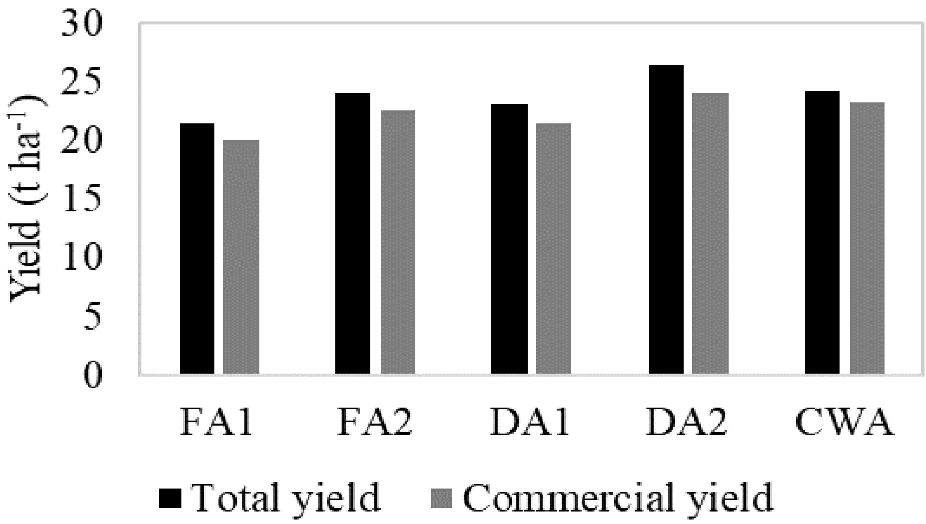

Figure 2. Total and commercial yield of lettuce depending on the dose and form of application of the accelerated liquid fertilizer for weeds. FA1: one foliar application per week of 10 mL L^{-1}, FA2: two foliar applications per week of 10 mL L^{-1}, DA1: one drench application each week of 50 mL L^{-1}, DA2: one drench application each two weeks of 50 mL L^{-1} and CWA: Control without application.

The analysis of variance did not show significant differences between treatments for fresh weight of lettuce heads. However, it should be noted that the highest fresh weight per plant (471 g $plant^{-1}$) was obtained with the FA1 treatment, followed by CWA (457 g $plant^{-1}$) (Figure 3). On the other hand, there were no significant differences between treatments for head height and diameter. Despite that the control showed greater height (14.05 cm) when compared to the other treatments (Figure 3).

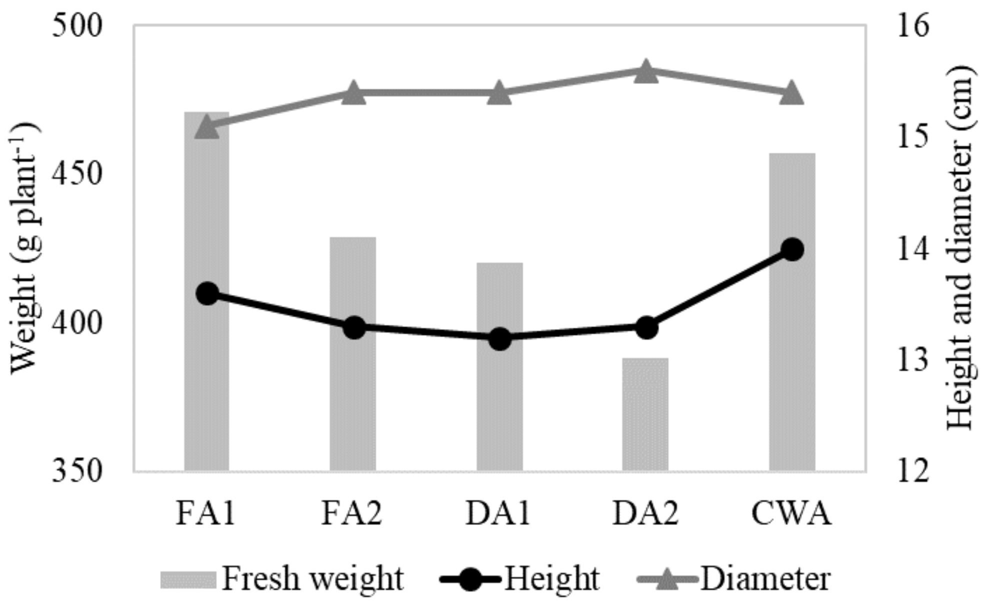

Figure 3. Fresh weight, height and diameter of lettuce depending on the dose and form of application of the accelerated liquid fertilizer for weeds. FA1: one foliar application per week of 10 mL L^{-1}, FA2: two foliar applications per week of 10 mL L^{-1}, DA1: one drench application each week of 50 mL L^{-1}, DA2: one drench application each two weeks of 50 mL L^{-1} and CWA: Control without application.

