ADOPTION OF ZEBU HORN POWDERS AND IMPROVEMENT OF AGRICULTURAL YIELDS

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ABSTRACT

Given the importance of the choice of fertilizers in agriculture, a study on the use of zebu horn powders « Poudre de Cornes de Zébu »(PCZ) in agricultural production was carried out in the Amoron'i Mania Region of Madagascar. These powders come from the horn processing workshop. How can the use of zebu horn powder could be optimized to improve agricultural yields, given that farm productivity remains relatively low? To address this issue, the objective is to establish a typology of producers based on their use of zebu horn powder and to identify the key factors influencing its adoption. Two hypotheses emerge: The use of zebu horn powders gains ground in the study area, and farmers in the study area mainly adopt the mixing of zebu horn powders with other fertilizers. A systemic approach was employed to identify and rank the factors influencing PCZ adoption, based on a survey of 226 farmers. The results categorize producers into three groups: PCZ users, mixed users, and non-users. Several factors determine PCZ adoption, including sources of information provided by farmers, producers' experience, household head's age and level of education, the crops chosen by farmers, land access and cultivated area, and ultimately, yield improvement. The use of PCZ varies from one farmer to another, either to enhance productivity or to protect the soil.

Keywords: *fertilizer, agriculture, grower typology, information sources, experiences, productivity, foresight*

1 INTRODUCTION

Zebu horn powder «*Poudre de Cornes de Zébu* »(PCZ), often derived from the black market in rhinoceros horn, is sometimes used in certain parts of the world for various cultural, medicinal or supposedly spiritual reasons. However, it is important to note that the use of these powders is controversial and often illegal due to the threat they pose to the conservation of rhinoceros species. Some European industries import horn powder for a variety of uses, such as fertilizers and fire extinguishers. These are limited outlets, but they would benefit from further clarification. Import duties are zero on these products. Horn meal is a 100% natural fertilizer, ideal for organic farming. Horn meal improves soil structure and promotes the growth of both leaves and stems. It is a simple nitrogen fertilizer that can be used in organic farming.

The Viano brand, well established in the international market, offers a complete range of garden products and various fertilizers (including simple and compound fertilizers, soil improvers, etc.) and operates on the international markets of horticulture, agriculture, organic farming, municipal services and landscaping.

In Switzerland, the most widely used fertilizers are horn meal mixed with feather meal, vegetable oilcake, and/or skin and hair meal, meat meal, and bone meal such as Azocor, Azomix, Biorga Quick, Biorga Plumos, etc. Horn-based fertilizers include Biorga (horn powder, horn shavings) and Oscorna (horn shavings), which are derived from horns. Provita semoule de corne and Biplantol Terra are made from horn semolina, either alone or blended with oat straw flour, rock powder, granulated lava, and opticulite. Nutricorn, Hauert Biorga Biorganic, etc. are also fertilizers made from horn meal.

In Madagascar, Madacompost, located in Mahajanga, specializes in organic agricultural inputs. It produces KORNECO, a fertilizer made from ground zebu horn. In the regions surveyed by the SECURE project, zebu horn powder was not available to farmers. It is authorized for use in organic farming. Its price is around 2,100 ariary per kilogram (Naâmane & al, 2020).

Farmers apply fertilizers based on their experience, techniques, and the specific crops they cultivate. Some use chicken droppings at a rate of 500 grams per square meter, zebu manure at one kilogram per square meter, and garbage compost (GC) at five kilograms per square meter. Others amend their soils with seabird guano, applying one handful per square meter, while vermicompost is used in quantities ranging from half a kilogram to one kilogram per square meter. The method of fertilizer application varies: some are spread on the soil, others are poured per plant, and some are buried. Market gardeners also supplement garbage compost (GC) with PCZ, a fertilizer derived from processed zebu horns. Despite its agronomic value as a fertilizer and organic matter source, PCZ remains underutilized by farmers. Given this contradictory reality, how can the use of zebu horn powder be optimized to enhance agricultural yields, particularly in the context of persistently low farm productivity? This study aims to classify farmers based on their use of zebu horn powder and to identify the key factors influencing its adoption. It explores two research questions: how are farmers characterized ? And what are the determining factors in the adoption of zebu horn powder? Two hypotheses are put forward: The use of zebu horn powder is beginning to gain ground in the study area, and farmers in the study area are mainly adopting the mixing of zebu horn powder with other fertilizers.

2 MATERIALS AND METHODS

2.1 The Study Area

This study focuses on the Amoron'i Mania region (20° 31' 49“ south latitude and 47° 14' 36.38” east longitude), located in the heart of Madagascar's central highlands. It targets farmers in Ambositra using zebu horn powder (UPCZ). Covering an area of 17,516 km², the Region is divided into four districts: Ambatofinandrahana, Manandriana, Ambositra and Fandriana. Its mountainous climate and dense hydrographic network favor a wide variety of agro-industrial activities[2]. With its rugged terrain, lush green meadows and rice terraces, the region offers a unique landscape ideal for farming. In addition to its agricultural assets, Amoron'i Mania is the cradle of Zafimaniry art and culture. Recognized as one of the leading centres of Malagasy art, the region is renowned for its craftsmanship and rich cultural heritage.

