Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 18(3): 882-893, June 2024

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Multi-criteria analysis of adoption paths for fertiliser resource optimisation technologies

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ACKNOWLEDGMENTS

The authors would like to thank ISRA and the DESIRA FAIR Sahel project for agreeing to fund this study.

Received: 06-05-2024 Accepted: 25-06-2024 Published: 30-06-2024

ABSTRACT

Agriculture in the 21st century faces the challenge of finding the balance needed to mitigate the evolving constraints of climate change while continuing to perform its functions. In Senegal, agricultural sector policy has been adjusted to reduce the use of chemical fertilizers by 30%. This policy is in line with the path of agricultural intensification, through microdosing technology, recommended for farms with low financial capacity. However, beyond the control of fertilizing resources, microdosing technology incorporates costs such as extra workload, drudgery and know-how, which have a strong influence on the choice of adoption. Indeed, the acceptability of an innovation depends on two factors, namely perceived usefulness and ease of use. Before introducing a new technology, it is therefore necessary to study its suitability for users' adoption or rejection criteria. With this in mind, this study uses a multi-criteria evaluation approach to analyze the adoption pathways for fertilizer resource optimization technologies. The study was carried out on millet in the 2020 and 2021 rainy season, comparing microdosing with current farming practice and the practice popularized in the Senegal cotton basin. Analysis according to the criteria of usefulness (profitability and economic autonomy) and ease of use (arduousness and work time) revealed three major results. It showed that the common farming practice, although it has no constraints on use, is not profitable and does not enable producers to be self-sufficient. The analysis also showed that the extension practice is not arduous, does not consume much labour time, and is also profitable. However, in an environment without input subsidies (currently at 50% for fertilisers), this practice does not empower farmers. With this practice, the State will always be obliged to bear part of the cost of inputs to relieve producers who consume more resources than they produce. The practice of optimising resources, using only 40% of the recommended doses of manure and fertiliser through microdose technology, is profitable and enables producers to be self-sufficient even in an environment without subsidies. This technology therefore relieves the State of the cost of fertiliser subsidies over the long term, as it produces more than it consumes in inputs, with a moderately high cost in terms of labour time. This is the main constraint on the adoption of this high-performance fertiliser optimisation technology. Fertiliser optimisation technology could therefore be a lever to enable agriculture to find the balance needed to adapt to climate change while making a significant contribution to mitigating its effects. But first, it will be necessary to overcome the labour-intensive nature of manual microdosing technology, which will certainly need to be adapted for better use, after appropriate mechanisation.

Keywords : Multi-Criteria Evaluation, Profitability, Economic Autonomy, Arduousness, Work Time.

DOI : https://dx.doi.org/10.4314/ijbcs.v18i3.12

INTRODUCTION

Agriculture in the 21st century faces the challenge of finding the balance needed to mitigate the evolving constraints of climate change while continuing to perform its functions, in particular feeding the ever-growing human population (Paillard and al., 2010; Le Gal and al., 2015; Saj et al., 2018). Because of the poor management of chemical fertilisers in particular, agriculture is in fact co-responsible for this phenomenon, as it contributes 12% of the development of triggering factors (Saj et al., 2018). On the other hand, the effects of these factors are damaging the production base, especially in small economies such as the Sahel, where agriculture is mainly rain-fed (Vodounou and Onibon Doubogan, 2016; Saj and al., 2018). To improve this balance, the international community has emphasised the use of environmentally friendly agricultural practices, including the reduction of synthetic chemical fertilisers and the use of organic fertilisers (Bureau Opérationnel de Suivi du PSE, 2021).

In Senegal, sectoral agricultural policy has been adjusted in view at adopting more environmentally-friendly soil fertility management strategies based on reducing the use of chemical fertilisers by 30% by 2030 (Bureau Opérationnel de Suivi du PSE, 2021). This fertiliser reduction policy is in line with the path of agricultural intensification, through microdosing technology, recommended by ICRISAT for farms with low financial capacity (Aune and al., 2020). Microdosing technology consists of applying small quantities of mineral fertiliser and organic fertiliser in small quantities to the crop to further improve yields while reducing input costs (Saba et al., 2019; Aune et al., 2020). By way of illustration, the best input for millet cultivation is a combination of mineral and organic fertilisation at doses of around 27 kg/ha DAP or 80 kg/ha NPK (15-15-15) and 2 t/ha manure, i.e. around 40% of the recommended doses (Sime and Aune, 2014; Aune et al., 2020).