For dry matter, the mean comparison test showed significant differences between FA2 (2.65%) compared to the other treatments (Table 7). Likewise, the control (CWA) presented the lowest percentage of dry matter (1.73%), in relation to the other treatments. A significant increase in the percentage of dry matter was evidenced by increasing the foliar application frequency, while in the drench application, the highest value was observed when the application frequency was lower (Table 7). This could be explained by lower sensitivity to fertilization in the root system than in the shoots (CÂNDIDO et al. 2018).

Table 7. Dry matter in lettuce subjected to different doses and forms of application of accelerated liquid fertilizer for weeds.

	Treatment	Dry Matter (%) *
FA2	Two foliar applications of 10 mL L^{-1} weekly	2.35a
DA2	One drench application of 50 mL L^{-1} every two weeks	2.01b
FA1	One foliar application of 10 mL L^{-1} weekly	1.88b
DA1	One drench application of 50 mL L^{-1} every week	1.88b
CWA	Control without application	1.73b

*Values followed by the same letter are not significantly different according to Tukey 's test.

The treatments that generated the highest nitrogen content were those that received weekly foliar application (FA1) (312.27 mg $plant^{-1}$) and twice a week (FA2) (291.49 mg $plant^{-1}$), followed by weekly drench treatments (DA1). (238.75 mg $plant^{-1}$) and every two weeks (DA2) (240.70 mg $plant^{-1}$). The CWA treatment showed the lowest foliar nitrogen content (216.65 mg $plant^{-1}$) (Figure 4). MEDINA (2015) indicates that normal levels of nitrogen in lettuce leaves are between 3.5 to 5%, those values in mg $plant^{-1}$ are similar to the ones reported in the present study (Figure 4).

There were no significant differences in phosphorus content, however the highest amounts were found in foliar treatments applied twice a week (FA2) (52.09 mg $plant^{-1}$) and weekly (FA1) (48.96 mg $plant^{-1}$) (Figure 4). The more frequently the foliar application was done, the better the response of the plant in terms of phosphorus content. Drench applications were similar with 41.94 mg $plant^{-1}$ when applied weekly (DA1) and 41.40 mg $plant^{-1}$ when applied every two weeks (DA2) (Figure 4). The foliar phosphorus values were within the normal range (0.3 to 0.6%) for lettuce (MEDINA 2015).

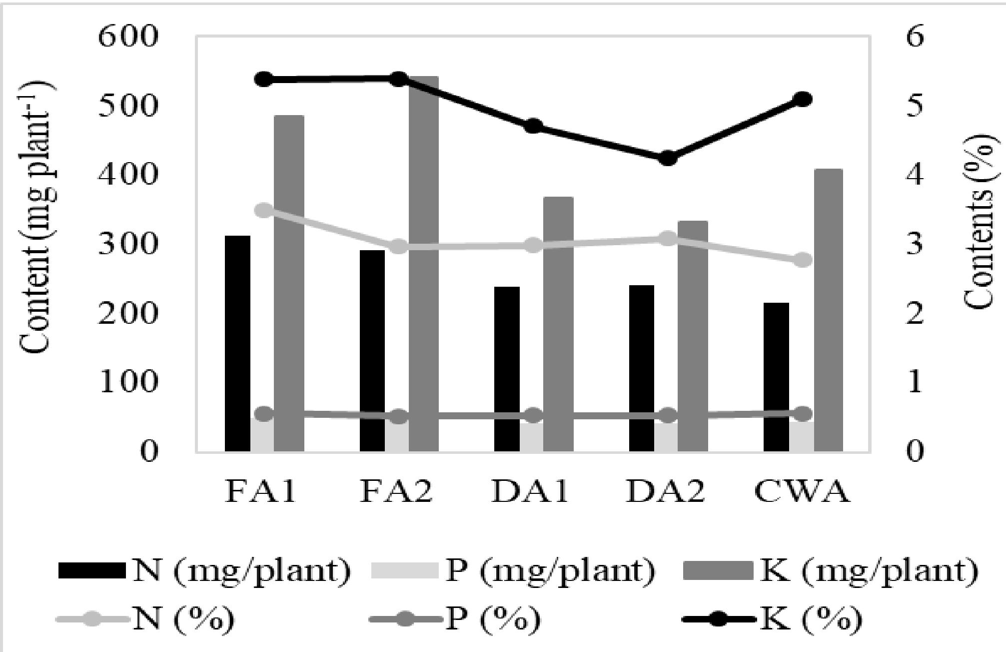

Figure 4. Foliar content of nitrogen, phosphorus and potassium in lettuce depending on the dose and form of application of the accelerated liquid fertilizer for weeds. FA1: one foliar application per week of 10 mL L^{-1}, FA2: two foliar applications per week of 10 mL L^{-1}, DA1: one drench application each week of 50 mL L^{-1}, DA2: one drench application every two weeks of 50 mL L^{-1} and CWA: Control without application.