2.2 Sampling And Studied Population

Based on the normal distribution, the formula $n=z^2 \cdot p \cdot (1-p)/e^2$ was applied to determine the sample size, resulting in 226 households, where :

n is the sample size,
e : margin of error (e=5%) at 95% confidence level
z = constant from the normal distribution at the confidence level (1.96)
p = percentage of population using PCZ (estimated at 18%)

The surveys were conducted in 14 fokontany (Table 1) identified by the head of the zebu horn processing workshop, who is familiar with PCZ users. It is important to note that PCZ users and non-users were randomly dispersed. Users have at least two years of experience fertilizing their soils with PCZ and have practiced market gardening at least twice by 2022.

Table -1. Distribution of respondents by primary administrative subdivision

Primary administrative Subdivision	Households		PCZ		NON- USERS PCZ		TOTAL	
	Nb	%	Nb	%	Nb	%	Nb	%
1. Zanaposa	300	9	24	63	14	37	38	17
2. Antoebositra	100	3	1	17	5	83	6	3
3. Andrainarivo	150	5	10	50	10	50	20	9
4. Antsaropy	250	8	9	45	11	55	20	9
5. Tanjona	120	4	10	50	10	50	20	9
6. Sahamamy	200	6	3	15	17	85	20	9
7. Ampivarotanomby	400	12	12	40	18	60	30	13
8. Anjoma-Masapoana	150	5	3	30	7	70	10	4
9. Est vinany	450	14	1	10	9	90	10	4
10. Alakamisy- Mahazoarivo	200	6	1	17	5	83	6	3
11. Ambohijativo Imady	130	4	1	17	5	83	6	3
12. Iajaky	500	15	2	9	20	91	22	10
13. Vatovory	200	6	2	17	10	83	12	5
14. Anovy	150	5	1	17	5	83	6	3
Effectif total	3 300	100	80		146		226	100

2.3 Methods

2.3.1 Producer classification methods

Benchmarking was used to categorize producers. The classes resulting from the Multiple Correspondence Analysis (MCA) were then used in a Discriminant Factorial Analysis (DFA). The latter confirmed the classification while refining the variables studied, by eliminating those whose p-values exceeded 0.05 (corresponding to the risk of error α). The ranking functions obtained from the SFM were then used to select the variables to be retained. Obtaining the stochastic matrices involved several steps:

- Transforming negative variables into positive ones by a change of scale according to the following formula:

  Value of a variable for a class - minimum value in the class

- Transformation of positive variables into a stochastic matrix, ensuring that the sum of each row equals 1, according to the formula :

  Value of a variable for a class/Total sum of variables in the row

- The stochastic matrices obtained are transformed into radars to illustrate benchmarking by class. The maximum value obtained for each variable thus represents the reference or benchmark.

The following variables were considered (Table -2)

Table - 2. Variables used

Code	*Variables used*	*Code*	*Variables used*
A-D	: Age of Household Head*: 46-55 ans*	*NBP PCZ-A*	: Number of Plants: 20 to 50 plants
Aexp-B	: Years of Experience*: 6 à 10 ans*	*NBP PCZ-C*	: Number of Plants: 101 to 150 plants
Aexp-C	: Years of Experience*: plus de 10 ans*	*NI-P*	: Education Level: Primary
Cult 1-B	: Main Crop Type: Bananas	*O-A*	: Origin: Indigenous
Cult 1-C	: Main Crop Type: Coffee	*O-B*	: Origin: Non-native
Cult 1-H	: Main Crop Type: Green Beans	*Rais pcz-A*	: Reason: High Yield
Cult 1-I	: Main Crop Type: Peanuts	*Rais pcz-C*	: Reason: Soil Quality Improvement
Cult 1-L	: Main Crop Type: Vegetables	*Rais pcz-H*	: Reason: Tolerance to diseases and pests.
Cult 1-O	: Main Crop Type: Oranges	*SE PCZ-A*	: Cultivated Area: Less than 5 ares
Cult 2-U	: Second Crop Type: Plum	*TP-MX*	: User Type: Mixed
INFO-V	: Source of Information: Neighbor	UT O-O	: Users of Other Energy Sources

2.3.2 Analysis of determinants of PCZ adoption

The aim is to prioritize the determining factors in the adoption of **PCZ** and to present the dominant and influential variables. The variables for the benchmarking have been utilized.

- Identification and sequencing of determinants of PCZ adoption

Ranking was used to prioritize the determining factors of PCZ adoption. A Multiple Correspondence Analysis (MCA) was conducted, followed by a Discriminant Factor Analysis (DFA). Variables with a p-value greater than 0.05 (α error risk) were eliminated. Subsequently, the lower diagonal part of the correlation matrix was removed. Only the variables located above the diagonal, whose absolute values exceed the significance threshold set |ρ| at 0.130, were retained according to the formula defined significance threshold

$$|\rho| > \frac{t_{\alpha=0,05}}{\sqrt{n - 2 + t^2_{\alpha=0,05}}}$$

with t = 1.96 and n = 226, where n represents the number of households surveyed.

The absolute values were then processed and replaced with 'X'. The correlation analysis made it possible to rank the variables according to their priority order by counting the number of 'X' per row. Gradually, the variables associated with the lowest values were grouped together, allowing the priorization of the variables.