However, over and above the control of fertiliser resources and yields, microdosing technology incorporates social costs such as extra workload, drudgery and know-how, which have a major influence on the choice of technology adoption. The acceptability of an innovation depends on two factors: perceived usefulness and perceived ease of use (Sime and Aune, 2014).

Consequently, before introducing a new cropping habit and/or strategy in a rural environment, it would be necessary to first study whether it meets the criteria for adoption or rejection by farmers. This is an innovative approach to the use of microdosing in the Sahel. As in the recent studies by Sime and Aune (2014), Sissoko et al. (2019), and the scientific evidence on the conditions for adoption of microdosing does focus on socio-economic characteristics, but it is most often measured by structural probability models rather than by the farmers' own interpretation and lasting appreciation of the system.

In order to take this important aspect into account, with a view to making better use of the performances described for this technology, this study seeks to co-assess the socio-economic sustainability criteria with a view to shedding light on the adoption pathways.

MATERIALS AND METHODS

Study area

The study was conducted in the dry zone of Senegal's cotton basin, which covers 46% of the country and accounts for 27% of the population, with a population growth rate of 2.7% (Ndour and al., 2018; Ba and al., 2015). The climate follows a north-south rainfall gradient of 700 to 1,200 mm (Ba and al., 2015). This basin is an agricultural area in the broadest sense. Indeed, 50-80% of household income comes from cropping systems and 10-50% from livestock farming (Goulé et al., 2008; Sene and Mbaye, 2019).

The communes of Koussanar and Ndoga Babacar in the department of Tambacounda have more than 25 years' experience of organic farming, including sustainable fertility management practices (Ferrigno and al., 2005). In view of this potential, these communes were chosen to conduct this study in view at having a relevant farming practice there to serve as a reference for assessing the socio-economic performance of microdosing technology.

Conceptual framework

The concept of multi-criteria evaluation is described as a decision-making tool that enables several alternatives to be ranked in order of preference on the basis of several criteria that may have different units (Zopounidis and Doumpos, 2002; Auberger et al., 2016; Damoiseaux, 2020). Multicriteria analysis is thus seen as a powerful approach for evaluating the performance of innovations and user perceptions. It is in this sense that multicriteria analysis is perceived and chosen by this study as a decision-making tool with a view to highlighting the economic performance and farmers' perception of the use of microdosing (Zopounidis and Doumpos, 2002; Craheix and al., 2012; Auberger et al., 2016; Damoiseaux, 2020).

System and scale of analysis

The evaluation applies to the rainfed millet production system, whose main function is grain production, measured in hectare units. This system covers the entire production process, from land preparation to millet harvesting.

The inputs evaluated consist mainly of practices contributing to soil fertility management, in particular mineral fertilisers (NPK, urea), organic matter (manure) and labour time. As for the outputs measured, they concern the effects linked to the socio-economic performance of these practices.

The measurements were carried out jointly at plot level for the different scenarios studied. The choice of millet was motivated by the fact that it is the leading food crop in Senegal in terms of area sown and the main crop in rotation with other crops such as groundnuts (Ba and al., 2015).

Different scenarios to be evaluated

Microdosing technology is evaluated in comparison with common farming practice and the intensification practice recommended by research (Figure 1). The dosage is inspired by farmers' practice and the work of (Sime and Aune, 2014) and (Ibrahim et al., 2015) which represents around 40% of what is recommended by research in the Sahel (Figure 2).

The evaluation was carried out in a participatory manner in the farmers' environment in the form of a common field (2021 and 2022 wintering seasons) with an experimental set-up in randomised blocks repeated three times. To make it easier to assess the different scenarios, satellite trials were set up in ten blocks scattered among ten farmers in three villages (Photo 1).

Choice of evaluation criteria and indicators

The determinants of strategic farm choices highlighted in the context section, namely ease of use (social) and usefulness (economic), are part of a dynamic logic. To master them, it is essential to have a clear understanding of the social and economic frameworks that encompass them in a given environmental context. This triptych forms the pillars of the concept of sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(Lairez et al., 2016). This global frame of reference is accompanied by a sectoral vision of agriculture, in this case agro-ecology, focusing in particular on reducing tillage and saving water and chemical inputs (Griffon, 2013; Meynard, 2017).

