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Analysis of the Zaï Practice Combined with Organic Manure in the Municipality of Ndiob (Fatick, Senegal)

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Abstract

In Senegal, family-based, rainfed agriculture faces land degradation and rainfall variability, which together create two major constraints on agricultural production: the loss of soil fertility (physical, chemical, and biological) in cultivated land, and the availability of water for crops, both of which compromise agricultural yields. This study aims to provide a preliminary assessment of the agronomic effectiveness of improved zaï on pearl millet (*Pennisetum glaucum*) cultivation, and to gather the perceptions of farmers who trialled this technology, which was entirely unknown in their area before 2020. Improved zaï technology was tested on four demonstration farm fields in the municipality of Ndiob during the 2021 cropping season. A basic comparative design consisting of eight (8) plots of 50 m × 25 m—four (4) improved zaï plots and four (4) control plots (managed under traditional farming practices)—was established across four soil types. Grain yields were measured using two 25 m^2 yield-assessment quadrats per plot. Surveys using a questionnaire were conducted among 113 farmers who had practiced the zaï technology in the 18 villages of the municipality to assess the agronomic effects of the improved zaï method compared to those of traditional farming practices. The results show that improved zaï combined with organic manure increased millet yields by 110 to 270 kg/ha compared with traditional farming practices in three of the four demonstration fields. Most farmers surveyed (95.4%) considered that zaï contributes to increased yields. For 61.1% of respondents, zaï improves soil fertility and optimizes the use of organic matter, and 55.1% considered that

zaï improves soil water retention. The main constraints reported were the physical strain of the work (57.7%), its slowness (51.4%), and the high labour demand (45.1%). These results confirm the agronomic relevance of improved zaï and point to the need to develop mechanized tools to facilitate its adoption at scale.

Keywords

Rainfed Agriculture, Improved Zaï, Organic Manure, Ndiob

1. Introduction

Agriculture is an important sector of the Senegalese economy, contributing 9.1% to Gross Domestic Product (GDP), primarily through the primary sector, which accounts for approximately 13.5% of GDP ([1] Republic of Senegal, 2024). Senegalese agriculture is largely family-based and rainfed, with 72% of agricultural households at the national level and 86% in the Fatick region ([2] DAPSA, 2023), and it constitutes the main source of food and income for these households. However, it faces several constraints, including its dependence on rainfall and land degradation ([3] Sène, 2023). Indeed, rainfall shows marked spatio-temporal variability, including early or late onset and end dates, long and recurrent dry spells within the rainy season, a southward shift of isohyets, and variable cropping season lengths, among other features ([4] Sagna, 2015). Cultivated soils are affected by various degradation processes, including clay leaching, water and wind erosion, siltation of lowlands, structural breakdown, salinization, acidification, depletion of organic matter and nutrients, and loss of biodiversity. These constraints compromise food security and increase the vulnerability of local populations, particularly women and youth.

Environmentally friendly agricultural initiatives and practices aimed at improving agricultural production in a changing climate are being implemented by farmers with the support of government and non-governmental organizations. These agricultural initiatives and practices are grounded in the reduction of synthetic fertilizers and pesticides and in due consideration of the two principal agricultural constraints, namely rainfall variability, which gives rise to limited water availability for crops, and the insufficiency of organic matter, notwithstanding the low organic carbon content of the soils. It is within this context that the municipality of Ndiob and the non-governmental organization (NGO) ENDA Pronat supported 113 farmers in trialling zaï combined with organic manure in order to optimise the water and the organic matter for crops during the 2021 cropping season, following a tentative introduction of the technology in 2020. Although it is mainly practised on compacted soils, here the zaï method is used on sandy and sandy-clay soils with low organic carbon, which therefore retain little water—not through runoff but through infiltration.

The overall objective of this study is to contribute to the promotion of sustainable agriculture through the development of appropriate water and soil fertility conservation technologies to improve agricultural production. Specifically, the study aims to assess the agronomic effectiveness of improved zaï combined with organic manure in the municipality of Ndiob, and to gather farmers' perceptions of this technology compared with traditional farming practices, with a view to its adoption.

