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ORIGINAL RESEARCH

Compost quality optimization through Plackett-Burman's design

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Abstract

Purpose: This research aimed at compost quality optimization through Plackett-Burman's design application. This statistical method was used to identify and evaluate key factors that impact compost quality and determine its optimal levels.

Method: Eight experiments were carried out with variables such as leachate recirculation, Carbon/Nitrogen ratio, manure type, bacterial and fungi incorporation, type of plant material, and compost pile height.

Results: Obtained results revealed significant influence of guinea pig manure in compost quality, improving pH and electric conductivity ($dS\cdot m^{-1}$) values, as well as its influence on purple corn fresh and dry weight increase. However, the use of guinea pig manure can increase arsenic, mercury, and lead compost levels, but within the range allowed by Peruvian technical standards. Leachate recirculation showed significant effect on compost humidity increase, which decreased its physical quality to not permitted values by Peruvian technical standards.

In addition, leachate uses a reduced number of corn leaves, as well as its fresh and dry weight. It was possible to identify optimal conditions to maximize composting process efficiency, through Plackett-Burman's Design. **Conclusion:** These findings provide a solid foundation for composting practice's continuous improvement, contributing to high-quality organic fertilizer production more efficiently and sustainably. This study has the potential to guide future research and feasible applications in the agricultural field, favoring more environmentally friendly practices adoption.

Keywords: Optimization, Compost quality, Plackett-Burman, Organic waste

Introduction

Various methods of compost production have been studied over the years, as well as their soil, and plant effects, which depend on the organic waste type used, and composting process characteristics. Agricultural systems compost use must consider soil evolution degree, impact on plants, its environmental effects, and that it does not generate risk to human health. (Chen et al., 2011).

During the production process, various parameters influence compost quality, which tends to oscillate within specific ranges due to its inherent variability to the initial mixture and possible seasonal fluctuations in its composition (Sánchez et al., 2017). Compost quality must comply with current regulations that establish acceptable ranges for materials to be composted and final product characteristics (INACAL, 2020). For example, compost's physical quality is determined based on its granulometry, water retention capacity, humidity, and odor. Chemical quality depends on organic matter content and stability, organic carbon mineralization rate, nutrient content, and organic and inorganic contaminants presence. Biological quality is determined based on voluntary plant seeds presence and primary or secondary pathogens presence.

The final product composition will depend largely on how the process has been controlled. Compost nutritional content depends on the organic source type used as initial material and the losses and transformations that occur during the process (Ouédraogo et al., 2001).

Understanding that compost's physical and chemical characteristics vary depending on its original nature material, composting operation-specific conditions, and decomposition time (Onwosi et al., 2017), is that there is a need to study different bioinputs use and its combination, with other application factors to achieve compost quality. However, the large amount of different substances contained in compost makes its analysis and comparison difficult, differing in its composition according to used materials and process conditions (Onwosi et al., 2017).

There is scientific evidence that demonstrates compost positive effects by improving soil physical properties and crops productivity. These positive effects are mainly due to humic substances formation, which are composting process byproducts, that improves soil's chemical, physical, and biological properties (Ho et al., 2022). Likewise, composted material's nutritional content and growth-promoting organism's presence, play a fundamental role in crop yield increase (Ho et al., 2022). In addition, organic amendments such as compost, increase acidic soil pH and enable available labile phosphorus to a greater extent than only applying triple superphosphate (Al Mamun et al., 2022). Compost application of 5 t·ha^{-1} level increased sorghum yield by 45%, in a carried out study in a ferric lixisol, due to a 4 to 6 cmol· kg^{-1} cation exchange capacity increase in the acidic soil (Ouédraogo et al., 2001).

This research studied different bioinput combination individually, along with the application of other factors, with the purpose of determining optimal blending for high-quality compost production. For this reason, this research's main objective is to optimize compost production parameters to obtain a high physical, chemical, and biological quality product that enhances soil fertility positive effects. Furthermore, it was intended to identify the most important factor that affects compost quality through Plackett-Burman's design. Thus, a product that contributes to the physical, chemical, and biological improvement of soil fertility will be obtained, and its impact on crop yields, as well as being a food security contributing tool.