The study is in line with this sectoral vision of sustainable development, based on the optimisation of resources along a multitude of dimensions, with a view to being able to rely on relevant criteria to inform economic performance and producers' perceptions. To this end, the study referred to criteria established by Ccraheix et al. (2012) to assess the sustainability of economic results and producer satisfaction. To this end, profitability and autonomy were used to provide information on economic performance. Profitability is assessed using the semi-net margin indicator, while autonomy is indicated by resource use efficiency and independence from fertiliser subsidies using ratios.

Producer satisfaction was assessed using indicators to guide the cost/benefit judgement. These included an assessment of the time spent working in relation to the results obtained, in order to determine the growers' perception of the extra work they had to do. In addition, the perceived difficulty of transport and application was assessed in relation to the agronomic results.

Calculation and evaluation of indicators

Quality of working conditions: arduousness and work overload

Qualitative and quantitative co-evaluations were carried out to assess the social indicators. Firstly, the qualitative assessment was carried out by means of observations and discussions on the behaviour of the scenarios in terms of drudgery and working time in relation to the agronomic advantages induced in the climatic context. To this end, an evaluation workshop was organised in the field in plenary session, where three groups of five growers toured the experimental plots to assess the different scenarios. These plot tours were completed by feedback sessions followed by plenary discussions to gather the different perceptions. Secondly, the quantitative assessment was carried out by means of ratings on a high, medium and low scale. After the qualitative phase, the producers voted on the ratings for each scenario (Photo 2).

Economic performance: profitability and economic autonomy

The economic indicators were calculated using the gross values obtained from the field evaluation, i.e. production, costs and subsidies for each cropping system. In order to harmonise the methods of assessment with the social dimension, the quantitative values of the indicators were discretised into qualitative types according to the high, medium and low scale rating. To do this, the semi-net margin indicator was assessed with reference to the performance achieved (133,204 FCFA/ha) in 2015 by the millet project in Fatick, Kaolack and Kaffrine as part of the development of Senegal's cereal corridors under US funding (Dia, 2016). This was achieved with a yield of 1.005 t/ha, representing a 57% increase in productivity. The indicators were assessed according to the classification established by Sester et al. (2012), i.e. a "low" value corresponds to less than 66% of the reference (i.e. 1/3 below the reference) and a "high" value to more than 133% (1/3 above the reference).

Aggregation of indicators

The indicators for each criterion were associated step by step using the decision rule method based on qualitative "if-then" reasoning such as: if "criterion 1 very weak" and if "criterion 2 is weak to medium" then "aggregate criterion is very weak" (Craheix et al., 2012).

Evaluation method and tools used

The criteria targeted by the study have already been developed and aggregated to provide information on sustainability using existing assessment methods such as MASC (Multi Attribute tool for the assessment of the Sustainability of Cropping system). The superiority of the latter has been demonstrated by a classification made, in France, of more than eight models according to criteria such as: (i) the scale of assessment (plot, farm, region); (ii) the audience concerned (farmers, advisors, researchers, decision-makers); (v) the possibility of aggregating indicators to arrive at a ranking of cropping systems (Colomb et al., 2010).

In line with the MASC, the study therefore used this powerful method for socio-economic assessments, relying on its tools such as the:

- CRITER, for calculating economic indicators;
- DEXI, for aggregating indicators and criteria.