2. Materials and Methods

2.1. Study Area

Ndiob is a municipality in the department and region of Fatick, in west-central part of Senegal's groundnut basin, located between latitudes 14˚26' and 14˚35'N and longitudes 16˚19' and 16˚24'W. It covers an area of 127 km^2 and comprises 18 villages (Figure 1).

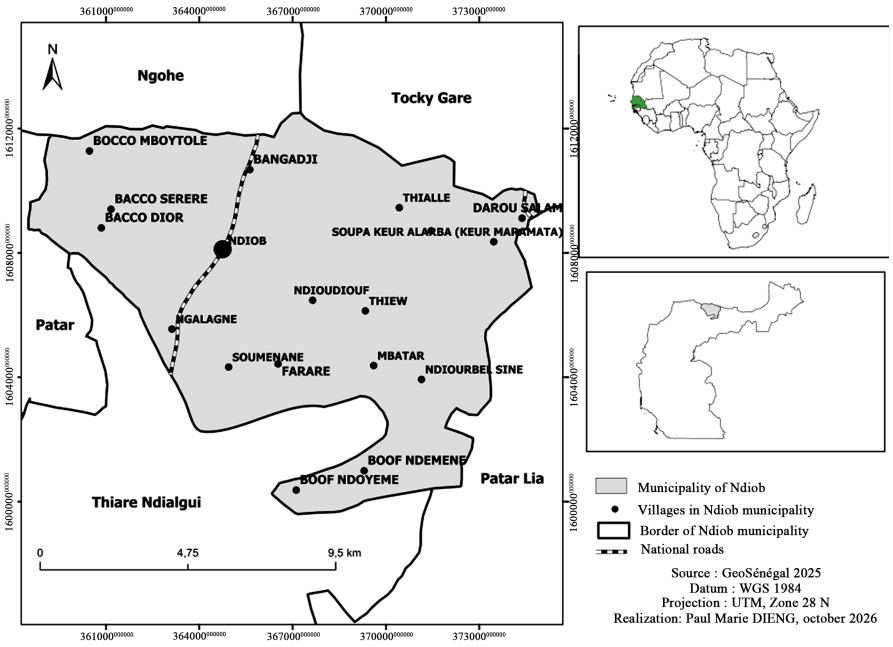


Figure 1. Location of the municipality of Ndiob.

Mean monthly temperatures in the Fatick department from 1991 to 2020 show a maximum of 30.4˚C in May and June and a minimum of 25.5˚C in January.

A dry season runs from October to June and a rainy season from June to October. Over the period 1991-2020, mean annual rainfall totaled 604.6 mm. Rainfall is characterized, among other features, by (i) interannual variability in rainfall amounts was (336.6 mm in 2007, the driest year, and 922.5 mm in 2012, the wettest year), with more deficit years than surplus years; (ii) variability in the length of the cropping season (early and/or late onset and end dates); and (iii) frequent, often long (more than 7 days), dry spells. Weather data is provided by the National Civil Aviation and Meteorology Agency (ANACIM).

Vegetation consists of shrub savanna, with some tree cover. Two demonstration farm fields were established on slightly leached, sandy tropical ferruginous soil, one on slightly leached, sandy-clay tropical ferruginous soil, and one on non-leached, clay-sandy tropical hydromorphic ferruginous soil.

2.2. Plant Material

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an annual cereal grass belonging to the family Poaceae and the order Poales ([5] Maiti & Bidinger, 1981; [6] Kadri *et al*., 2019). Genetic and archaeobotanical evidence places its domestication process in West Africa ([7] Oumar *et al*., 2008; [8] Burgarella *et al*., 2018). From germination onward, it develops a root system that provides extensive soil exploration capacity and considerable plasticity, conferring resistance under water deficit conditions ([5] Maiti & Bidinger, 1981; [9] Shrestha *et al*., 2023). Indeed, pearl millet is particularly well adapted to arid and semi-arid environments owing to morphological and physiological traits that allow it to maintain growth and production under water deficit ([10] Dancette, 1983; [9] Shrestha *et al*., 2023).