Materials and method

Experiment location

The experimental phase was carried out at the National Institute of Agrarian Research (INIA), located in La Molina district, province, and department of Lima. Geographic location coordinates were: Latitude: 12° 04' 57.4" S, Longitude: 76° 56' 42.3" W, Altitude: 287.

Experimental design

Plackett and Burman design, which is a special type of fractional factorial design, was used with the objective of determining which of the studied variables had greater compost quality effect. Table 1 resumes considered composting process variables levels, as well as two fictitious variables (F1 and F2). Two repetitions or blocks were used for each trial.

Table 1. Composting process variables to consider

N	Variables	(-1)	(+1)
X1	Leachate recirculation	with	without
X2	C/N ratio	low (20/1)	high (30/1)
X3	Manure type	guinea pig	bovine
X4	Bacterial incorporation	with	without
X5	Fungal incorporation	with	without
F1	Plant material type	corn crop residue	lawn mow waste
F2	Stack height	1.50 m	1.60 m

Table 2 describes tests or trials matrices for the 7 variables distributed in 8 elementary experiments according to Plackett and Burman's methodology.

Experiment setup

Experimental area dimensions

Four 20 m length and 2.4 m wide concrete stacks were used. Four experimental units were installed per stack, making a total of 16 experimental units. Each experimental unit was 3 m long by 2.4 m wide. 8 treatments were tested with 2 repetitions each, being randomly located between the four concrete piles.

Table 2. Arrangement for seven variables with eight trials

N	X0	X1	X2	F1	X3	X4	X5	F2
E1	1	1	1	1	-1	1	-1	-1
E2	1	1	1	-1	1	-1	-1	1
E3	1	1	-1	1	-1	-1	1	1
E4	1	-1	1	-1	-1	1	1	1
E5	1	1	-1	-1	1	1	1	-1
E6	1	-1	-1	1	1	1	-1	1
E7	1	-1	1	1	1	-1	1	-1
E8	1	-1	-1	-1	-1	-1	-1	-1

Plant materials sampling and preparation

Hard yellow corn unhulled stubbles and American ray grass pruning remains were collected, transported and weighed, near the pile assembly area, sorting out inorganic materials such as papers, plastics and fabrics.

Manure sampling and preparation

Guinea pig manure of the National Guinea Pig Program from La Molina Experimental Center (INIA) was collected, which had a mixed feeding system and rearing in cages, removed after 14 days with an approximate 25% humidity. Cattle manure was collected from "Señor de Luren" fattening center located in Lurín district, which had a balanced feeding system and stabled breeding, removed after 50 days with an approximate 18% humidity. Both manures were transported and weighed near the pile assembly area, separating the inorganic materials found such as plastics and metals.

Leachate recirculation

Leachate recirculation was carried out individually for each experimental unit, using a 5% slope drainage system, in which independent leachate was received for subsequent recirculation according to the evaluated tests.

Carbon-Nitrogen ratio determination (C/N)

C/N ratio calculations were carried out based on laboratory-obtained results for each animal and plant origin organic material used, thus obtaining the amount of the mixture of each material to obtain the final C/N ratio of 20/1 and 30/1, according to the evaluated tests, as detailed in the following formula:

$$\mathbf{C/N_f = (\%A_1 \times C/N_1) + (\%V_2 \times C/N_2)\ 100}$$

C/N_f = Final C/N ratio.

$\%A_1$ = Amount of animal organic matter in percentage.

C/N_1 = C/N ratio of animal organic matter obtained from the laboratory.

$\%A_2$ = Amount of plant organic matter in percentage.
C/N_2 = C/N ratio of plant organic matter obtained from the laboratory.

Bacterial acquisition and incorporation

Bacillus subtilis BAC 117 strain, from INIA's biofertilizer culture collection, was incorporated into the composting process. This strain was grown for 72 h in nutrient broth at a $1x10^6$ $CFU \cdot mL^{-1}$ concentration. 4 L of this broth was diluted in 200 L of water at a 7.0 pH and applied in the respective irrigation system, according to evaluated trials, at a 25 L mixture dose.