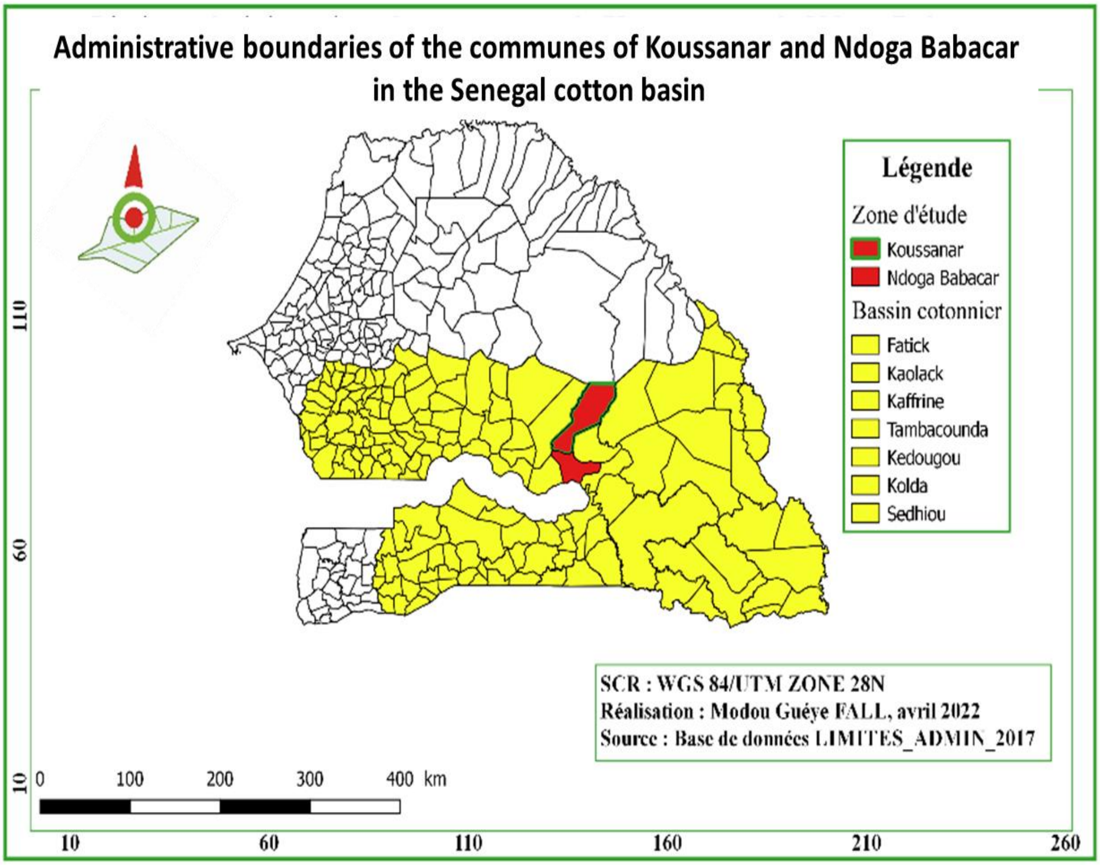

Figure 1. Map of the communes of Koussanar and Ndoga Babacar

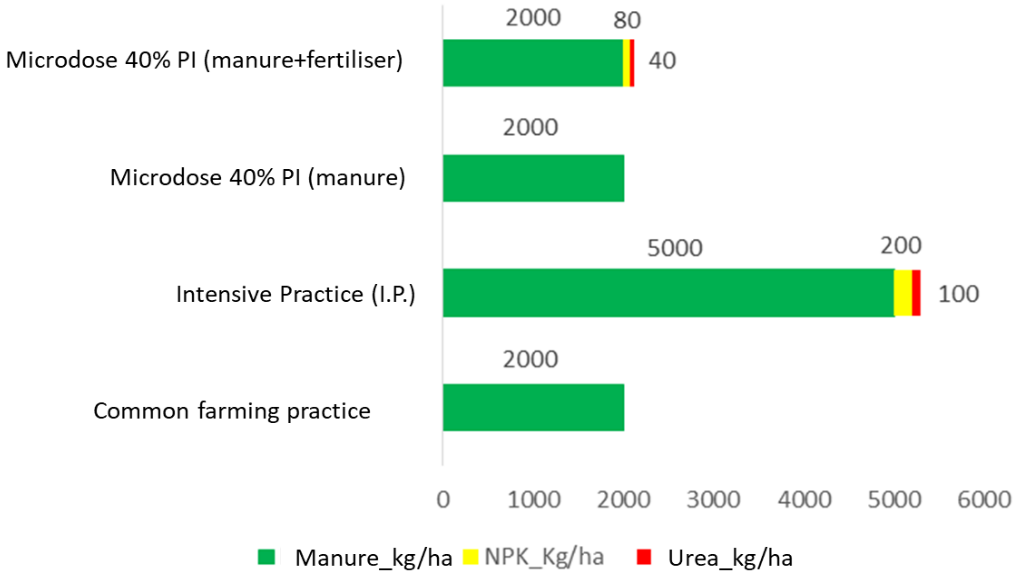

Figure 2: Different scenarios assessed.

Photo 1: Satellite trials installed and monitored by growers.

Photo 2: Tour of plots and voting according to established criteria.

RESULTS

Economic performance: profitability and economic autonomy

The combined application of microdose manure and mineral fertilizers has a very high economic performance. This performance is supported by very high profitability and economic autonomy, with real market prices without input subsidies, from medium to high. On the other hand, this performance is only high in the case of extension practice because of the low to medium level of economic self-sufficiency (Figure 3). The common farming practice and the simple application of microdoses of manure have very poor economic performances.