- Dominant and influential variables determining PCZ adoption

The strategic rectangle helped identify the influential and dominant variables by considering those used in the ranking (Table 1). Intervariable correlations were used to verify the significance and influence of the determining factors in PCZ adoption. Non-significant variables were eliminated, and the values of X and Y were then calculated according to the following formulas :

$$X = L/P$$
$$Y = L*P$$

Where:

L= sum of the absolute values of the row variables in the correlation matrix,
P = sum of the absolute values of the column variables in the correlation matrix.

The values of X were sorted in descending order, with those exceeding 1 (X > 1) designated as influential variables. The values of Y were then sorted in descending order as well, enabling the identification of the most dominant and influential variables.

3 RESULTS

3.1 Producers' typology

Three categories of producers using zebu horn powder (PCZ) have been identified (Fig 1, 2, 3).

Class 1: Users of the zebu horn powder and vermicompost mixture

Farmers in this group have between 6 and 10 years of experience in using PCZ (Aexp-B). Information regarding its application is primarily obtained through informal knowledge exchange with neighboring farmers (INFO-V). Their main crops include coffee (Cult1-C) and various vegetables (Cult1-L).

Most of them have completed at least secondary education (NI-S) and access land predominantly through inheritance (Fonc-H). The number of plants treated with PCZ on their farms generally ranges from 51 to 100 (NBP pcz B).

The adoption of PCZ in their production systems is motivated by its perceived positive impact on soil fertility (Rais-PCZ-C) and its contribution to increased crop yields (Rais-PCZ-A).

Class 2: Users of raw zebu horn powder

This category of farmers is mainly composed of non-native individuals (O-B). They acquire information on the use of PCZ primarily through interactions with neighboring farmers (INFO-V) and from their own on-farm experimentation (INFO-T). The cultivated area under PCZ application is generally less than 500 square meters (SE-pcz-A).

Class 3: Mixed users

This group consists of household heads aged between 46 and 55 years (A-D), with over 10 years of experience in the use of PCZ (Aexp-C). These farmers apply PCZ while maintaining their traditional agricultural systems. They utilize several forms of powdered zebu horn: in its raw form, mixed with vermicompost, or combined with zebu manure.

Land access is primarily through family inheritance (FONC-H). Their main crops are vegetables (Cult11-L), and the adoption of PCZ is driven by its positive effects on soil improvement (Rais-PCZ-C). The number of plants amended with PCZ on their farms ranges between 50 and 100 (NBP-PCZ-B).

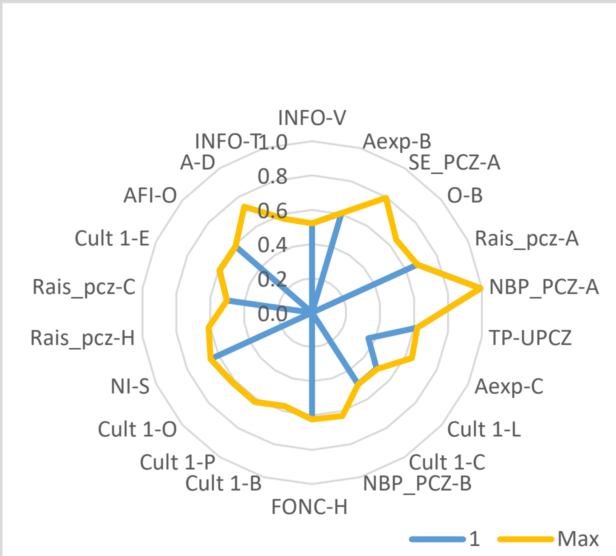

Fig -1: Class 1. Users of PCZ and Vermicompost mixture

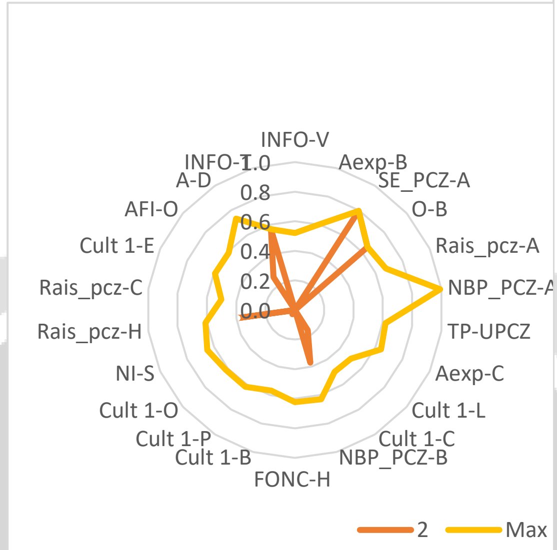

Fig -2: Class 2. Raw PCZ users

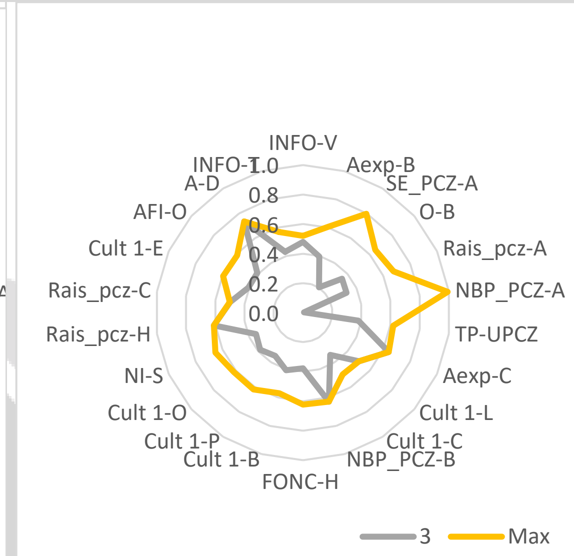

Fig -3: Class 3. Mixed users

Legend :