Its development cycle is characterized by three phases:

- the vegetative phase, from coleoptile emergence to panicle initiation;
- the reproductive phase, ending with panicle flowering (female flowering followed by male flowering);
- the maturation phase, during which the grain develops and ripens ([5] Maiti & Bidinger, 1981).

Millet production remains strongly influenced by soil fertility. Improved nutrient availability and soil physical properties favor increased millet yields ([11] Mason *et al*., 2015; [6] Kadri *et al*., 2019). Millet is a thermophilic cereal ([12] Mohamed *et al*., 1988a), with optimal germination temperatures between 29 and 36.5˚C and maximum germination temperatures between 41 and 47˚C depending on genotype. It is an important cereal crop in the arid and semi-arid regions of sub-Saharan Africa ([11] Mason *et al*., 2015; [6] Kadri *et al*., 2019). In Senegal, millet accounted for 51% of the area sown to cereals in 2023 (DAPSA, 2023). It directly contributes to household food security and is consumed in various forms ([13] Vieira Junior *et al*., 2024; [14] O'Brien *et al*., 2022). Its processing is also an important economic activity, particularly for women involved in the processing and marketing of millet-based products ([14] O'Brien *et al*., 2022). Beyond its food and economic functions, millet holds a strong social and cultural significance, particularly for the Serer ethnic group.

2.3. Zaï Combined with Organic Manure

Zaï is a technique for restoring sterile, hardened soils (*zipellé*) in the Sahelian environment, best known in West Africa (Niger, Burkina Faso, Mali, Senegal). It consists of digging pits 10 to 60 cm in diameter and 10 to 50 cm deep before the onset of the rainy season ([15] Bowers *et al*., 2024; [16] Danjuma & Mohammed, 2015; [17] Roose *et al*., 1993). An earthen ridge is formed downslope of the pit

using the excavated soil. The pits are filled with organic matter. The main objectives are water conservation, improvement of soil structure, and stimulation of biological activity, among others.

2.4. Data Collection Methods and Tools

2.4.1. Selection of Farmers and Demonstration Plots

The trial was conducted during the 2021 agricultural season and tested on four demonstration plots established across four soil types in the municipality of Ndiob. The experimental setup involved splitting each plot into two identical subplots (50 m × 25 m): one managed using the improved zaï method and the other using traditional farming practices. Four local volunteer farmers made four demonstration farm fields available for the zaï trial. To account for the variability between compound farm fields (near the village) and bush farm fields, one demonstration farm field was selected within the village and three in the bush. The compound farm fields are located in the immediate vicinity of the houses and are richer in organic matter due to regular contributions of household waste and manure from parked animals. The bush farm fields are in the remote outskirts of the village and are less fertile. Two demonstration farm fields were established on slightly leached, sandy tropical ferruginous soil, one on slightly leached, sandy-clay tropical ferruginous soil, and one on non-leached, clay-sandy tropical hydromorphic ferruginous soil.

2.4.2. Location and Digging of Zaï Pits

To mark the location of the zaï pits, perpendicular lines (a grid pattern) spaced 80 cm apart were laid out. The zaï pits were dug at the intersection points of these perpendicular lines.

2.4.3. Pre-Sowing Amendment

As organic matter was in short supply, each farmer spread the amount available on their field, prioritizing the areas they considered least fertile. Horse and donkey manure was spread on the control plots, although the quantity applied per unit area could not be determined. The zaï pits were amended with horse and donkey manure at a rate of 250 g per pit. Usually, the amount of organic matter applied ranges from 300 to 600 g per pits. However, farmers are very often faced with a shortage of organic matter. For this reason, the amount has been limited to 250 g per pits.

2.4.4. Sowing

Sowing was done by hand in the zaï pits and with a horse-drawn seeder on the control plots. Approximately, 10 to 20 millet grains are sown per pits, whether by hand (zaï) or using a horse-drawn seeder. In both cases, thinning out the seedlings helps to reduce the number of millet plants and thus limit competition for water and nutrients. Subsequent crop management was carried out identically on both plot types: first weeding, thinning, and second weeding.