Fungal acquisition and incorporation

Trichoderma harzianum was used as a fungal incorporation source, which was acquired from the National Agrarian Health Service - SENASA. 4.8 kg of this fungi were diluted in 200 L of water at 5.5 pH and applied in the respective irrigation system, according to evaluated trials, at a 25 L mixture dose.

Stack formation according to treatments

Stack formation of four plant-origin organic material layers and three animal-origin organic material layers were set up, each one 3 m long by 2.4 m wide, starting first with a layer of plant organic material in the respective proportions according to the essays evaluated. This was done with the corresponding irrigation to obtain process's optimal humidity. Finally, organic materials used were mixed homogeneously.

Aerobic fermentation monitoring and conducting

Process temperature was determined daily at three different points (upper, middle and lower) of each experimental unit by using a 50 cm long stainless-steel probe thermometer, as well as the respective turnings and irrigations according to the evaluated tests. Homogeneous and representative samples were obtained according to the *Counting and Quartering Procedure* method at the beginning and every 4 weeks, until reaching the maturation phase at 16 weeks, thus achieving physical, chemical, and microbiological parameter results for final evaluation.

Inputs quality determination

Prior to composting process, physicochemical characteristics such as humidity (Hd), apparent density, organic matter (OM), C/N ratio, pH, electrical conductivity (EC) and presence of heavy metals were determined in associated bioinputs to carbon and nitrogen sources, as shown in Table 3 and 4.

Compost final quality determination (physical, chemical and biological properties)

At 16 weeks, according to the Peruvian Technical Standard (NTP:201.207:2020, 2020) and NTP 201.208:2021, 2021), (i) Physicochemical characteristics (humidity, apparent density, organic matter, C/N ratio, pH, electrical conductivity, presence of heavy metals, nutrient content) and (ii) Microbiological characteristics (fecal coliforms, *Sallmonella* spp and viable helminth eggs) were determined.

Table 3. Bioinputs physicochemical characteristics for compost elaboration

Inputs	Hd (%)	pH	EC (mS/cm)	OM (%)	Organic carbon content (%)	Total nitrogen content (%)	C/N
Guinea pig manure	7.29	7.1	8.32	56.52	31.40	**2.84**	11.06
Bovine manure	24.27	**8.5**	**25.86**	45.90	25.50	2.58	9.88
Corn stubble	7.02	6.0	4.27	83.61	46.45	1.34	34.66
Lawn mow	12.66	6.7	4.49	75.26	41.81	1.20	34.84

Table 4. Bioinput's heavy metal content for compost elaboration

Inputs	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
Guinea pig manure	1.04	0.24	2.83	0.02	4.49	1.14
Bovine manure	**1.86**	0.30	3.71	0.02	2.53	1.54
Corn stubble	1.54	0.36	1.70	0.03	1.06	3.63
Lawn mow	1.00	0.53	1.70	0.02	1.19	3.64

Compost effect on purple corn cultivation

In addition, elemental assays (E1-E8) were evaluated as fertilizer on purple corn cultivation in 5 L pots at greenhouse conditions. Sandy loam soil was incorporated to the pots and 200 g of each compost type was applied, in two stages: before sowing and 28 days after sowing. Purple corn height, number of leaves and foliar accumulation of NPK were measured.

Statistical analysis

Obtained results were subjected to Variance Analysis for means comparison and for multiple comparison tests, Duncan's test was used, both with a 5%, significance level for which the statistical software R (R Core) was ran. Team, 2021).

Results and discussion

Compost physicochemical quality

It was observed that the most influential factor on compost pH is manure type, as shown in Table 5. When going from guinea pig manure to cow manure, pH increases by 0.63. Consequently, we can affirm bovine manure tends to increase compost pH value. Furthermore, it is the only significant factor in pH variations, concerning other variables tested. EC also significantly increases (5.33 $dS{\cdot}m^{-1}$) when bovine manure is used.