Code	Variables	Code	Variables
A-D	: Household head's age: 46-55 years	INFO-V	Source of information: Neighbor
Aexp-B	: Years of experience: 6 to 10 years	INFO-T	; Source of information: Test
Aexp-C	: Years of experience: more than 10 years	NBP_PCZ-A	: Number of plants: 20 to 50 plants
AFI-O	: Financial access: Yes	NBP_PCZ-B	: Number of plants with PCZ: 51-100 plants
Cult 1-B	: Main type of crop: Banana	NI-S	: Level of education: Secondary and higher
Cult 1-C	: Main type of crop: Coffee	O-B	: Origin: Allogeneic
Cult 1-E	: Main type of crop: Tomato	Rais_pcz-A	: Reason: High yield
Cult 1-L	: Main type of crop: Vegetables	Rais_pcz-C	: Reason: Improvement of soil quality
Cult 1-O	: Main type of crop: Orange	Rais_pcz-H	: Reason: Tolerance to diseases and pests
Cult 1-P	: Main type of crop: Sweet potato	SE_PCZ-A	: Cultivated areas with PCZ: Less than 5 ares
FONC-H	: Land access: Inheritance	TP-UPCZ	: PCZ users

3.2 Determining Factors in the Adoption of Zebu Horn Powder

3.2.1 Prioritization of factors determining the adoption of zebu horn powder

The variable importance ranges from 1 to 13 (Fig -4).

1. The adoption of powdered zebu horns (PCZ) is influenced by several factors. Among the main ones are the age of the household head, which ranges from 46 to 55 years (A-D) or under 25 years (A-A). The level of education also plays a role, including household heads with a secondary or higher education level (NI-S).The origin of households, particularly their status as allogeneic (O-B), is another influential factor.

2. Additionally, land access through inheritance (FONC-H), financial access (AFI-O), and household size exceeding five individuals contribute to encouraging the use of PCZ.

3. The experience of PCZ users varies. Some have between six and ten years of practice (Aexp-B), while others have accumulated more than ten years of experience (Aexp-C). The primary source of information about PCZ generally comes from neighbors (INFO-V) or personal tests (INFO-T). These sources play a key role in their dissemination.The number of children in households is also significant: some families have between 0 and 3 children (NENF-A), while others have more than 5, whether they are enrolled in school (NES-C) or not (NEN-C).

4. The main crops cultivated by users include vegetables (Cult 1-L), tomatoes (Cult 1-E), bananas (Cult 1-B), mangoes (Cult 1-M), oranges (Cult 1-O), sweet potato (Cult1-P) and coffee (Cult 1-C). Some crops, such as plums, are also found as a secondary crop (Cult 2-U).

5. The cultivated and PCZ-amended areas range between 0.5 and 5 ares (SE-PCZ-A) or between 6 and 10 ares (SE PCZ B).

6. Furthermore, the number of fruit tree seedlings amended with PCZ varies among farmers: some use it for 20 to 50 plants (NBP_PCZ-A), while for others, it reaches between 51 and 100 plants (NBP_PCZ-B).

7. The main reasons for using PCZ based on their ability to provide high yields (Rais_PCZ-A), ensure a health-beneficial yield (Rais_PCZ-G), tolerate diseases and pests (Rais_PCZ-H), improve soil quality (Rais_PCZ-C), and promote plant growth (Rais_PCZ-D).

8-13.The variables within these ranks are regarded as having minimal importance in the adoption of PCZ usage.

1	2	3	4	5	6	7	8	9	10	11	12	13
TP-UPCZ	FONC-H	Aexp-B	Cult 1-L	INFO-T	NBP_PCZ-A	Cult 2-U	HA_D-O	QPCZ_U21-C	DEP-C	UT_O-N	COMP-C	DOS-C
A-D	TM-C	Aexp-C	Cult 1-E	Cult 1-B	SE_PCZ-B	Rais_pcz-C	QPCZ_U21-A	QPCZ_U22-B	TEN-OR	TEN-FP	DOS-A	DOS-D
A-A	AFI-O	INFO-V	Cult 1-C	Cult 1-M	Rais_pcz-A	Rais_pcz-D		DEP-B	TEN-FL	MUT-S		DOS-F
NI-S		NENF-A	Cult 1-O	NBP_PCZ-B	Rais_pcz-H	HA_EN-N				MUT-P		DOS-G
O-B		NEN-C	Cult 1-P	SE_PCZ-A								

Fig -4: Ordering of the key factors determining the adoption of PCZ.