2.4.5. Post-Sowing Amendment

After thinning and before the second weeding, 50 g of *Organova*—an organic amendment—was applied to each millet plant on both the zaï plots and the control plots.

2.4.6. Harvest and Yield Calculation

Grain yields were measured using the yield-square method ([18] Fermont & Benson, 2011). Two 5 m × 5 m yield squares were laid out and delimited with string in each of the 8 plots across the 4 demonstration farm fields (4 zaï plots and 4 control plots). They were positioned along the diagonal of each plot, avoiding border effects (a three-plant margin). Panicles within each yield square were harvested and weighed immediately, before being sun-dried on a tarpaulin for twelve (12) days. After drying, the panicles were weighed again before threshing. Grain weight was determined after threshing. Grain weight was extrapolated to a per-hectare yield for each plot using the formula below:

$$\text{Yield}\left(\text{kg}/\text{ha}\right) = \left(\text{grain weight} \times 10000\right)/50$$

All weighing was carried out using a precision digital scale.

2.4.7. Perception Surveys

A perception survey was conducted using a standardized questionnaire administered to 113 farmers, who had trialled the improved zaï technology. The survey focused on heads of households, all of whom are men. The questionnaire covered several aspects, including information on the farmer, the demonstration plot, farming practices, the main constraints on farming, and the advantages and disadvantages of the zaï method compared with traditional farming practices, etc.

2.5. Data Processing and Analysis

The questionnaire was designed using the ONA data collection, management, and visualization platform, compatible with Microsoft Excel, which allowed questions to be coded to facilitate subsequent processing. Data were cleaned and statistically analyzed using Stata. Graphs were produced using Microsoft Excel.

3. Results and Discussion

3.1. Agronomic Effectiveness of Improved Zaï

Grain yield in the zaï plots was higher than in the control plots in 3 of the 4 demonstration farm fields, with the difference ranging from 110 to 270 kg/ha (**Figure 2**). In contrast, for demonstration farm field 4 (a compound farm field), the yield of the control plot, cultivated using local traditional practices, was 1280 kg/ha versus 1190 kg/ha for the zaï plot, a difference of 90 kg/ha. The control plot's superior performance in field 4 could be explained by the fact that compound farm fields are generally more fertile than bush farm fields ([19] Fatondji *et al*., 2006), and that the sowing density achieved with a seeder is higher than with the zaï method, which has a regular spacing of 80 cm between pits. The better perfor-

mance of the zaï plots is likely attributable to the beneficial effects of water capture and use, localized organic matter input, and improved nutrient uptake by crops. Indeed, [20] Roose *et al.* (1999) demonstrated an increase in sorghum grain yield from 150 to 1700 kg/ha and in plant biomass from 500 to 5300 kg/ha on deep brown soil in Burkina Faso. Similar results were reported by [19] Fatondji *et al.* (2006) in Niger, with a 3- to 4-fold increase (up to 19-fold in one case) in grain yield under zaï compared with flat cultivation, both without amendment. With organic amendment, the same authors reported a 2- to 68-fold increase in grain yield compared with unamended conditions.

These results are also consistent with those of [21] Sawadogo *et al.* (2008), who found that organic matter significantly improves yield levels. [22] Mando (1997) attributes this phenomenon to the stimulation of soil biological activity: burying organic matter in the pits promotes nutrient mineralization and termite activity, which perforate the surface crust and thereby improve soil structure and infiltration capacity. [23] Somé *et al.* (2016) add that this could be explained by the combined effects of the improved soil moisture profile created by the zaï pits and the organic manure input.