Quality of working conditions: drudgery and work overload

Extension practice is perceived in the same way as common farming practice. Farmers consider the drudgery and time required for these technologies to be low (Figure 4). On the other hand, combined or simple microdosing is perceived by farmers as being moderately demanding in terms of working time, but the arduousness is judged to be high.

Farmers' perception of the costs/benefits of technologies

Farmers' perceptions of the costs/benefits of the different scenarios are shown in figures 5, 6 and 7. Compared with constraints linked to fertilizer costs and the arduous task of transporting manure, the benefits derived from the extension practice and the technology of microdosing mineral fertilizers and manure are judged to be good by the majority of farmers. For common farming practice and manure microdosing alone, however, the benefits are rated as average overall. Compared with constraints linked to work time, the advantages of microdosing technology are judged to be average by the majority of farmers. On the other hand, the majority of farmers consider these advantages to be good for both common farming and extension practices.

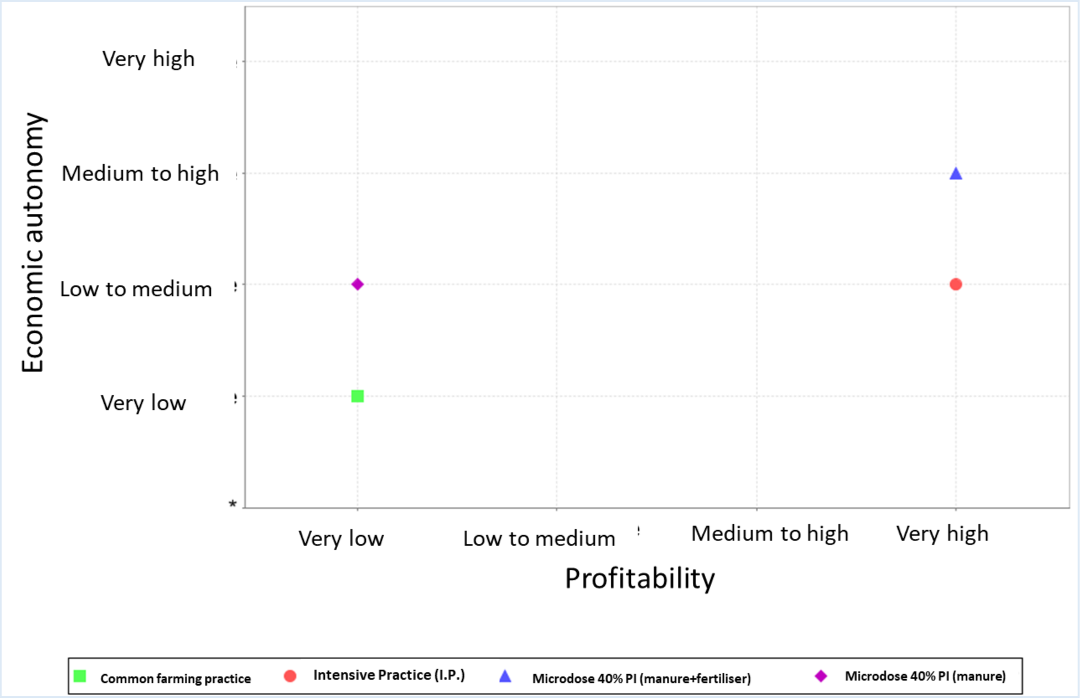

Figure 3: economic performance.