Contreras-Ramos et al. (2004) reported that cow manure derived compost results in a high EC of 28.1 dS·m^{-1} and alkaline pH of 8.5 product, with strong basicity for the soil. León-Teran et al. (2023) published that cow manure-based compost had 7.8 pH, which is higher than chicken manure-based compost 7.5 pH. Likewise, a greater pH increase had greater impact on calcium and phosphorus absorption in alfalfa. Furthermore, Gil et al. (2008) determined that the composting process increases cow manure pH by up to 9.6, after 75 days, likewise, the electrical conductivity also increases up to 3.35 dS·m^{-1}. These same authors maintain that compost application in combination with mineral fertilization does not increase corn yield, but only increases grain iron and protein content. That is, positive effects are more evident in corn grain nutritional quality improvement. Compost quality gets affected by salinity caused by cattle manure, which will limit any seed germination susceptible to salt stress, with the exception of tolerant crops such as quinoa. This saline characteristic conditions transplanted crops compost application technique, which must be done at the bottom of the furrow, or away from plant neck and effective root area

It was also observed (Table 5) that compost final humidity increases when the leachates are recirculated. It is likely that leachate high carbon concentration positively influences final product moisture retention capacity, causing a higher moisture content compared to irrigation with water. However, although leachates have organic matter and nutrients in high concentrations, they contain toxic contaminants such as heavy metals, which needs to be removed by biological, physical, chemical or oxidation treatments to give greater value to leachates (Roy et al. 2018). The way leachate is applied is essential to increase its positive effects in accelerating the process. It is possible to increase carbon stabilization degree in waste with a 2 L leachate dose at a 4 times application rate per week (Šan & Onay 2001). Other quality parameters such as OM, C/N ratio and total percentage of N are not affected by the evaluated variables.

Although Plackett Burman's Design purpose is not to identify differences between elementary trials (E1 to E8) belonging to factorial fraction arrangement, results presented in Table 6 show physicochemical parameters of each tested arrangement in comparison with Peruvian Technical Standard (NTP) 201.207. and NTP 201.208. As observed, humidity values are close to the permitted range between 35 to 50% of the NTP 201.208 standard, which regulates municipal organic waste produced compost. pH values are within both standards range. EC exceeds the standardized values (> 5.0 mS·cm^{-1}). OM content is within the minimum required by both standards (≥ 20%), while the C/N ratio data are within NTP 201.207 values that regulate compost for agricultural use.

Compost heavy metal content

Heavy metals content is one of the most influenced characteristics by the factors tested (Table 7). Thus, Arsenic (As) content significantly decreases by 9.13 mg·kg^{-1} when the leachate is recirculated, and by 10.56 mg·kg^{-1}when cattle manure is used. Dissolved organic carbon in leachates increases As mobilization, so leaching is possible. During the first 4 weeks of composting, arsenite As (III), the most toxic form of As, is mobilized, and then increases with compost maturation, to finally be mobilized mainly in arsenate As (V) form (Hartley et al. 2010). Another factor that influences As decrease in compost is biomethylation caused by microbes such as *Streptomyces* sp., *Amycolatopsis mediterranei* and *Sphaerobacter thermophilus*, which produce dimethylarsinic acid, a compound that due to leachates effect can produce trimethylarsine, a volatile substances that reduces total As content by up to 35% (Zhai et al. 2017).

Table 5. Studied variables effect on compost quality physicochemical characteristics

Variables	pH	EC (dS·m^{-1})	OM (%)	C/N	Humidity (%)	Total N (%)
Leachate recirculation	0	0.48	-1.26	-1.8	**3.88 ***	0.36
C/N ratio	0.175	-1.51	7.31	2.14	-1.33	-0.12
Manure type	**0.63 ***	**5.33 ***	-1.46	2.67	0.49	-0.68
Bacterial incorporation	0.25	1.46	-13.64	-2.49	0.78	-0.16
Fungal incorporation	-0.125	-0.94	-3.05	-1.39	1.76	0.06
Plant material type	-0.225	-1.25	8.83	-0.7	1.01	0.54
Stack height	-0.05	0.16	1.83	1.12	1.31	-0.12

Table 6. Compost physicochemical parameters in comparison to Peruvian technical standards (NTP)