Legend

Code	Variables	code	Variables	code	Variables
A-A	: Ages: 26-35 years	DOS-A	: 1/2 soubique of mixture per 7 m²	NI-S	: Level of education: Secondary and higher
A-D	: Ages: 46-55 years	DOS-C	: 1 handful per plant	O-B	: Origin: Allogeneic
Aexp-B	: Years of experience: 6 to 10 years	DOS-D	: 1kg PCZ + 7kg vermicompost per plant	QPCZ_U21-A	: Quantity of PCZ used in 2021: 0-0.5 t
Aexp-C	: Years of experience: More than 10 years	DOS-F	: To be spread / 5 double handfuls per m²	QPCZ_U21-C	: Quantity of PCZ used in 2021: More than 1 t
AFI-O	: Financial access: Yes	DOS-G	: 1 tablespoon per hole for pistachios	QPCZ_U22-B	: Quantity of PCZ used in 2022: 0.6 to 1 t
COMP-C	: Composition: Raw PCZ	FONC-H	: 1 basket of mixture to pour per 7 m²	Rais_pcz-A	: High yield
Cult 1-B	: Banana cultivation	HA_D-O	: Land access: Inheritance	Rais_pcz-C	: Improvement of soil quality
Cult 1-C	: Coffee cultivation	HA_EN-N	: PCZ purchase on demand: YES	Rais_pcz-D	: Promotion of plant growth
Cult 1-E	: Tomato cultivation	INFO-T	: Source of information: Test	Rais_pcz-H	: Tolerance to diseases and pests
Cult 1-L	: Vegetable cultivation	INFO-V	: Source of information: Neighbor	SE_PCZ-A	: Cultivated areas: 0.5 to 5 ares
Cult 1-M	: Mango cultivation	MUT-P	: sage method: Pouring per plant	SE_PCZ-B	: Cultivated areas: 6 to 10 ares
Cult 1-O	: Orange cultivation	MUT-S	: Usage method: Spreading on the soil	TEN-FL	: Type of other fertilizer: Rabbit manure
Cult 1-P	: Sweet potato cultivation	NBP_PCZ-A	: Number of plants with PCZ: 20-50 plants	TEN-FP	: Type of other fertilizer: Chicken droppings
Cult 2-U	: Secondary crop: Plum	NBP_PCZ-B	: Number of plants with PCZ: 51-100 plants	TEN-OR	: Type of other fertilizer: Organic
DEP-B	: PCZ purchase: Up to 1 million Ar	NEN-C	: Number of non-schooling children: More than 5 children	TM-C	: More than 5 individuals
DEP-C	: PCZ purchase: Between 1 and 1.5 million Ar :	NENF-A	: Number of children: Less than 3 children	TP-UPCZ	: PCZ users
				UT_O-N	: Non-users of other fertilizers

3.2.2 Key factors influencing the adoption of Zebu Horn Powder within the strategic rectangle framework

The adoption of PCZ is influenced by several key factors. The strategic rectangle includes 5 dominant and influential variables as well as 17 influential variables (Table -3).

The adoption of powdered zebu horns (PCZ) is influenced by several key factors. Firstly, the main source of information regarding their existence and mode of use comes from neighbors (INFO-V). Secondly, users' experience, generally ranging between six and ten years (Aexp-B), plays an essential role in this adoption process.

Moreover, household origin, particularly their status as non-natives (O-B), the high yield associated with the use of PCZ (Rais pcz–A), and cultivated areas of less than 5 ares (SE-PCZ-A) are key elements driving their appropriation.

Several other influential variables have been identified. Among them, the number of fruit trees treated with PCZ varies among farmers: some apply the powders to 20–50 trees (NBP_PCZ-A), while others use them on 51–100 trees (NBP_PCZ-B). These farmers are already users of PCZ (TP-UPCZ).

Furthermore, producers cultivate a wide variety of plants, including vegetables (Cult 1-L), coffee (Cult 1-C), sweet potatoes (Cult P), oranges (Cult 1-O), and bananas (Cult 1-B). Their land access is generally by inheritance (FONC-H).

These different factors highlight the importance of mixed users in the adoption of PCZ. Experience with PCZ use for over five years (Aexp-C) is also an influential factor in their continued adoption.

In addition, factors such as secondary or higher education levels (NI-S), tolerance to diseases and pests (Rais_pcz-H), improvement in soil quality (Rais-PCZ-C), and the age of the household head, generally between 46 and 55 years (A-D), also play a crucial role in the adoption and effectiveness of these powders. Moreover, some farmers have conducted personal trials (INFO-T) on the use of PCZ.

Table -3: Key factors influencing the adoption of PCZ

	Variables code	Variables	X= L/P	Y=L*P
Dominant and Influential Variables	INFO-V	Source of information: Neighbor	2,40	57,31
	Aexp-B	Years of experience: 6 to 10 years	3,80	42,62
	SE_PCZ-A	Cultivated area with PCZ: Less than 5 ares	1,27	37,88
	O-B	Origin: Allogeneic	4,59	22,85
	Rais_pcz-A	Reason: High yield	1,12	18,28
Influential Variables	NBP_PCZ-A	Number of plants: 20 to 50 plants	1,11	14,93
	TP-UPCZ	PCZ users	13,91	13,91
	Aexp-C	Years of experience: More than 10 years	1,53	11,25
	Cult 1-L	Main type of crop: Vegetables	1,95	11,19
	Cult 1-C	Main type of crop: Coffee	1,82	9,95
	NBP_PCZ-B	Number of plants with PCZ: 51-100 plants	1,32	9,88
	FONC-H	Land access: Inheritance	2,86	9,52
	Cult 1-B	Main type of crop: Banana	2,36	9,20
	Cult 1-P	Main type of crop: Sweet potato	1,33	8,50
	Cult 1-O	Main type of crop: Orange	1,57	8,13
	NI-S	Level of education: Secondary and higher	2,42	7,64
	Rais_pcz-H	Reason: Tolerance to diseases and pests	1,21	5,54
	Rais_pcz-C	Reason: Improvement of soil quality	1,02	5,37
	Cult 1-E	Main type of crop: Tomato	1,76	5,32
	AFI-O	Financial access: Yes	3,59	5,26
	A-D	Household head's age: 46-55 years	3,76	5,16
	INFO-T	Source of information: Test	2,44	5,03

