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Original Research Article

Circular economy and sustainable development: Evaluation of soil fertilization methods in Kaolack region (Senegal)

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Variations in temperature and changes in precipitation patterns can lead to prolonged droughts and/or floods, which are likely to damage farms while increasing the decline in soil fertility and the proliferation of diseases. This study is based on an analysis of the impact of fertilizers on the sustainable development of agricultural and related activities in Kaolack area. In Senegal, agriculture is constantly evolving, with multiple challenges and technical, economic and social opportunities improvement, which are all levers for development. Despite of 87% rate of exploitation low fertile land, 78,26% of farmers conform that fertilizers application enable them to increase their income. However, fertilizers use stabilized 16,3% of farmers level income while having no impact on 4,55% for those who do not sell their production. Then agriculture is a vital, important activity for sustainable development because of the large number of people working in agricultural sector and its high potential for creating sustainable income throughout created agricultural surplus, especially in rural areas. And it's also a principal source of employment and livelihoods for many families, and can make a substantial contribution to poverty reduction and food self-sufficiency.

Keywords: Circular economy, sustainable development, soil fertility, productivity, agricultural products

INTRODUCTION

Climate change is a major global concern, with far-reaching repercussions for agricultural production systems and food security. This situation is of concern to both developed and developing countries. Climate change is having a significant impact on food production in developing countries.

In Senegal, agriculture is highly complex due to the effects of climate change and the agricultural sector alone accounts for more than 60% of the country's working population (ANSD, 2023). Agriculture plays an important role in the development process, meeting food needs, supplying the industrial sector and reducing unemployment through entrepreneurship and job creation (Dia, 2022).

However, the performance of agriculture, as a lever of growth remains relatively weak despite the various development policies to improve agricultural sector (Dia, 2022; Mbow, 2017). The sector faces difficulties linked among other, the vulnerability of the production base; land (availability, fertility, accessibility) and dependence on rainfall (PRACAS II). So there is a necessity to remove the constraints on agricultural production (Diouf et al., 2020).

Indeed, agriculture has been the principal point of development for all the major powerful developed countries and therefore the basis of all sustainable development. It is therefore 'at the basis of the circular

economy' (Jeuffrault, 2020). And in a context of climate change, in order to boost agricultural production, it would be important to implement adapted strategies such as the use of resistant varieties adapted to different agro-ecological zones (to heat, salt, diseases, drought…), efficient water management, improved soil management and the promotion of sustainable agricultural practices (Ange, 1990; Ouedraogo et al., 2022). Continued investment in agricultural research and development would also help to mitigate the negative impacts of climate change on agricultural production.

Senegal is facing up a growing demand for food products. And in order to achieve the objectives of food security and self-sufficiency in a context of globalization, it is imperative to add value to agricultural sectors and residues. Sustainable development of agricultural sector is based on good control of its uncertain environment through the choice of a structured start-up approach that enables farmers to optimize their production while preserving natural resources (Iyabano et al., 2022). So, if the obstacles are overcome, agricultural production could make a substantial contribution to food and nutritional security, food sovereignty and, significantly, economic growth, job creation, regulation of macroeconomic balances and poverty reduction (PRACAS II).

Abbreviations

ANSD: National Agency of Statistics and Demography (Agence Nationale de la Statistique et de la Demographie)
CIRAD : Centre for International Cooperation in Agricultural Research for Development
DRDR: Regional Office (Direction) of Rural Development (Direction Régionale du Developpement Rurale)
IFDC: International Fertilizer Development Center
SESN: Senegal's economic and social situation (Situations Economiques et Sociales Nationale)
PRACAS: Programme to accelerate the pace of Senegalese agriculture (Programme d'accélération de la Cadence de l'agriculture Sénégalaise)
WD: World Bank

Context

Traditionally, Senegalese farmers used chemical and organic fertilizers to increase productivity and quality of their crops. Chemical fertilizers are generally rich in essential nutrients such as nitrogen, phosphorus and potassium, which promote resistance and rapid growth of plants. However, the excessive and inappropriate use of chemical fertilizers can have harmful effects on the environment, such as soil pollution and ground and surface water pollution, as well as risks to human and animal health (Gala et al., 2007).