Trial	Hd (%)	pH	EC (mS·cm^{-1})	OM (%)	C/N
E1	53.33**ab**	7.70	8.00**ab**	65.65	10.79**b**
E2	53.33**ab**	8.25	13.29**ab**	70.83	17.77**b**
E3	56.95**ab**	7.10	7.28**ab**	70.76	10.87**b**
E4	51.50**ab**	7.75	7.99**ab**	56.86	13.02**b**
E5	55.89**ab**	8.25	15.16**ab**	45.00	10.63**b**
E6	52.57**ab**	8.10	14.52**ab**	59.96	14.23**b**
E7	50.91**ab**	7.95	10.45**ab**	76.04	16.36**b**
E8	48.99**a**	7.50	8.83**ab**	64.40	13.64**b**

[*]**a**: is out of quality values range according to NTP 201207. (%Hd: 15-35; EC: ≤ 5.0). **b**: is out of quality values range according to NTP 201.208 (%Hd: 35-50; EC: 2-4; C/N: 25-35).

In Chromium (Cr) case, it increases by 5.59 mg·kg^{-1} when used materials C/N ratio increases from 20:1 to 30:1. Cr (VI) is the most toxic oxidized state of chromium for animals and plants, due to its high solubility and mobility. Cr (III) is 10 to 100 times less toxic than Cr (VI), and is an essential micronutrient for humans, plants and animals (Prabhakaran et al. 2009). Composted materials organic carbon increase allows enhancement in chromium removal by organic form in 5 ± 4%, to forms that are not bioavailable for plants (Taiwo et al. 2016). Likewise, Chen et al. (2018) demonstrated that municipal waste materials derived compost with an 8.9 C/N ratio and 308.35 g·kg^{-1} Total Organic Carbon (TOC), had greater increase in non-bioavailable Cr associated with humus, than chicken manure derived compost with 6.4 C/N ratio and 148 g·kg^{-1} TOC. Cr can increase between 30.4 to 36% in compost, due to Cr complex formation with carbonates, Fe-Mn oxides and linked to humic acid. However, this substance is very stable and less mobile, which reduces its toxicity (Zheng et al. 2007).

Mercury (Hg) increases by 0.15 mg·kg^{-1} when C/N ratio increases from 20:1 to 30:1. This fact is due to *Bacillus subtilis* incorporation to the process. It also highlights that this element decreases in 0.18 mg·kg^{-1} when cow manure is used. Hg is mainly found as an organomercury form, such as methyl mercury, and is the most toxic and easiest to biomagnify form in food chains (Christakis et al. 2021). Liu et al. (2022) reported that composting can increase methyl mercury content due to microbial methylators effect such as *Myxococcota*, *Firmicutes*, *Cyclobacteriaceae* and *Methanothermobacter*, during composting initial periods. These microorganisms carry the hgcA gene responsible for Hg methylation. In addition, they present similar metabolic pathways such as being methanogenic and sulfur oxidizing, that is, they use sulfur as an energy source. Likewise, it has been shown a 50.09% to 64.55% increase in compost total Hg due to a Hg compound that is strongly linked to organic sulfur and inorganic sulfides (Janowska et al. 2017).

It has been reported that guinea pig manure has much higher Sulfur (S) content than cow manure, the former can reach up to 0.1% and the latter up to 0.04% (Hormaza 2020). Also, guinea pig manure has a higher C/N ratio than cow manure (Table 3). For these reasons, Hg content increased due to a higher source C/N ratio which had higher Hg content than other treatments. Hg decrease results has been demonstrated with bovine manure use.

It is likely that Hg content increase due to *Bacillus subtilis* incorporation occurs since during composting process, horizontal transfer of hgcA gene from other methylating microorganisms to *Bacillus subtilis* takes place (Liu et al. 2022).