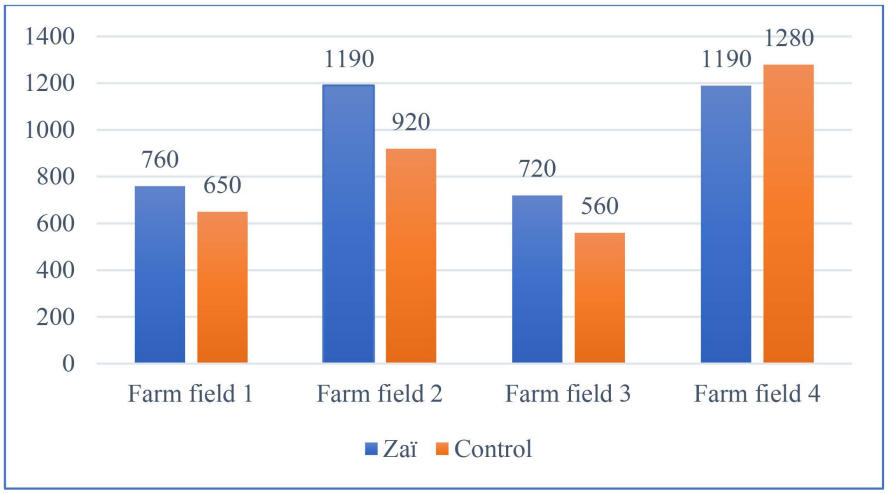


Figure 2. Grain yield (kg/ha) across demonstration farm fields.

3.2. Stakeholder Perceptions

Increased agricultural yields were the main benefit of zaï reported by farmers during the perception survey.

Surveyed farmers attributed several benefits to the zaï practice (**Figure 3**). The most frequently cited were increased yields (95.4%), improved soil fertility (61.1%), and water retention (55.1%). Farmers also mentioned more efficient use of organic matter (33%), adaptation to climate change (12.8%), and faster crop growth (23.9%).

The ability to collect and retain rainwater in the pits was frequently cited as a benefit of zaï. This water retention capacity is linked to climate change adaptation, which was also considered a benefit by the farmers surveyed. In a changing climate

marked by spatio-temporal rainfall variability, the ability of crops to cope with periods of water stress is vital. Water collection in the zaï pits helps maintain soil moisture for longer and supports adaptation to climatic hazards, particularly during deficit years. [24] Roose *et al.* (1994) confirm this finding, concluding that zaï can reduce the negative impact of climatic hazards and secure production. The ability of crops to withstand dry periods was observed in our study, in which crops experienced a 23-day dry spell during which plants in the zaï plots withstood the stress better than those in the control plots through a higher survival rate, certainly because of to the better water retention in the zaï pits. [20] Roose *et al.* (1999) affirms that zaï pits treatments increased infiltration of water and stores water for more periods compared to conventional tillage. Consistent with our findings, [25] GIZ (2012) states that, in the context of climate change, zaï is particularly valuable because it limits water losses.

More efficient use of organic matter, cited by 33% of respondents, is also considered an important benefit of zaï. Indeed, placing organic manure directly in the pit is more economical than broadcast spreading, which is the most commonly applied method in the area—particularly since the scarcity or insufficiency of organic matter was cited by 23% of respondents as a difficulty facing the agricultural sector. In this regard, [25] GIZ (2012) states that localized application of organic manure directly at the base of plants allows for its optimal use.

Ultimately, the benefits of the zaï practice observed in this study, corroborated by scientific findings on the subject, demonstrate the relevance of its introduction in the study area and its agronomic effectiveness.

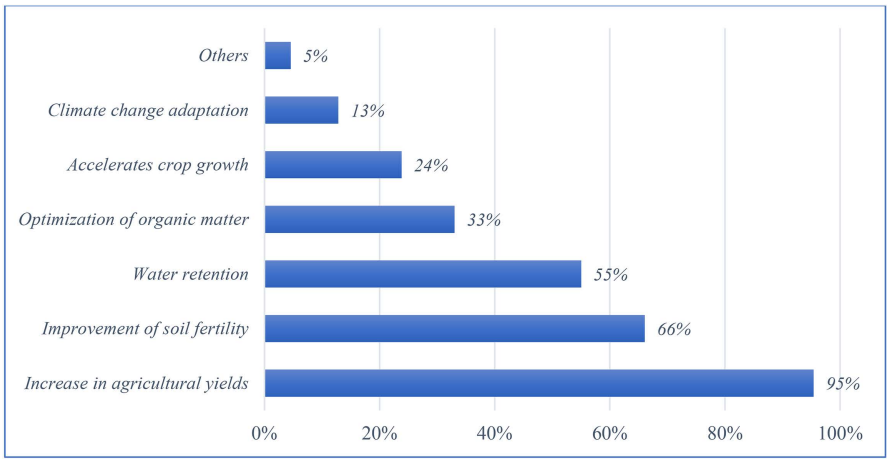


Figure 3. Farmers' perceptions of the benefits of improved zaï.