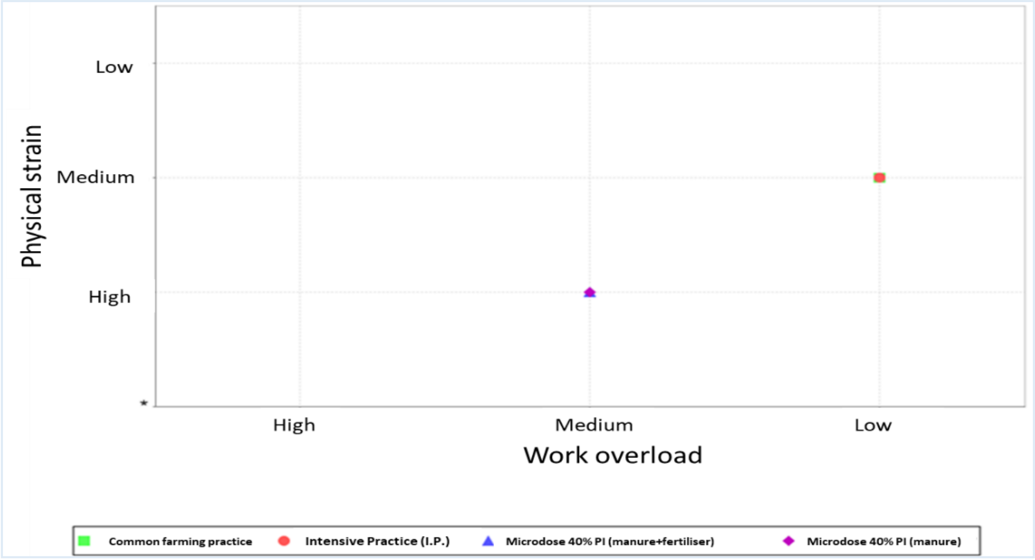

Figure 4: Quality of working conditions.

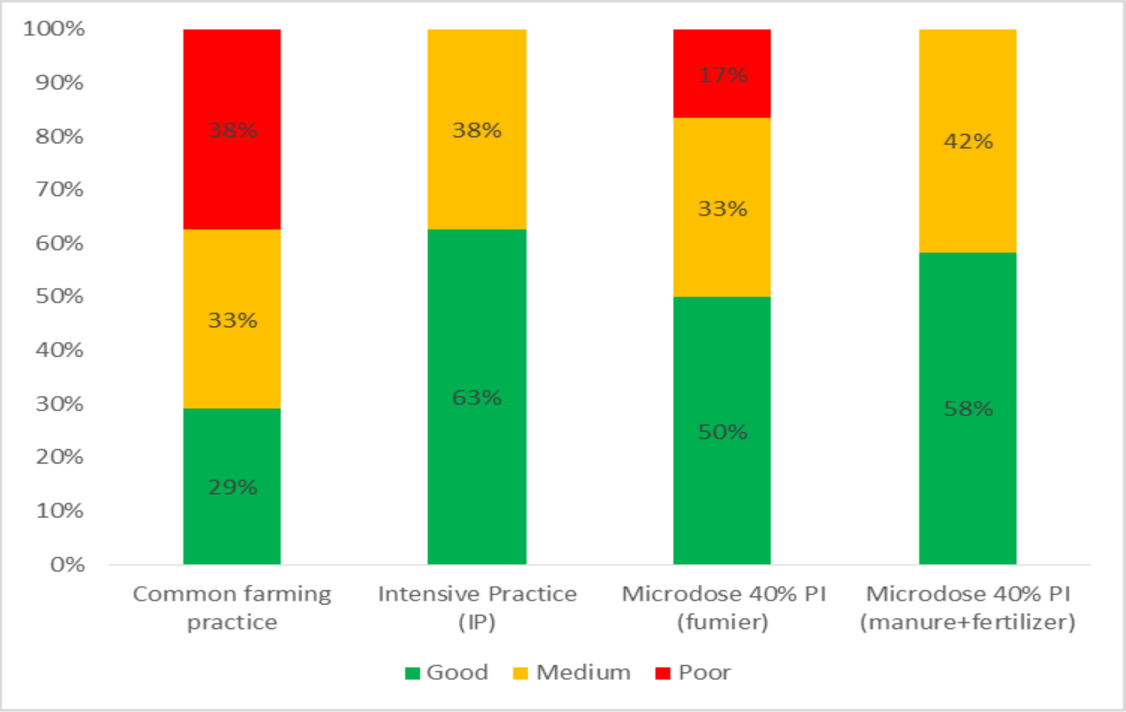

Figure 5 : Perception of the yield obtained in relation to the cost of mineral fertilizers.