Given producers' low incomes and the high cost of fertilizers, the amount of fertilizer used by farmers in general, is insufficient for many socio-economic reasons. And according environmental and economic concerns to sustain Agricole sector, fertilization use has become a promising alternative for many farmers. Organic fertilization involves using natural improvers such as compost, plant and animal waste to fix, enrich soil fertility by inputted necessary nutrients and improved its structure. In addition to its ecological benefits, organic fertilization is also known to improve in long-term soil fertility and promote more sustainable agriculture. Then, agriculture, a fundamental pillar of Senegal's development policy, is characterized by a production of cash crops, generally groundnuts and subsistence food crops (rice, millet, maize, sorghum) (ANSD, 2023). It is a key sector of the national economy, contributing around 3.75% of Senegal's GDP (ANSD, 2024).

The region of Kaolack, is an agricultural area located in the groundnut basin. Agricultural productivity in this region is highly dependent on soil fertility. This is limited by many factors such as erosion, soil degradation, salinization and climate change. Fertilization is a key component in improving soil fertility and increasing crop yields. As a result, soil fertilization methods such as mineral fertilization (chemical fertilizers), organic fertilization (compost, manure, slurry, etc.), organo-mineral fertilization and soil regeneration techniques (fallow, Assisted Natural Regeneration, crop rotation, etc.) can be used to regenerate and restore soil fertility, to increase yields and incomes of all stakeholders of agricultural sector.

It is in this context, that there is a particular need to evaluate the different methods of soil fertilization in the region of Kaolack in order to analyze their effectiveness in agricultural sector and in related activities.

Literature review

Soil fertility can be defined as "the natural, sustainable ability of a soil to produce plants" according to Prof. Ernst Klapp, 1960 and can be affected by climate changes. Fertilization therefore involves improving the soil's ability to provide plants with what they need for good growth and better yields (Akanza et al., 2016; Botoni et al., 2010). Agronomy specialists characterize soil fertility in terms of a multitude physical, chemical and biological parameters (Tounkara et al., 2022).

Indeed, farmers can boost production by using mineral fertilizers, organic fertilizers or organo-mineral fertilizers (Girard et al., 2005).

Organic fertilization, also known as organic fertilizer, refers to the use of organic matter to enrich the soil with essential plant nutrients. Organic matter consists mainly of manure, crop residues, green manures, compost, etc. (Asdrubal et al., 2006; Etter, 2017). It's aims to maintain and improve the soil's stock of organic matter (Alui et al., 2022). Furthermore, the addition of organic matter does not only restore soil fertility, but also provides the plant with the elements it needs for growth by increasing the capacity of the clay-humus complex to store nutrients (Guindo et al., 2024).

Mineral or chemical fertilization is the supply of mineral

Table 1. Characteristics of the sample

Departments	Communes	Villages	Numbers of farmers
Kaolack	5	11	73
Nioro	2	2	9
Guinguineo	2	2	10
Total	9	15	92

Table 2. Number of people in the sample by gender and age group

Gender (Age)	Men	Women	Total
[30 to 50 Years]	26.1%	12.0%	38.0%
[Overs 50 Years [	56.5%	5.4%	62.0%
Total	82.6%	17.4%	100%

Source: DRDR Kaolack, IFDC, 2023

elements to the plant and it is generally carried out through the use of mineral nitrogen fertilizers (NPK, urea, ammonium sulphate), phosphate fertilizers (rock phosphates,), potassium fertilizers (potassium chloride, potassium sulphate). It provides plants with essential nutrients quickly, which can be particularly useful in situations where soil nutrient levels are insufficient to meet crop needs (Abebe et al., 2022).

Fertilizers play a very important role in restoring and improving fertility, as well as in meeting the expectations of stakeholders (Kampelmann, 2016; CIRAD, 2020). Fertilizers make possible to improve the quality and quantity of agricultural products in order to meet direct and indirect needs of users (Collard, 2020).

METHODOLOGY

The methodology used to analyze the contribution of fertilizers to the circular economy concept is based on the processing of quantitative and qualitative data collected in the Kaolack region by IFDC through its project Dundel Suuf. Kaolack is a Sudano-Sahelian agricultural area, essentially flat land with three types of soil; leached ferruginous tropical soils, hydro-morphic soils and halo-morphic soils.

