Agricultural Sciences, 2024, 15, 704-718
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Perception of the Mechanization of Rice Cultivation and Its Effects on the Soil in the Senegal River Valley

Cheick Atab Mane[1,2], Siré Diedhiou[2*], Arfang Ousmane Kémo Goudiaby[2], Mohamed Sall[3], Guillaume Gillet[4]

[1]Machinery and Renewable Energy Department, University of Sine Saloum El Hadji Ibrahima NIASS, Kaolack, Senegal
[2]Agroforestry Department, Assane Seck University, Ziguinchor, Senegal
[3]Department of Agronomy, Vegetable Production, University of Sine Saloum El Hadji Ibrahima NIASS, Kaolack, Senegal
[4]National Training School for Agricultural Education, Toulouse, France
Email: *sdiedhiou@univ-zig.sn

How to cite this paper: Mane, C.A., Diedhiou, S., Goudiaby, A.O.K., Sall, M. and Gillet, G. (2024) Perception of the Mechanization of Rice Cultivation and Its Effects on the Soil in the Senegal River Valley. *Agricultural Sciences*, **15**, 704-718.
https://doi.org/10.4236/as.2024.156038

Received: April 1, 2024
Accepted: June 22, 2024
Published: June 25, 2024

Abstract

In Senegal, particularly in the Senegal River valley, agricultural mechanization remains limited, mainly due to a lack of agricultural equipment, a lack of expertise in agricultural machinery and an apprehension of the consequences on soil quality. To better understand agricultural mechanization of rice cultivation, this survey study has been carried out in the Senegal river valley. Precisely, this work aimed to characterize farm machinery and its effects on soil and rice cultivation. A questionnaire was administered to 304 out of 1270 farmers, spread over 8 rice-growing areas, 4 of which are located in the Podor department, three in Dagana and one in Saint-Louis. The results showed that 99.3% of farmers used motorized equipment, with 95.7% using tractor and 3.6% a power tiller. Offset tillage, which is a shallow cultivation practice carried out to break up hard soil without turning it over, was most widespread among growers (95.4%). 78.3% of the valley's farmers felt that the machinery used to carry out tillage operations was inefficient. According to the farmers, the main constraints on the use of agricultural machinery in the valley were: the upkeep and maintenance of equipment (57%), the lack of expertise in mechanization (31%), and issues adapting machinery to local conditions (12%). Those constraints have contributed to a drop in yields in recent years, the spread of weeds on cultivated plots and the gradual degradation of the soil in the area according to 78% of farmers.

Keywords

Agricultural Mechanization, Characterization, Constraints, Soil, Rice

1. Introduction

In Senegal, agriculture is considered a driving force behind economic development. The agricultural sector employs around 30.6% of the working population. In 2018, this sector was characterized by the good performance of certain crops such as millet, groundnuts and rice, according to the National Agency for Statistics and Demography [1]. Agricultural GDP was estimated at CFAF 1217 billion in 2018, up 9.1% on 2017 [1]. Nevertheless, Senegalese agriculture's share of GDP remains low, averaging 8.68% [2]. However, despite sustained growth in recent years, the agricultural sector is encountering difficulties linked to, a lack of agricultural equipment, a lack of expertise in agricultural mechanization, progressive soil degradation, climatic variability, poor or non-existent water management in lowland rice-growing areas, persistently high post-harvest losses, galloping population growth, increased food demand, etc. [2]. Agricultural mechanization policy with plans and programs aimed at overcoming these constraints has been implemented since 1960 to make agriculture efficient and self-sufficient [3]. According to the [4], agricultural mechanization in Africa is still in its early stages called "energy substitution", which consists of replacing animal energy with the energy of internal combustion engines or electric motors for agricultural machinery. This mechanization ensures that energy-intensive and often arduous tasks such as tilling the soil and milling grain are carried out, requiring sufficiently powerful equipment and tools [4]. Mechanization should therefore make it possible to increase the size of sown areas and crop yields [5]. However, the development of mechanization, with the emergence of increasingly heavy machinery, could accentuate the degradation of agricultural soils with soil compaction causing erosion, a depletion of organic matter and ultimately a decline in soil fertility [6]. After more than a decade of motorization in the Senegal River valley, the problem of power optimization from the tractor-accessories combination remains unresolved. In the Senegal valley, and particularly on rice-growing plots, the problems associated with the use of agricultural equipment is particularly acute as it is part of an agroecological transition perspective [7]. However, farm mechanization needs to be well thought out and adapted to agroecological practices if rice production is to be improved sustainably and efficiently. It is therefore essential to study rice-growing mechanization in the valley. The aim of this study was to characterize the machinery used for tillage and its impact on the soil and rice production in the Senegal River valley.