Lead (Pb) is the most affected element by evaluated variables, since leachate recirculation decreases its content by 20.69 mg·kg^{-1}, and cattle manure application decreases it by 33.51 mg·kg^{-1}. The opposite occurs when C/N ratio increases, Pb increases by 21.2 mg·kg^{-1}, and when *Bacillus subtilis* is incorporated, Pb also increases by 21.39 mg·kg^{-1}. Zhou et al. (2018) found that Pb concentration increases after composting, due to a residual mass reducing effect. However, when organic compounds such as biochars or humic acids are applied to compost, Pb is transformed into a stable and non-mobile form, reducing exchangeable Pb in soil and accumulation by plants by up to 65.5%. It is likely that leachate recirculation and waste use with a higher C/N ratio is causing this Pb content effect on compost. Liu et al. (2017) maintain that biochar's treatment application to compost, reduces lead mobility by 51.9%, due to heavy metals high adsorption capacity.

When heavy metals content associated parameters are compared according to Peruvian Technical Standards with Plackett Burman's factorial fraction tests (Table 8), it was evident that all trials comply with the agricultural technical standards for heavy metal use (Cr, Hg, Ni, and Pb). However, regarding As, only derived compost from the E4 trial was above NTP 201.207. allowed range. On the other hand, Cd was above the allowed range in E1, E4, E7 and E8 trials. E1, E4, and E7 trials used 30:1 C/N ratio sources. It is likely that higher carbon content increased the Cd level accumulated in compost.

Table 7. Studied variables effect on compost heavy metal concentration

Variables	As	Cd	Cr	Hg	Ni	Pb
Leachate recirculation	-9.13 *	-0.33	-1.92	-0.07	1.51	-20.69 *
C/N ratio	6.59	0.3	5.59 *	0.15 *	2.83	21.2 *
Manure type	-10.56 *	-0.46	-2.65	-0.18 *	1.6	-33.51 *
Bacterial incorporation	8.43	0.1	1.79	0.14 *	-2.56	21.39 *
Fungal incorporation	4.2	0.11	0.07	0.01	-2.39	6.97
Plant material type	-3.72	-0.20	-1.99	0.02	-3.53	-8.96
Stack height	1.32	-0.11	1.56	0.02	3.00	-2.75

Compost microbiological quality

Since variables in this aspect are qualitative such as presence or absence of *Salmonella* sp, or in some cases not detectable according to microbiological methods like most probable number (MPN), procedure for analyzing the variables contribution under study was avoided and microbiological quality is shown by elemental assay (Table 9). It was observed that all trials are below the Peruvian Technical Standards allowed values. In general, leachate use or the lack of beneficial bacteria applications, contributes to further pathogen observations.

Compost effect on purple corn cultivation

It was evaluated whether tested variables in elemental experiments or compost types with their respective achieved quality, affected INIA 601 purple corn plants NPK content. Obtained results showed that only C/N ratio significantly affected foliar nitrogen content, with a 0.03% decrease when increasing C/N ratio from 20 to 30 (Table 10). This happens because high C/N ratios tend to prolong composting time, generating greater nitrogen loss through volatilization. Likewise, organic materials with higher nitrogen content form a more stable amendment, which decreases mineralization rate and reduces nitrogen supply available to the plant (Kopittke et al. 2020; van der Sloot et al. 2022).

On the other hand, regarding vegetative growth, a considerable negative effect of cattle manure use and the leachate recirculation on crop final fresh and dry weight was found (Table 10). pH increases and cattle manure derived compost EC is likely to negatively affect biomass accumulation. Higher pH level makes Fe, Mn and Zn less available which are leaf and root growth photosynthetic activity essential nutrients. In this sense accumulation of dry matter is reduced (Marschner 2012). EC increase negatively affects water absorption, due to the osmotic effect of salts. For this reason, the plant tends to close stomata and indirectly harm CO_2 entry as photosynthesis substrate (Taiz et al. 2011).

Guinea pig manure not only improved compost chemical characteristics based on pH and EC, but also increased corn plant biomass. It has been shown that the guinea pig manure based biofertilizers increase available nitrogen, phosphorus and potassium on soil, when applied at a 600 $mL \cdot L^{-1}$ dose (Huerta et al. 2021). Likewise, combination of ashes with guinea pig manure during the composting process increases compost calcium and magnesium content (Bustinza and Gomero 2023). It is likely that guinea pig manure use increases compost nutritional content and improves its value as an agricultural amendment.