Data are collected by IFDC interns using a survey from Sphinx Plus2 V5 software and the sampling is a random sample created throughout the database of the host structure in Kaolack; the Rural Cooperative for Local Development of Sibassor.

For the sample size (n), the below Cochran's formula is used

$n = t^2 \times p \times (1 - p) / m^2$ where

t : Standard value of confidence level (95%)

t = 1.96

p : Estimated proportion of the population (farmers) with the characteristic

p = 60%.

m : Margin of error

m = 10%.

n : Sample size

n = 92 farmers

Areas of data collection are Kaolack department in eleven villages (73 farmers), Guinguineo department in two villages (10 farmers) and Nioro department in fifteen villages (92 farmers). And all data were collected during the raining season of 2023, Table 1.

Data analysis and interpretation

Characteristics of the sample

Among the 92 producers surveyed in the 15 villages, 82.6% are men against 17.4% women. In 82.6% of men, 56.5% of them have more than 50 years old and the rest between 30 and Years old. The number of women owning land is very low due to a number of socio-cultural factors, including the inheritance system and the status of women as well as socio-economic factors (low-level school and low-level income).Table 2.

In fact, 26.1% of producers practice agriculture and animal production simultaneously, compared with 73.9% of farmers. And 94.56% of producers produce for self-consumption and marketing to meet other needs, while 5.44% farm solely for self-consumption. This confirms that the area is an agricultural area (ANSD, 2023) and that family farming is more developed there. Because of the seasonal nature of farming activities, 21.74% of farmers carry out secondary activities, of which 9.78% traders within and outside Kaolack. Despite the large number of stakeholders and the potential of the agricultural sector, producers unanimously face a number of obstacles: declining soil fertility, access to land, financial difficulties, accessibility of agricultural equipment, delays and inadequacy of subsidized fertilizers and seeds, as well as salinization of the soil.

In terms of land ownership, 88% and 1.1% of farmers respectively inherited and borrowed their land, compared with 10.9% who did both. The average area held per farmer is 4.6 ha, with a minimum of 1 ha and a maximum of 23 ha.

Table 3. Soil fertility status

Land fertility	Farmers	%
Fertile lands	2	2.2
Medium fertile lands	10	10.9
Low fertile land	80	87%
High fertile land	0	0
Total	92	100

Avarage= 2.85 ; δ=0.42
Source: DRDR Kaolack, IFDC, 2023

Table 4. Different used fertilizers by crop

Crops	Chemical fertilizer	Chemical and organic fertilizers	Organic fertilizer	Organo-chemical fertilizer	Chemical and biological fertilizers
Groundnut	74%	-	-	1.08%	-
Millet	53.26%	4.34%	21.74%	4.34%	1.08%
Sorghum	1.08%	-	-	-	-

Source: DRDR Kaolack, IFDC, 2023

The main cash and food crops are groundnuts, tomatoes, bissap, chilli peppers, cowpeas, millet, maize, sorghum and okra on collective or individual farms (29.3% and 70.7% of farms respectively).

Characteristics of farms and fertilization

The results of the study show that 76.1% of producers have land in sandy soils, while another 20.7% have land in clayey-sandy soils, and 3.3% have only land in clayey soils. Furthermore, in terms of fertility, 87% of producers have fertile land, 10.9% medium-fertile land and 2.2% low-fertile land. And none of them have high-fertile land (Table 3). So, in order to improve their lands fertility, farmers use 4 different fertilization methods: mineral fertilization, organic fertilizers, organo-mineral fertilizers and organic fertilizers according to their income level.

Among them, 67.4% opted for mineral fertilization, 19.6% for organic fertilization, 4.3% for a combination of the two and 8.7% for organo-mineral fertilization and others, depending on the availability of organic matter to increase the quantity and quality of their products.