2. Materials and Methods

2.1. Presentation of the Study Area

The study was conducted in northern Senegal, in the Senegal River valley, specifically in the three departments of the Saint-Louis region: Saint-Louis, Dagana and Podor (**Figure 1**). The area is characterized by irrigated rice cultivation. The valley has great agricultural potential, with rice being grown over two periods:

the winter season and the off-season with hydro-agricultural settings. The climate is arid Sahelian, characterized by hot, dry continental trade winds or Harmattan and maritime trade winds to the west [8]. The continental zone has high temperatures almost all year round, sometimes exceeding 40˚C in the department of Podor. However, the softening influence of the sea to the west is favorable for market gardening [9]. The dry season is marked by the Harmattan, a hot, dry, dust-laden wind [10].

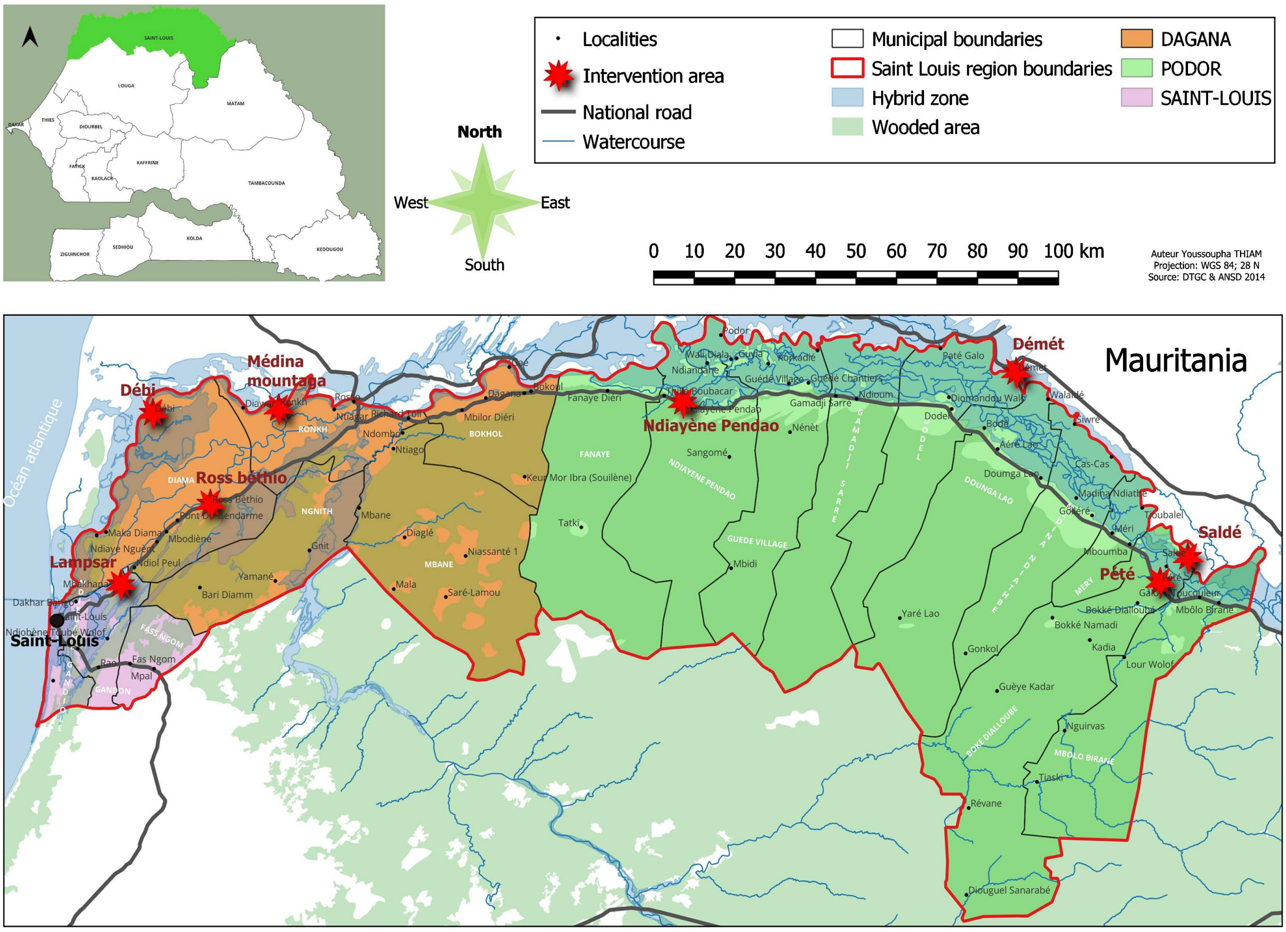

Figure 1. Geographical location of the Saint-Louis Region.

Rainfall is fairly low, 330 mm·yr^{-1}, and occurs from mid-July to mid-October with high temperatures and intense evaporation (**Figure 2**) [11] [12]. The Senegal River valley present 4 main types of soil. The Hollaldé soils (chromic vertisols) represent 36% of irrigable potential; these soils are favorable for rice growing, but are difficult to till due to their high clay content (50% to 75%) and poor drainage. The False-hollaldé soils (eutric fluvisols) represent 31% of irrigable potential; these soils are favorable for rice growing and other crops; they contain 30% to 50% of clay, have no structure with a poor drainage. The fondés soils (Eutric