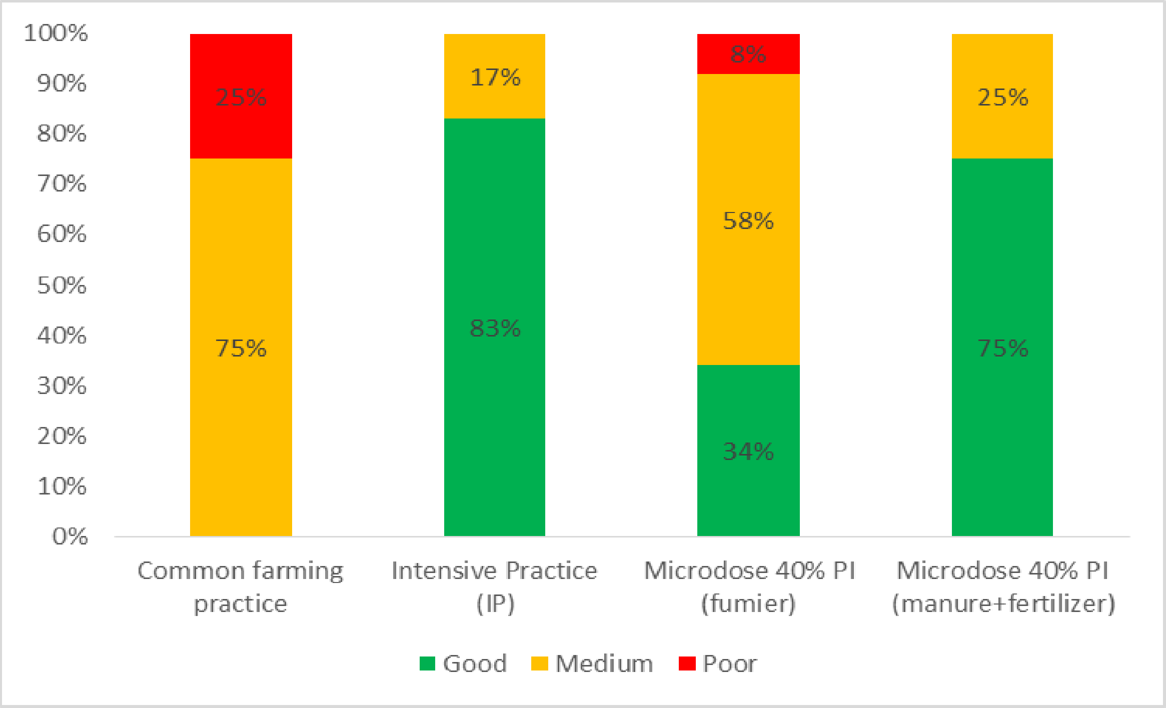

Figure 6: Perception of the yield obtained with regard to the difficulty of transporting organic matter.