Legend

L: Sum of the absolute values of the variables in the rows of the correlation matrix
P: Sum of the absolute values of the variables in the columns of the correlation matrix
X: L/ P
Y: L* P

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4 DISCUSSION

4.1 Analysis of producer profiles based on PCZ usage

4.1.1 Users of the Mixture of Zebu Horn Powder and Vermicompost

In this group, farmers adopt the mixture of PCZ and vermicompost

4.1.1.1. Analysis of the Role of Neighbors (INFO-V) as a Source of Information

Neighbors play a crucial role in the dissemination of agricultural practices, particularly facilitating the adoption of powdered zebu horns and vermicompost. Their influence is based on several factors (Fig 1):

- Geographical proximity: Neighbors serve as a primary point of contact for the exchange of practical information on agricultural techniques.
- Social trust: Farmers rely on the real-life experiences of their peers, which enhances the credibility and adoption of recommended practices.
- Informal transmission and adoption of agricultural practices.

Information exchanges among farmers occur spontaneously, without the need for formal structures, which promotes the rapid diffusion of innovations. A convinced farmer can influence several others, thereby creating a domino effect that amplifies the adoption of powdered zebu horns (PCZ) and vermicompost.

A study conducted by Qiao & al. (2022) highlights the positive impact of neighborhood interactions on the adoption of organic fertilizers. Similarly, research by Aquino & al. (2021) examines how information sharing influences farmers' decisions regarding organic agriculture.

Conversely, a study by Boun (2022) shows that, in some cases, formal networks and social incentives may play a more decisive role than neighborhood interactions in the dissemination of agricultural practices.

4.1.1.2. Adoption of the Mixture of Vermicompost and Powdered Zebu Horns in Coffee Cultivation

Farmers use mixtures of vermicompost and powdered zebu horns for the cultivation of fruit trees such as coffee (Cult1-Café) (Fig 1). Rakotomanana (2011) describes the use of vermicompost by Malagasy farmers, highlighting its advantages in terms of profitability and quality for plant cultivation, including fruit trees.

Although the study by Razafindramanana & al. (2020) does not specifically address powdered zebu horns, it emphasizes the importance of organic fertilizers in Malagasy agriculture. They studied the use of bone meal and zebu manure in bean cultivation in Madagascar. Their research showed that the combination of these organic fertilizers improves plant growth and increases grain yields. However, the study does not specifically mention the use of powdered zebu horns.

In contrast, Madacompost confirms the use of powdered zebu horn as an effective fertilizer, particularly for coffee cultivation. The company Madacompost offers a product called Korneco, made from ground zebu horns. This fertilizer is rich in nitrogen and is characterized by its slow dissolution, which allows for a prolonged release of nutrients into the soil. It is particularly well suited to perennial crops such as coffee, as it enhances soil microbial life, stimulates root growth, and strengthens plant resistance to pests.

The study conducted by Razafindrakoto & al. (2022) highlights the importance of vermicompost in improving soil fertility in Madagascar, emphasizing its role in promoting earthworms for sustainable agriculture. Their article presents an action-research project aimed at identifying local plant resources usable for vermicompost production, involving farming communities in Madagascar's Highlands.

4.1.1.3. Education Level and Land Access Considered as Key Factors in the Adoption of Powdered Zebu Horns

In this group, farmers have a secondary or higher education level (NI-S) and primarily access their land through inheritance (Fonc-H). Education level and land access play a key role in the adoption of powdered zebu horns as a fertilizer. Farmers with a secondary or higher education are more likely to experiment with innovative agricultural techniques, including the use of organic fertilizers such as powdered zebu horns (Fig 1).

Moreover, land inheritance directly influences agricultural practices. Farmers who acquire land through inheritance tend to continue traditional methods while incorporating improvements based on their education level.

The report presented by Kouassi and Jakkie (2023) explores the challenges related to education and development in Africa, notably structural and political obstacles. The work of Chika Ezeanya-Esiobu (2019) highlights the importance of indigenous knowledge in African education and its integration into curricula. Eve & al. (2014) examine the relationship between education and land access.

The study conducted by Ranjatoson & al. (2021) investigates agricultural and land practices in Madagascar, particularly land access and the influence of traditions on the adoption of agricultural techniques.