fluvisols) account for 33% of irrigable potential and are suitable for all crops except rice; these silty-clay soils have a clay content of 10% to 30% and a moderate drainage. The Diéri soils (eutric regosols) contain 80% to 90% sandy deposits, these soils can support all crops other than rice [10].

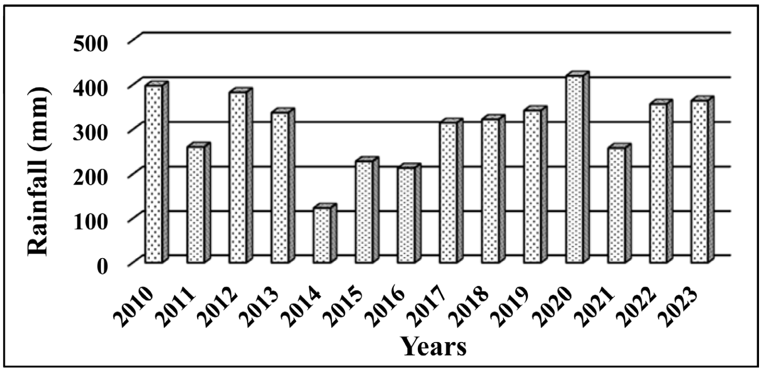

Figure 2. Mean annual rainfall between 1961 and 2017, Source: [13].

The vegetation of the valley depends essentially on the type of soil, the water available and the topography [14]. Several species are found from the south to the north of the Senegal River valley: *Sterculia setigera Del*, *Combretum glutinosum Perr. Ex DC*, *Sclerocarya birrea A. Rich. Rich*, *Boscia senegalensis Pers*, *Acacia Sénégal* (L.) *Wild*, *Cenchrus biflorus Roxd*, *Euphorbia balsamifera Ait*, *Commiphora africana (A. Rich.) Endl*, *Acacia nilotica* (L.) *Wild. Ex Delile*, *Mimosa pigra* (L.), *Echinochloa colona* (L.) *Link and Aeschynomene* ssp. (L.) [15].

2.2. Method

Field Surveys

1) Choice of sites

The study area was chosen because of the importance of rice cultivation, the organization of producers into unions or MSEs and their experience over the last two decades in using motorized machinery for tillage operations. Eight rice-growing areas were targeted in this study: 4 in Podor (Mca Dental Ngallenka, Pete, Ndormboss 1 PIV, Cuvette Salde Ouallah), 3 in Dagana (Debi/Tiguet, Amen. de Louge Demisse, Périmètre 3PRD) and 1 in Saint-Louis (Cuvette Lampsar). These areas were selected on the basis of the following criteria: functionality, availability of agricultural equipment, area sown and rice production performance.