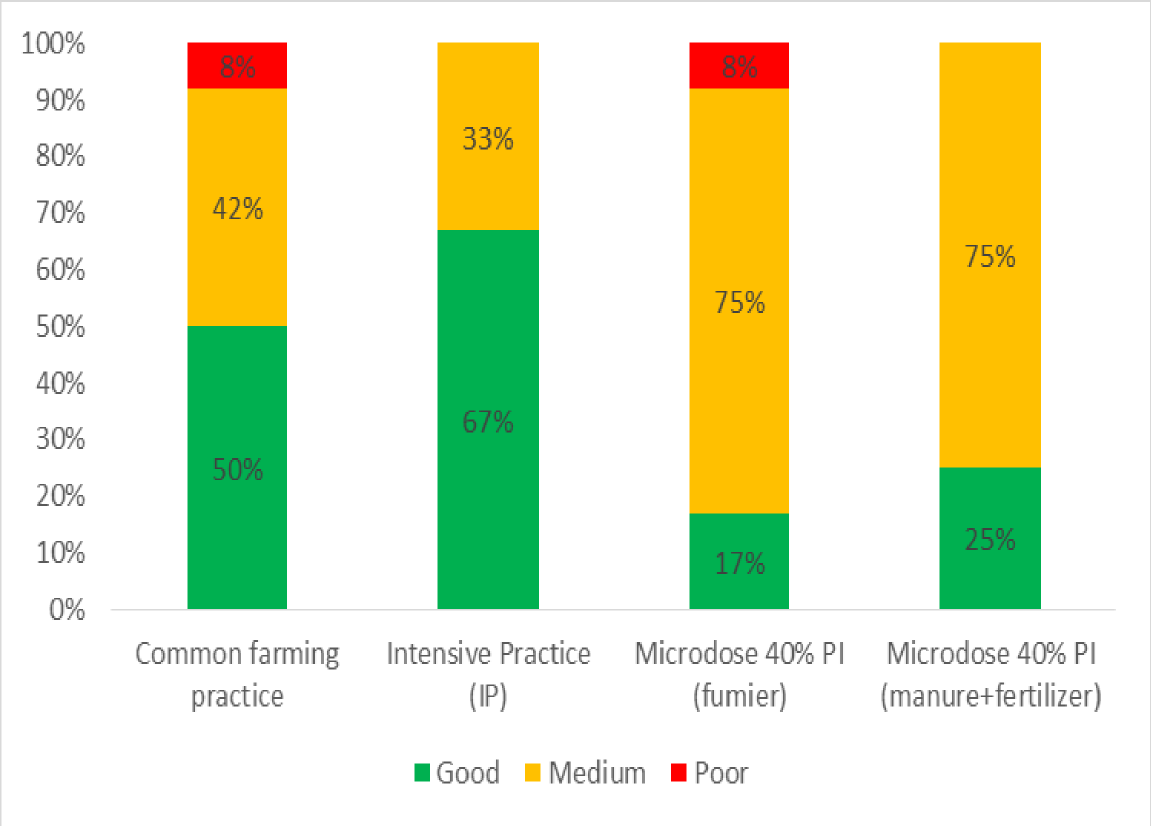

Figure 7: Perception of performance in relation to work time.

DISCUSSION

This multi-criteria evaluation study of the optimisation of fertiliser resources revealed that the common farming practice of soil fertility management is not effective. Using microdose technology, however, it is possible to reduce inputs (fertiliser and manure) by 60%, while achieving higher economic performance than 100% use in a non-subsidised environment.

However, for this input reduction technology, the drudgery is high for producers, even though it is considered to be moderately demanding in terms of working time. The economic performance of microdosing technology is confirmed by Sime and Aune (2014), who consider that benefit-cost ratios could be as high as 7 or even 11, an ideal level for reducing investment costs, especially for small-scale, risk-averse growers. Also, Sigue et al (2019) find that microdosing has a positive and significant effect on the economic performance of production. On the other hand, regarding the conclusions of Sissoko et al. (2019) and Sigue et al. (2018) on the social constraints of adoption, these are much more related to the arduousness of use than to working time and/or the availability of labour. Thus, despite its economic performance, this technology will only significantly satisfy growers if the arduousness of use is considerably reduced.

According to the technology acceptance model developed by Davis in 1986, the acceptability of an innovation depends on two factors, namely perceived usefulness and perceived ease of use (Atarodi and al., 2019). In this case, although utility is well perceived, ease of use is poorly perceived by producers. In order to make the technology acceptable to adopters in such a situation, Davis suggests identifying the changes that need to be made to reduce the difficulty of use. In fact, in the Sahel, agricultural activities are already arduous, with 65% of agricultural energy supplied by humans, compared with only 25% in other developing countries (Clarke and Bishop, 2002). Thus, any additional hardship is likely to be a factor of rejection, even if the utility is high.

In line with the Davis model, Mazoyer proposes the use of mechanisation to reduce the drudgery of work while improving gross labour productivity (Mazoyer and Roudart, 2009).

Supported by Davis's model and Mazoyer's conclusions, the main lesson to be drawn from the results is that if the high-performance microdosing technology is to be put to better use, it must be accompanied by an appropriate form of mechanisation to facilitate its use by growers who are already overwhelmed by arduous tasks (Balse and al., 2015).

Conclusion

Against this backdrop of climate change, this study has shown that the technology of optimizing fertilizer resources through the microdosing of fertilizers and manure is an intelligent practice that can both reduce the use of chemical inputs, a triggering factor, by 60%, while improving the productivity and sustainable competitiveness of cropping systems. In fact, it ensures crop profitability and promotes the economic empowerment of farmers, even without subsidies. It is therefore a useful technology for producers. However, the adoption of this technology is limited by the arduous nature of its use. This is mainly due to the manual nature of the application. To facilitate the adoption and scaling-up of this microdosing technology, it would be worthwhile to overcome this difficulty, certainly by switching from manual application to appropriate mechanization.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

MGF took part in developing the research protocol, investigation, data curation and analysis, and writing the document. KT participated in protocol development, data curation, proofreading and document validation. NHD-D participated in protocol development and proofreading. MS participated in supervision and proofreading. LD participated in supervision and proofreading. SN participated in document validation.

ACKNOWLEDGMENTS

The authors would like to thank ISRA and the DESIRA FAIR Sahel project for agreeing to fund this study; The NGO ENDA pronat for mobilising producers..

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