In the case of potassium, weekly foliar application of ALF (FA1) resulted in 484.19 mg $plant^{-x1}$ and 541 mg $plant^{-1}$ when applied twice a week (FA2). The drench application was 367.22 mg $plant^{-1}$ when applied weekly (DA1) and 332.75 mg $plant^{-1}$ when applied every two weeks (DA2). Therefore, a higher frequency in applications improved potassium content in the plant. Significant differences were found in the analysis of variance, with the FA2 treatment being statistically different from the others (Figure 4). Leaf potassium content was within the normal values (4.5 to 6.3%) reported by MEDINA (2015).

Based on previous research where the potential as a source of nutrients and their availability in the soil has been investigated (CHEN et al. 2014, DAMON et al. 2014), the use of weeds as a source to produce organic fertilizers can be suggested. More research is still needed to determine weeds with a higher nutritional contribution that allow us to develop organic fertilizers with better nutritional characteristics and at the same time reduce allelopathic effects that could come from any of the weed species used.

CONCLUSION

It was possible to recycle weed residues for the elaboration of an accelerated liquid organic fertilizer (ALF) through a homolactic fermentation process.

ALF characteristics such as pH, titratable acidity, microbiological analysis, nutrient content, etc. indicate that it has potential as a biofertilizer.

The application of ALF generated from weeds did not significantly affect the fresh weight, height, and diameter of lettuce, but it did affect the contents of dry matter and potassium. The best total and commercial yield was attained with DA2 treatment; however, the nutritional characteristics were inferior to the other treatments.

ACKNOWLEDGEMENTS

To the funding received from the Research Office Direction of the National Agrarian University La Molina to translate this article from Spanish to English.

REFERENCES

ANDREWS EM et al. 2021. A Review of Potassium-Rich Crop Residues Used as Organic Matter Amendments in Tree Crop Agroecosystems. Agriculture 11: 1-22.

AOAC. 1998. Official Methods of Analysis of the Association of Official Analytical Chemists. 16th Edition, AOAC, Gaithersburg.

BADDI GA et al. 2016. The Production of Liquid Organic Fertilizers Enriched with Humic Substances from Mature Alperujo (Olive Mill Wastes) Compost. In: BATES L. (Ed.). Humic Substances and Natural Organic Matter. New York: Nova Science Publishers. p.19–28.

BRUST G. 2019. Management Strategies for Organic Vegetable Fertility. In: BISWAS D & MICALLEF S. (Eds.). Safety and Practice for Organic Food. London: Elsevier. p.193–212.

BUCHELLI H. 2014. Producción de biofertilizante de bagazo de cebada, excretas de vacuno y suero de quesería mediante fermentación homoláctica. Tesis (Ing. Ambiental). Lima: UNALM. 127 p.

CALLEJAS G et al. 2018. Capacidad solubilizadora de fosfato de aluminio por hongos rizosféricos aislados de un Andisol colombiano. Entramado 14: 218–227.

CÂNDIDO Á et al. 2018. Fertigation and foliar application with liquid mineral fertilizer doses on lettuce. Revista scientia agraria 19: 37–43.

CHEN B et al. 2014. Soil nitrogen dynamics and crop residues. A review. Agronomy for Sustainable Development 34: 429-442.

CHEN X et al. 2017. Silage preparation and fermentation quality of kudzu, sugarcane top and their mixture treated with lactic acid bacteria, molasses and cellulase. Animal Science Journal 88: 1715–1721.

DAMON PM et al. 2014. Crop residue contributions to phosphorus pools in agricultural soils: A review. Soil Biology and Biochemistry 74: 127-137.

DE MATOS et al. 2018. Accumulation potential and nutrient cycling of apple of Peru (*Nicandra physalodes*). Revista Caatinga 31: 360-369.

GARCÍA L. 2008. Uso de bacterias probióticas en el ensilado de residuos de pescado. Tesis (Biólogo). Lima: UNALM. 142 p.