4.1.1.4. Number of Plants Amended with PCZ and the Reasons for Choosing PCZ by Farmers

Farmers in this group adopt PCZ in their production due to its positive impact on soil improvement (Rais-PCZC) as well as for achieving high yields (Rais-PCZ-A) (Fig 1). Frédéric (1997) highlights local agroecological practices in Madagascar, emphasizing the importance of compost, manure, and organic amendments (including powdered horn) to restore degraded soils. He presents practical methods for preparation and use to improve soil structure and support sustainable production.

The study conducted by Razafindramanana & al. (2020) in the Malagasy Highlands evaluates the impact of bone meal and zebu manure on the growth and yield of beans (Phaseolus vulgaris).

4.1.2 Users of Raw PCZ

Users of raw PCZ are mainly composed of non-native households (O-B). They obtain information about the use of PCZ primarily from their neighbors (INFO-V) and through their own trials (INFO-T). Their cultivated areas are less than 5 ares (SE-PCZ-A) (Fig 2). Non-native households (O-B) are often open to new techniques and show a willingness to adopt new agricultural methods, thereby facilitating the acceptance and experimentation of PCZ.

A study conducted by Rizzo & al. (2024) confirms this finding by exploring the socio-economic and psychological characteristics influencing the adoption of agricultural innovations. Similarly, Ouedraogo's thesis (2021) supports this observation by examining the socio-economic and cultural factors determining the adoption of agricultural innovations in sub-Saharan Africa.

The adoption of PCZ can strengthen community networks through the sharing of agricultural knowledge. A study conducted by Qiao & al. (2022) confirms these ideas, highlighting the positive effect of neighborhood interactions on adoption.The report by Bélières & al. (2023) presents the practices of seed multiple farmers and ordinary farms, emphasizing differences in access to information and resources. It also highlights the importance of local social networks in the dissemination of agricultural knowledge.

A cultivated area of less than 5 ares (SE-PCZ-A) is extremely small for a farming operation. It often corresponds to a household garden or an experimental plot rather than a conventional commercial production unit.

Penot & al. (2015) discusses the barriers and drivers of adopting conservation techniques based on farm size.

4.1.3 Mixed User

The identified class of producers, composed of household heads aged 46 to 55 with extensive experience in the use of powdered zebu horns (PCZ) (Fig 3), illustrates an interesting dynamic of adaptation and coexistence between agronomic innovations and traditional practices. Their combined use of PCZ and traditional systems reflects a pragmatic strategy for optimizing available resources, as well as a certain caution in adopting new techniques, often observed among experienced farmers (Giller & al., 2009; Tittonell, 2013).

Their diversified use of PCZ, whether in raw form, combined with vermicompost, or with manure, demonstrates a strong understanding of the interactions between organic matter and soil fertility, and suggests active on-farm experimentation aimed at improving the effectiveness of soil amendments. This confirms the central role of endogenous knowledge in the agroecological management of soils (Altieri, 2002).

The fact that these producers have access to land through family inheritance (FONC-H) provides a certain level of land tenure security, often a key factor in the willingness to invest in long-term organic soil fertilization. Moreover, their choice to primarily grow vegetables, crops that are typically nutrient-demanding, highlights the relevance of adopting PCZ as a means to maintain or improve productivity.

Finally, owning 50 to 100 plants amended with PCZ reflects a partial but significant adoption of this practice. This may indicate a gradual appropriation phase, typical of the incremental adoption process described in farmer innovation models (Rogers, 2003).

Thus, this group underscores the importance of technical support that values hybrid practices, taking into account both local knowledge and innovations, within a sustainable agriculture framework.

4.2 Analysis of the Determinant Factors Influencing the Adoption of Zebu Horn Powders (PCZ)

4.2.1 According to Their Hierarchy

The results show that the adoption of PCZ by farmers is influenced by a combination of socio-demographic, economic, and technical factors, revealing a complex dynamic of innovation in rural agricultural settings (Figure 4).

First, age and experience play a structuring role. Farmers aged between 46 and 55, who are often experienced, tend to combine PCZ with traditional practices, reflecting a gradual adaptation process rather than a radical shift. This supports the idea that innovations are often integrated incrementally based on local realities (Rogers, 2003; Giller & al., 2009). In contrast, younger producers under 25, although a minority, are more open to rapid experimentation, reflecting a positive attitude toward innovation.

The level of education also appears to be a determining factor. Producers who have attained secondary education or higher seem to have a better understanding of how PCZ works and are more likely to experiment with various combinations (with compost or manure), suggesting a link between education and innovative capacity. Furthermore, access to land, often inherited, encourages long-term investments in soil fertility (Altieri, 2002).

The observed agricultural practices reveal a differentiated adoption: some farmers use PCZ on limited areas (20 to 50 plants), while others apply it to over 100 plants, depending on the targeted crops (vegetables, coffee, tubers). This heterogeneity reflects gradual and context-specific appropriation strategies, reinforcing the idea that innovation is first tested on a small scale before possible expansion (Tittonell, 2013).

Another key factor is the circulation of information. Learning from neighbors or through personal experimentation (INFO-V, INFO-T) is predominant, highlighting the importance of social networks in the dissemination of techniques. As Rogers (2003) points out, the adoption of an innovation often occurs through informal channels, where farmers place greater trust in their peers than in formal institutions.