Leachate recirculation reduced corn plant biomass. It is likely that humidity percentage increases since leachate is indirectly affecting compost nutritional value. A very wet compost loses physical quality, due to lack of oxygenation for microbial activity and root growth. These characteristics could be limiting nutrients absorption and plant root activity.

Finally, Fig. 1 shows growth characteristics effect on corn biomass accumulation trials. E1, E4, and E8 elemental trials had greater effect on growth, which were guinea pig manure compost made.

Table 8. Compost heavy metal content compared to Peruvian technical standards (NTP)

Trial	As (ppm)	Cd (ppm)	Cr (ppm)	Hg (ppm)	Ni (ppm)	Pb (ppm)
E1	17.08 **b**	1.16 **a**	12.56	0.48	5.08	54.64
E2	3.13	0.69	11.68	0.16	15.77	5.95
E3	7.58	0.77	6.82	0.22	5.42	16.27
E4	35.45**a**	1.69 **a**	18.1	0.56	7.71	88.51
E5	7.85	0.71	6.39	0.14	4.99	15.86
E6	10.38	0.63	7.81	0.23	5.35	17.87
E7	11.41	1.04 **a**	10.11	0.24	5.34	27.4
E8	14.91	1.29 **a**	9.09	0.24	6.83	41.7

***a**: is out of quality values range according to NTP 201.207 (As ≤ 20; Cd ≤ 1.0). **b**: is out of quality values range according to NTP 201.208 (As ≤ 15).

Table 9. Compost microbiological quality

Treatments	Fecal coliforms (MPN·g^{-1})	Helminth eggs (Number of eggs per 4g of compost)	Presence/absence of *Salmonella* sp in 25 g of compost
E1	26	0.32	Presence **b**
E2	<3	0.48	Absence
E3	23	0.16	Absence
E4	<3	0.4	Absence
E5	6.5	0.24	Absence
E6	8	0	Presence **b**
E7	240	0.28	Presence **b**
E8	42	0.56	Absence

*b: is out of quality values range according to NTP 201.208 (Salmonella sp. : Absence).

Table 10. Studied variables effect on purple corn growth variables

Variables	Height (m)	Number of Leaves	Fresh weight (kg)	Dry weight (kg)	N (%)	P (%)	K (%)
Leachate recirculation	-14.42	**-1.09 ***	**-38.78 ***	**-6.13 ***	0.01	164.66	7.65
C/N ratio	-2.71	**-0.91 ***	15.08	1.68	**-0.03 ***	459.72	-11.02
Manure type	-4.87	0.16	**-52.98 ***	**-8.13 ***	0.01	787.96	3.66
Bacterial incorporation	-5.33	**-0.43 ***	12.88	1.58	-0.01	-348	0.22
Fungal incorporation	5.04	**0.66 ***	-10.13	-3.83	0.02	410.21	14.16
Plant material type	-7.79	-0.08	10.03	1.38	0.01	-699.74	4.84
Stack height	-9.25	0.01	-2.83	-1.73	0.01	351.51	7.82