2) Sampling frame, sampling and distribution of respondents

The ANSD database on the distribution of the Senegalese population by administrative region and the rice producer monitoring file supplied by the Company for the development and exploitation of the Senegal River delta (SAED) were used to select the producers to be surveyed in each of the 8 rice-growing areas in the 3 communes. The producers targeted own a plot of land developed by the SAED. In total, 1270 rice growers were identified in the 3 communes.

Simple random sampling was carried out, and the sample obtained was distributed over the 8 rice-growing areas. In each of the 8 rice-growing areas, the sample size, *i.e.* the number of producers surveyed, was determined on the basis of the total number of rice producers in the area using Fisher's (2012) formula as described in Equation (1).

$$nf = \frac{n}{\left(1 + \frac{n}{N}\right)} \quad (1)$$

With $n = 1/d2$;

nf = sample size;

d = degree of error = 5%;

N = total number of Producers.

In this study, a margin of error of $\varepsilon = 5\%$ was used to calculate the sample size.

Application: $n = 1/(0.05)^2 = 400$ donc $nf = 400/(1 + 400/1270) = 304.19 \approx 304$.

This method produced a sample of 304 producers to be surveyed. The rice-growing perimeters in the study area had the same number of producers, which explains the equal distribution of the individuals surveyed (**Table 1**).

Table 1. Breakdown of farmers surveyed by rice-growing area.

Region	Delegation	Department	Perimeter	Producers
Saint-Louis	Podor	Podor	Mca Dental Ngallenka	38
			Pete	38
			Ndormboss 1 PIV	38
			Cuvette Salde Ouallah	38
	Dagana	Dagana	Debi/Tiguet	38
			Amen. from Louge Demisse	38
			Périmètre 3PRD	38
		Saint-Louis	Cuvette Lampsar	38

3) Socio-economic survey tools

The surveys were carried out using a questionnaire containing both closed-ended and open-ended questions. The questionnaire covered: 1) the identification of producers; 2) production techniques and areas sown; 3) machinery used; and iv) the effects of mechanization and production techniques on the soil. The questionnaire was administered to 304 farmers in the eight rice-growing areas of the study zone.

3. Statistical Analysis of Data

The data collected was analyzed using SPSS software version 28.0.1.0. The statistical data obtained was then exported to an Excel spreadsheet for graphing.

4. Results

4.1. Types of Mechanization

The analysis shows that 99.3% of farmers in the valley carry out tillage before sowing (Figure 3(a)). Motorized equipment is the type of mechanization most used for tilling soil for 99.3% of farmers (Figure 3(b)), 95.7% of whom use tractors compared with 3.6% who use motor cultivators (Figure 3(c)).