The motivations of adopters focus on agronomic performance: improved plant growth, increased yields, better soil quality, and reduced disease incidence. These perceived benefits suggest that PCZ are not merely substitutes for chemical fertilizers but are part of a sustainable agroecological approach based on better use of local resources (Altieri, 2002).

4.2.2 According to the Strategic Rectangle

The results show that the adoption of powdered zebu horns (PCZ) by farmers does not depend on a single factor, but rather on a complex set of elements related to individual characteristics, available resources, the social environment, and perceptions of the technology's performance (Table 3).

One of the key conditions facilitating adoption is the circulation of information among peers, particularly through neighbors (INFO-V). This finding aligns with the work of Rogers (2003), who argues that the adoption of innovation largely relies on interpersonal communication, especially among members of the same social network. This dimension is further strengthened by the fact that several farmers also conducted their own trials (INFO-T), enhancing the credibility of the innovation through personal experimentation.

The primary source of information for adopting PCZ comes from neighbors, which highlights the importance of social networks and the local dissemination of agricultural practices. This result is consistent with the findings of Vincent & al. (2024) and Raphaël and Vincent (2023), who discussed the use of local social networks and how they influence the spread of agricultural practices. It also confirms the study by Godefroy and Virginie (2010) on the impact of social networks on sociability and how this can affect farming practices. Conversely, Darré (1996), in his study, does not confirm this result due to the social positions of farmers and their practical and argumentative stances toward the implementation of new practices. Communication among farmers plays a key role in facilitating the dissemination of knowledge about the beneficial effects of PCZ, particularly in terms of yield improvement. These findings are consistent with the literature, which highlights that producers tend to adopt practices they observe among their neighbors or family members (Foster and Rosenzweig, 2010). In contrast, Pénard and Miltgen (2014) disagree with this result, as their studies analyze how digital social networks can sometimes undermine traditional sociability and local exchanges.

The accumulated experience in using PCZ over a period of 6 to 10 years (Aexp-B) also represents a significant lever. Experienced producers develop better technical mastery and adapt doses or combinations according to their crops, which supports long-term appropriation. This capacity for gradual learning fits within the co-construction of knowledge process, as advocated by Altieri (2002) in agroecology. The cultivated area of less than 5 ares (SE-PCZ-A) is a key element in this appropriation.

In terms of land tenure, access to land through inheritance (FONC-H) serves as a stabilizing factor, enabling the implementation of long-term practices to improve soil fertility without the fear of losing land rights. This land security encourages biological investments such as PCZ, which are low-cost but have long-lasting effects.

The results also show that crop diversity (vegetables, coffee, sweet potato, banana, orange) encourages the adoption of PCZ, as these organic amendments improve both soil quality (Rais-PCZ-C) and plant resistance to diseases and pests (Rais-PCZ-H). These positive effects are perceived as agronomic and economic advantages, motivating producers to apply them to an increasing number of plants, ranging from 20 to over 100 fruit trees (NBP-PCZ-A/B). This reflects a dynamic of progressive adoption, as observed in agroecological transitions (Tittonell, 2013).

From a socio-demographic perspective, several characteristics support this innovation: the age of household heads between 46 and 55 years old (A-D), their secondary or higher education level (NI-S), and their status as confirmed users (TP-UPCZ). These variables reveal that the profiles most likely to adopt PCZ are both experienced, well-informed, and capable of making autonomous and strategic decisions. The level of education also influences PCZ adoption; it is more commonly used by household heads who have attained secondary or university-level education. This result aligns with the findings of Tossavi (2015) who emphasized that PCZ users generally have a relatively high level of education.

Finally, the fact that several households are of non-native origin (O-B) yet actively adopt PCZ shows that this practice transcends identity or cultural divisions, provided that the agronomic results are convincing (high yield – Rais-PCZ-A). This observation suggests that innovations based on local, low-cost resources can serve as vectors of cohesion and knowledge transfer across different social categories.

5 CONCLUSION

This research aims to analyze the factors influencing the adoption of zebu horn powder (PCZ) in agricultural production in the Ambositra district, located in the Amoron'i Mania region of Madagascar. To achieve this, an initial phase of qualitative surveys was conducted in the study area to meet the Users of Zebu Horn Powder (UPCZ) and collect data from 226 farmers, selected through a stratification process.

The results show that 26.5% of farmers use PCZ in their agricultural production. Additionally, 8.8% of them maintain the traditional production system while simultaneously adopting PCZ. Finally, 64.6% of respondents are Non-Users of Zebu Horn Powder (NUPCZ).These observations invalidate Hypothesis 1, which assumed that "the use of zebu horn powder is beginning to gain ground in the study area."

Hypothesis 2, which states that "farmers in the study area adopt the mixing of zebu horn powders with other fertilizers because increased production encourages the choice of PCZ," is confirmed. The main determining factors for the adoption of zebu horn powders are information sources from farmers, producers' experience, the age of the household head, their level of education, the crops chosen by farmers, land access, cultivated area, and yield improvement.

Information shared by neighbors, as well as their usage methods, is considered dominant and influential variables due to their importance in the overall system. Farmers tend to opt for fertilizers deemed more effective by other farmers to enhance their yields.

To further develop this research area, it would be valuable to explore the methods of using powders in agricultural production to enhance crop yields. This would help guide agricultural policies towards the adoption of innovative practices, increase national production, and contribute to achieving food self-sufficiency.

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