GOSS MJ et al. 2013. A Review of the Use of Organic Amendments and the Risk to Human Health. Advances in Agronomy 120: 275-379

KOLOTA E & OSINSKA M. 2001. Efficiency of foliar nutrition of field vegetables grown at different nitrogen rates. Acta Horticulturae 563: 87–91.

LINDSEY LE et al. 2013. Nitrogen Release from Weed Residue. Weed Science 61: 334–340.

MAQSOOD Q. et al. 2020. Overviewing of weed management practices to reduce weed seed bank and to increase maize yield. Planta Daninha 38.

MEDINA F. 2015. Necesidades nutricionales y de riego de la lechuga. Revista agropecuaria 22: 103-105.

MEZA L. 2014. Elaboración de abono líquido mediante fermentación homoláctica de papas de descarte utilizando el consorcio microbiano ácido láctico B-lac. Tesis (Biólogo). Lima: UNALM. 122 p.

MINISTERIO DE LA PRESIDENCIA ESPAÑA. 2013. Real Decreto 506/2013, de 28 de junio, sobre productos fertilizantes.

MNTHAMBALA F et al. 2022. Effect of Various Organic Fertilisers on Phosphorus Mineralisation, Use Efficiency and Maize Yield. Resources 11: 1-10.

ODEPA (Oficina de Estudios y Políticas Agrarias). 2015. Desarrollo de un Estudio para un Protocolo de Agricultura Sustentable. Santiago de Chile, s.e. Available in: https://www.odepa.gob.cl/wp-content/uploads/2018/04/informeProtocoloAgriculturaSustentable.pdf. Acessed in: 12 oct. 2021

PERALTA L et al. 2016. Obtención y caracterización de abono orgánico líquido a través del tratamiento de excretas del ganado vacuno de un establo lechero usando un consorcio microbiano ácido láctico. Ecología Aplicada 15: 1–10.

PURBAJANTI ED. 2019. Effects of organic and inorganic fertilizers ongrowth, activity of nitrate reductase and chlorophyll contents of peanuts (*Arachis hypogaea* L.). IOP Conference Series: Earth and Environmental Science 250: 1-7.

QUIÑONES H. 2016. Producción de abono líquido acelerado con heces de alpaca, lactosuero bovino y melaza de caña mediante fermentación homoláctica. Tesis (Mg. Sc. en Producción animal). Lima: UNALM. 130 p.

REYES E. 2017. Generación de biogás mediante el proceso de digestión anaerobia, a partir del aprovechamiento de sustratos orgánicos. Revista Científica de FAREM-Estelí 6: 60–81.

RICSE Y. 2013. Elaboración de biofertilizante acelerada vía fermentación homoláctica del residuo de procesamiento de rocoto (*Capsicum pubescens*). Tesis (Ing. Ambiental). Lima: UNALM. 113 p.

RIVERA J et al. 2017. Identificación de bacterias acidolácticas antagónicas de *Salmonella enterica* var. *Typhimurium* aisladas de queso artesanal. Revista Mexicana de Ciencias Agrícolas 8: 785–797.

SAKONNAKHON SPN et al. 2006. Weeds – friend or foe? The role of weed composition on stover nutrient recycling efficiency. Field Crops Research 97: 238–247.

SIEA (Sistema Integrado de Estadística Agraria). 2019. Anuario Estadístico de Producción Agrícola.

SOBRERO M & RONCO A. 2004. Protocolos de ensayo: Ensayo de toxicidad aguda con semillas de lechuga (*Lactuca sativa* L). In: CASTILLO G. (Ed.). Ensayos toxicológicos y métodos de evaluación de calidad de aguas. Estandarización, intercalibración, resultados y aplicaciones. Mexico: IDRC, IMTA. p. 71–80.

TIQUIA SM. 2000. Evaluating Phytotoxicity of Pig Manure from the Pig-on-Litter System. In: WARMAN PR & TAYLOR BR (Ed.). Proceedings of the International Composting Symposium. Truro: CBA Press Inc. p:625-647.

VARNERO MTM et al. 2007. Índices de fitoxicidad em resíduos orgânicos durante el compostaje. Revista de la Ciencia del Suelo y Nutricion Vegetal 7: 28-37.

ZHAO J et al. 2019. Effects of lactic acid bacteria and molasses on fermentation dynamics, structural and nonstructural carbohydrate composition and in vitro ruminal fermentation of rice straw silage. Asian-Australasian Journal of Animal Sciences 32: 783–791.

ZUCCONI F et al. 1981. Evaluating toxicity of immature compost. Biocycle 22: 54-57.