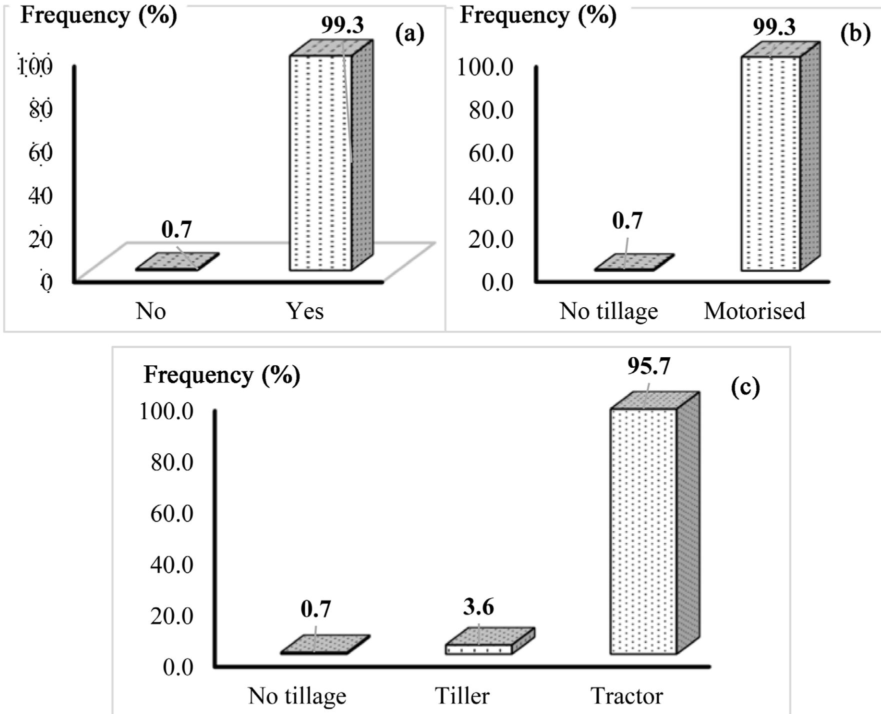

Figure 3. Tillage operations (a), Type of farm mechanization (b) and Type of motorized equipment (c).

4.2. Growers' Perception of Operations, Equipment and the Importance of Tillage

4.2.1. Farmers' Perception of Tillage Operations and Equipment

Several tillage operations are carried out in the Senegal River valley. 95.4% of rice growers in the valley carry out offset tillage, which is a superficial operation without turning over the soil, using a disc sprayer commonly known as an offset tiller, compared with 3.6% who carry out ploughing, which is a deep operation which turns over the soil, using disc ploughs for 2.6% of respondents and ploughshares for 1% (Figure 4). Only 0.3% of growers prepare the seedbed for sowing, which involves levelling with tools such as cultivators and rollers to promote soil-seed contact.

4.2.2. Farmers' Perception of the Frequency of Tillage Operations

82% of the growers surveyed carry out offsetting before sowing several times a year, compared with 6% who carry out offsetting once a year (Figure 5). As for ploughing, 5% of farmers do so every year, compared with 1% who plough their plots every two years. On the other hand, 6% of growers only prepare the seedbed before planting the crop.

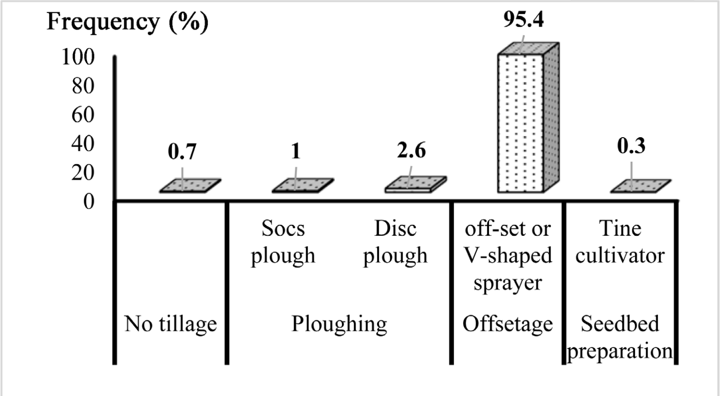

Figure 4. Tillage operations and equipment.

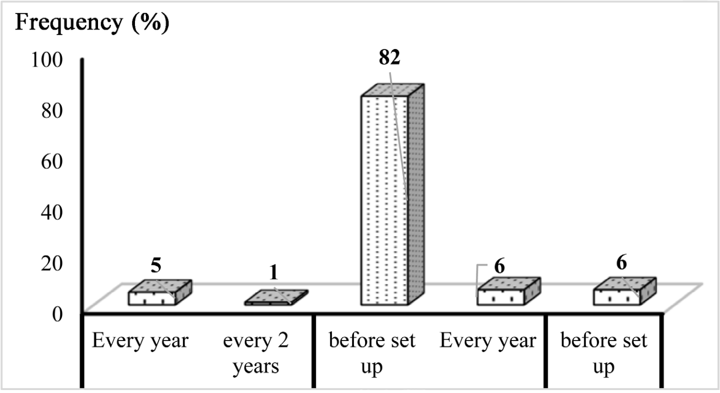

Figure 5. Frequency of tillage operations.