The benefits of improved zaï combined with organic manure convinced 77% of respondents of its effectiveness as a soil and water conservation response.

3.3. Constraints Identified by Farmers

The main constraints of zaï (**Figure 4**) reported by surveyed farmers were: (i) the physical strain of the work (57.7%), its slowness (51.4%), lack of labour (45.1%),

and insufficient organic matter (35.1%). Farmers also noted that the pits are easily spotted by grain-eating birds that dig up the seeds. Overall, 61% of respondents expressed a wish to adopt zaï technology, against 39% opposed. Implementing zaï technology requires considerable energy and time, particularly for digging the pits. Many studies confirm these findings, noting that zaï is very labour-intensive, particularly for the manual digging of pits ([26] Kimaru-Muchai *et al.*, 2021); [16] Danjuma & Mohammed (2015); [27] Dugué (2014). To this must be added the insufficient availability of organic matter and labour in Senegalese agricultural communities. These constraints are consistent with the findings of [17] Roose *et al.* (1993), who state that zaï adoption is limited by the availability of organic matter and labour.

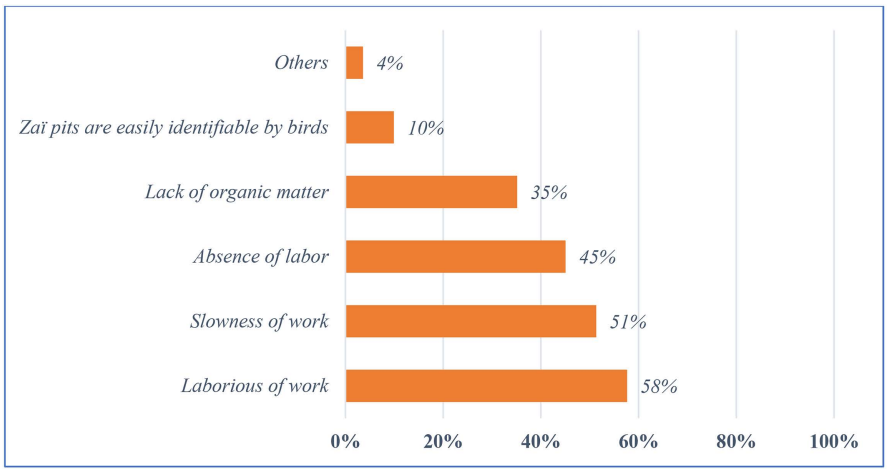


Figure 4. Constraints of improved zaï reported by respondents.

4. Conclusions and Perspectives

This exploratory study demonstrates that improved zaï combined with organic manure constitutes an agronomically promising alternative to traditional farming practices in the commune of Ndiob, in the face of rainfall variability, water stress, and insufficient organic matter. In three of the four fields monitored, this technique increased millet yields by 110 to 270 kg/ha by stimulating soil biological activity, improving water retention, and increasing nutrient availability. It also offers improved resistance to water stress, a valuable asset in an uncertain climate ([26] Kimaru-Muchai *et al.*, 2021; [16] Danjuma & Mohammed, 2015).

The overall positive perception of the 113 farmers surveyed—61% of whom wish to permanently adopt the practice—confirms its social acceptability. However, labour constraints and the physical strain of digging the pits remain obstacles to large-scale dissemination. Mechanizing these operations, as proposed by [28] Barro *et al.* (2005) and [29] Clavel *et al.* (2008) in other Sahelian contexts, is a priority avenue to explore.

Further studies, incorporating soil analyses, multi-criteria experimental designs and economic assessments, are needed to refine these findings in the context of

the municipality of Ndiob and indeed the Senegalese groundnut basin, which is characterized by well-drained soils and low organic matter content.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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