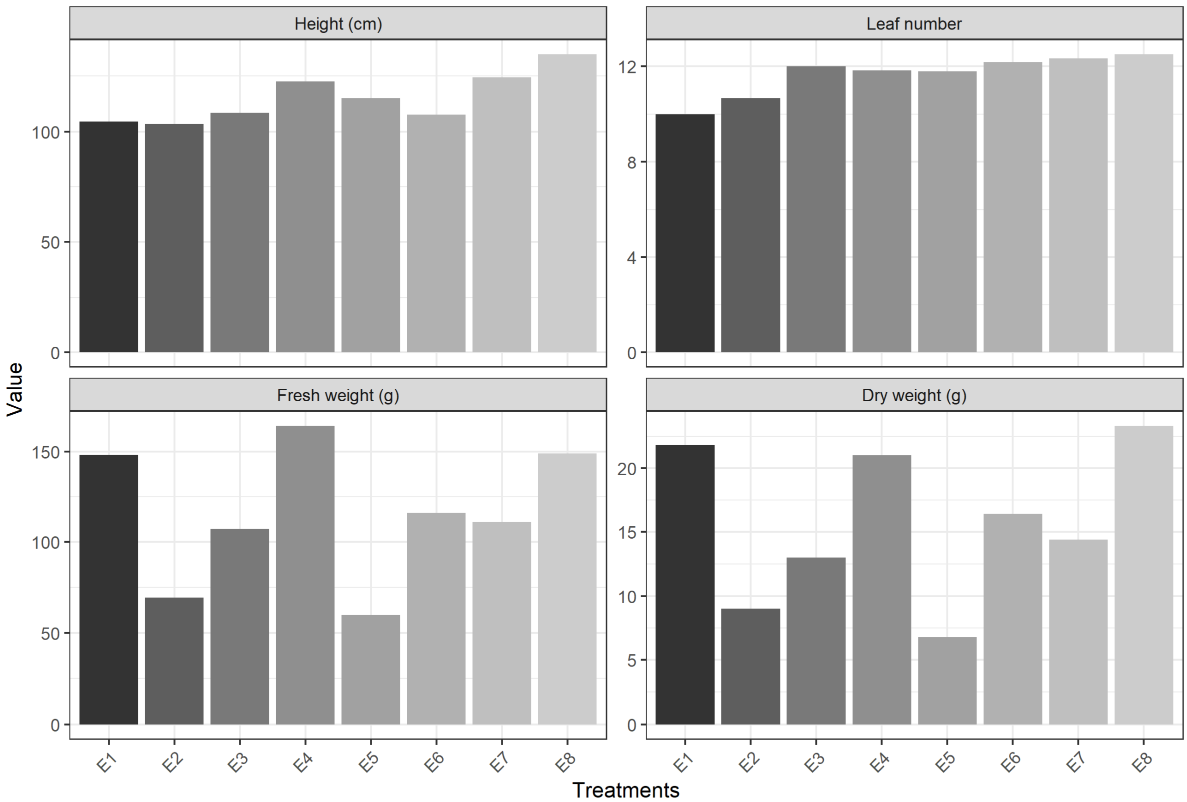

Fig 1. Plant growth variables affected by fertilization dose treatments and biofertilizer application

Conclusion

EC and humidity (%) exceed Peruvian Technical Standard allowed ranges in all trials. According to Plackett-Burman's design results, leachate recirculation is the variable that increases humidity (%), and cattle manure use is the variable that increases EC. Leachate recirculation increases compost moisture retention, resulting in a lower physical quality compost. Cattle manure has a six times greater EC than guinea pig manure, severely affecting compost chemical quality and its use in agriculture. However, the variables behavior trend in Plackett-Burman's design shows that if C/N ratio is increased to values greater than 30:1, a compost EC and humidity (%) reduction is likely.

Concerning trace elements, trials 1, 4, 7, and 8 present higher Cd values than Peruvian Technical Standard allowed limits (1 $mg \cdot kg^{-1}$). Plackett-Burman's design did not identify any variable that significantly affects cadmium concentration variations in compost. However, the design identified that leachate recirculation decreases As and Pb in compost. Cattle manure reduces As, Hg and Pb content from compost and a lower C/N ratio decreases Cr, Hg, and Pb content. For this reason, all composts contain As, Cr, Hg and Pb concentrations within the Peruvian Technical Standard recommended range. Further research is necessary to identify variables that reduce compost Cd content.

The compost biological quality was good. Composting process allowed fecal coliforms level reduction and *Salmonella* spp. and viable helminth eggs absence, being within the Peruvian Technical Standard recommended range in all tests.

Derived composts from E1, E4 and E8 trials turned out to be those with greatest effect on plant fresh and dry matter increase. These composts were made from guinea pig manure. In addition, composts from E4 and E8 trials, that reached highest plant height, were made with grass pruning waste. Guinea pig manure had higher nitrogen percentage than cattle manure, which results in a greater nutritional contribution for plants. Likewise, grass pruning waste had lower organic matter and organic carbon percentages than corn stover, which increases its mineralization rate, as it is more labile organic compounds. However, Plackett-Burman's design shows that leachates recirculation composts elaboration and bovine manure reduces growth characteristics and dry matter accumulation due to compost EC increase and osmotic stress generated in the plant.

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