4.2.3. Producers' Perception of the Importance of Tillage

In the Saint-Louis region, 44% of the farmers surveyed thought that tillage improved the seedbed, compared with 26% who thought that tillage increased rice yields. In addition, 18% thought that tillage improved soil fertility and 9% believed that tillage was an effective way of controlling weeds. Only 3% of respondents thought that tillage was important because it loosens the soil (**Figure 6**).

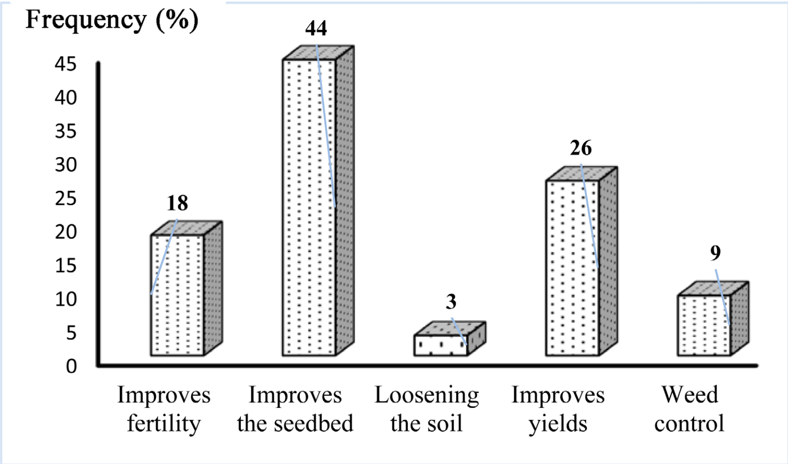

Figure 6. Importance of tillage on rice cultivation.

4.3. Effect of Farm Machinery Use on the Quality of Tillage

4.3.1. Producers' Perception of the Field Performance of Agricultural Machinery

Analysis of Figure 7 shows that 78.3% of farmers in the valley consider that the machinery used to carry out cultivation operations is not efficient and therefore does not perform well. On the other hand, 21% of those surveyed felt that the machinery performed well. The constraints identified, including the lack of expertise and the problems of adapting and maintaining the machines, could explain the low performance of the machines in the field.

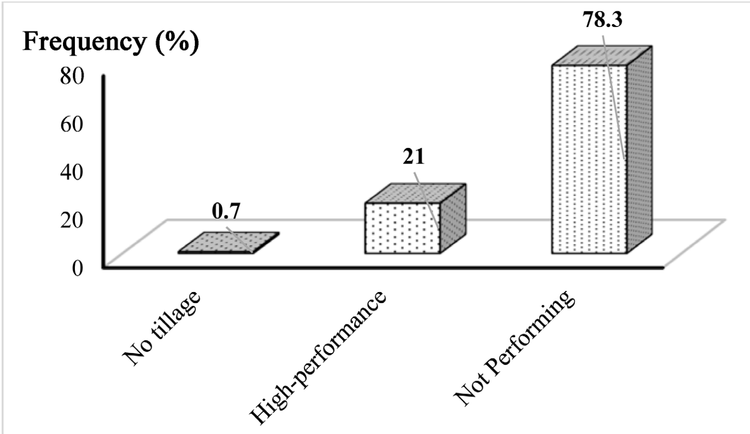

Figure 7. Tillage machine performance.

4.3.2. Producers' Perception of the Quality of the Work

Figure 8 shows that 97.3% of the farmers surveyed practice tillage. However, it should be noted that 0.7% of farmers in the study area do not carry out tillage operations. A total of 78.3% of the rice growers surveyed considered that the operations were poorly carried out. Of these, 39% believe that this poor quality of service is linked to the permanent presence of weeds in the plots, competing with the rice and thus contributing significantly to the drop in rice yields (Figure 8). 14.3% and 15% believe that poor tillage is due respectively to incomplete turning during ploughing and poor drainage of excess water. In addition, 16.7% of respondents felt that tillage was fairly well done, helping to reduce grass-rice competition for 6.7% of respondents and improve organic matter content by turning over plants and debris at the bottom for 10% of respondents (Figure 8). Only 4.3% of respondents felt that tillage was very well executed and would help to reduce grass-rice competition for 1.3% of respondents and improve organic matter content for 2% of respondents, while facilitating drainage of excess water for 1% of respondents (Figure 8).