The type of fertilizer used varies according to the outlook and the crops grown. Indeed, 74% of producers use mineral fertilizer for groundnuts as a cash crop because of its high potentiality to improve groundnuts productivity (Chabi et al., 2021). The utilization of mineral fertilizers allows farmers to improve their productivity and quality of crops at farm level. This improvement, will increase simultaneously the quantity of produced pods and straw of peanut. Then all up and downstream activities of peanut sector will develop, such as, the distribution, the commercialization and transformation (artisanal and industrial for direct and indirect consumption). Mineral fertilizer is used by 53.26% of farmers for millet to ensure self-consumption in the face of growing dependence on imported rice. These high percentage use of mineral fertilizers can be explained by the government politic of distribution of subsidized chemical fertilizers to support producers. The weak rate of 1.08% for sorghum, is due to the fact that traditionally, farmers do not utilize fertilizers on it. 21.74% of farmers use organic fertilizers for millet, and there is a low percentage of organo-mineral fertilizer users (1.08% and 4.34% respectively) for groundnuts and millet for some financial reasons (Table 4). A small number of farmers combine mineral fertilization with organic fertilization for millet (1.08%). Some producers, namely 4.34%, use both mineral and organic fertilization on millet because of the scarcity of mineral fertilizer to improve the fertility of their soils. These low percentage of organic and mineral-organic fertilizers rely on organic matter inaccessibility and low income of user. Indeed, organic matter enable to sustain soil fertility, productivity and environment (Verma et al., 2020) while guaranteeing human, animal and environmental health.

Agro-economic performance of different fertilizers

Producers confirm an increase in yields, regardless of the type of fertilizer used. However, this increase in yield is below average (ANSD, 2023). For millet, the average yield is 1.2 tons/ha, for groundnuts 0.8 tons/ha and for sorghum 0.9 tons/ha. And since fertilizer is one of the factors for improving and increasing the quality and productivity of agricultural products, it will effectively enable the development of up and downstream activities of crop production (World Bank, 2015). This improvement in the value chain of the various agricultural sectors will boost the various activities related to agriculture (Callois et al., 2016), namely livestock farming, agro-industry, renewable energy

in the processing of agricultural products and the recovery of agricultural residues (Kampelmann, 2016).

In this context of climate change, which is accentuating the barriers to the development of agricultural sectors, research into the development of adopted fertilizer formulas (Tounkara et al., 2022) occupies an important place in development policies and programs (Callois et al., 2016).

In terms of collected data, financially, farmers confirmed that the use of fertilizer led to an increase in income. Applying fertilizer enabled 78.26% of farmers to increase their income. Then, they had created agricultural surplus after removing their self-consumption. The created agricultural surplus is very important for the development of related activities of agriculture (Diagana et al., 2008) the development of agricultural sectors, across innovations in research (Callois et al., 2016). 16.3% of them stabilized their income, meaning that fertilizers use allowed to maintain their income level. On the other hand, 5.44% of farmers who did not market their products recorded no change in their income.

This confirms, the strategic position that agriculture occupies in economic development as soon as an agricultural surplus is created (Pingault et al., 2016). In fact, it is the created agricultural surplus, obtained after deducting the portion intended for self-consumption, that will contribute to the emergence of other related activities or sectors.

Conclusion

The impact of climate change on crop production is devastating and deserves special attention from policies makers and researchers in order to implement adapted agricultural production development strategies to different agroecological areas. In addition, there must be accompanying measures to facilitate the adoption of the proposed solutions, the accessibility of fertilizers and the mastery of standards and application methods.

From collected data, most of farmers had low fertile soil; 87% of them and 78.26% conformed fertilizers allow them to increase the level of their income. Then, the mastery of soil fertilization techniques is essential to correct and improve soil fertility as well as, 0% and 2.2% of them have respectively high fertile land and fertile land. This mastery can enable farmers to achieve their expected results, i.e. high quality and high productivity in order to satisfy the expectations of the recipients; direct consumption and indirect consumption.

So, in order to improve agricultural production by a good sustainable management of soil fertility to boost all related activities of agricultural sector for a uniform growth, difficulties that are faced farmers must be resolved appropriately.

And difficulties are among others; a lack of application equipment, inaccessibility to fertilizers, the high cost of fertilizers, a lack of training and supervision, far distance from supply points, and slowness during the agricultural season.

Conflict of interests

The authors declare that they have no conflicting interests.

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