4.4. Constraints and Effects Associated with the Use of Farm Machinery

4.4.1. Constraints Linked to the Use of Agricultural Machinery

According to the surveys carried out, mastering of agricultural machinery techniques appears to be a major constraint on the use of agricultural machinery, with 64% of the farmers surveyed not mastering these techniques (**Figure 9(a)**).

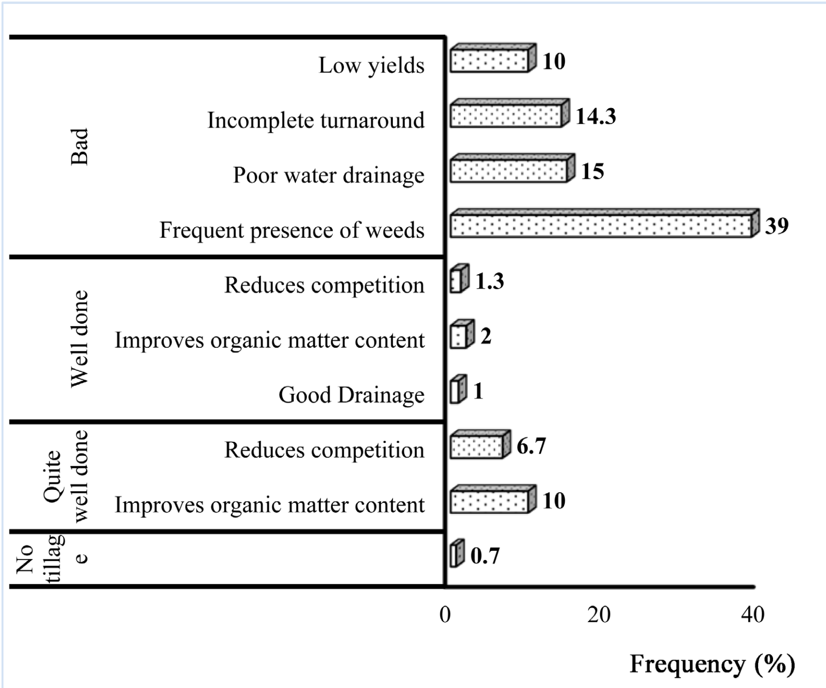

Figure 8. Adoption of tillage and its effects on rice cultivation.

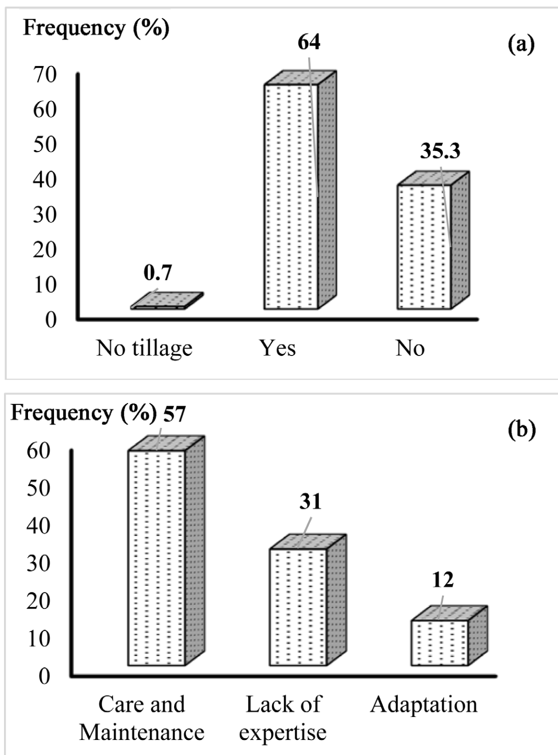

Figure 9. Mastery of Machine use techniques (a); Constraints linked to the use of agricultural machinery (b).

In addition, there are a number of constraints linked to their use, which have a major impact on the performance of the machines. These include, as shown in **Figure 9(b)**: maintenance and servicing problems, which 57% of rice growers consider to be the main constraint, lack of expertise on the part of growers (31%) and problems adapting the machines to local conditions (12%).

4.4.2. Effects Associated with the Use of Farm Machinery

The constraints listed in **Figure 9(b)**, which have a direct effect on the quality of the work carried out, have contributed in recent years to a fall in yields and the spread of weeds on cultivable plots according to 53% of respondents, and to the gradual degradation of the soil in the area according to 25% of producers (**Figure 10**). On the other hand, 22% of respondents felt that the soil had been gradually restored over the years since the introduction of agricultural machinery in the Senegal River valley.

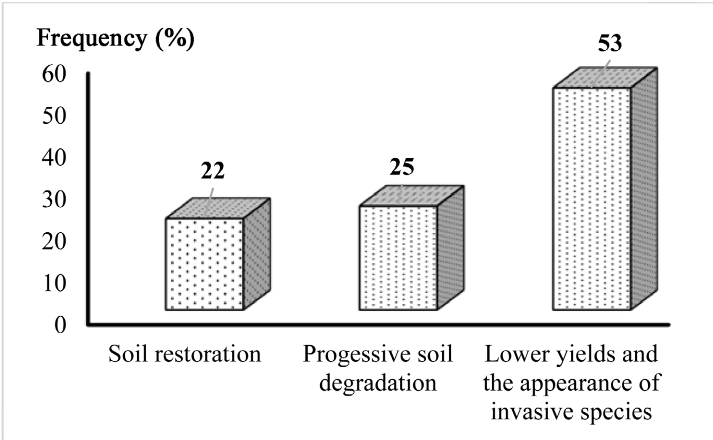

Figure 10. Effects of the use of agricultural machinery.

5. Discussion

Tillage operations are carried out with a view to modifying the structural state of the soil to meet crop needs [16]. Rice growers in the valley believe that if tillage operations are carried out properly, they will reduce the spread of weeds, improve soil fertility, promote good drainage of excess water in the field and help to increase rice yields. This perception by growers is in line with the work of [17], who reported that soil preparation allowed seeds to be evenly distributed and buried at a suitable depth. This burial of seeds in loosened soil not only protects them from granivorous animals but also, in spring or summer, enables them to be in contact with sufficiently moist and loose soil to encourage germination. According to [18] [19], tillage therefore leads to better infiltration of water into the soil, and the water stored at depth can be used by crops. [15] showed that tillage improved the permeability of the tilled layer by preserving and increasing soil porosity. It can lead to an increase in water percolation, *i.e.* the descent of water to depth, as well as an improvement in the lateral circulation of water. For [20] [21], tillage has a beneficial effect at the very beginning of the crop cycle. This beneficial effect reaches its peak at the time of cereal bolting.

Agricultural motorization has become an indispensable tool for making cultivation operations efficient and productive. Agricultural motorization has enabled farmers to obtain a better income [22]. In our work, the predominant use of motorized equipment by rice growers attests to the advantages attributed to them: reduced drudgery of work, speed in carrying out tillage operations, increase in area sown and improved income. Our results are in line with those of the [4], which showed that motorization helped to reduce the arduousness of farming activities, increase the area under cultivation and improve the quality of production and processed products. These authors also showed that motorization encouraged industrialization driven by agriculture.

However, the use of motorized equipment does not only have advantages. In our study, it was noted that the use of motorized equipment led to lower yields, the appearance of weeds and the gradual degradation of the soil. This could be explained not only by the poor quality of the equipment, which accentuates the phenomenon of erosion and salinization of the land, but also by a lack of control over the techniques used to operate the machinery (tractor-implement linkage), as evidenced by an imbalance in the loads on the tractor-implement unit and poor grip and pressure on the pneumatic system. The better the tractor's grip on the ground via its tyres, the more efficient the transmission of tractive effort from the drive wheels to the ground. Added to this is the repetitive passage of machinery over the soil, which creates soil compaction, depletion of organic matter and erosion. According to [22], heavy machinery has a negative impact on rice production because soil compaction affects the structural quality of the soil; root penetration into the soil is limited, and the circulation of water and air is reduced, leading to a slowdown in biological activity. [23] concluded that the development of motorization and the emergence of increasingly heavy machinery were exacerbating the degradation of agricultural soils. For [24], the use of heavy agricultural machinery in intensive farming has led to a widespread problem of soil compaction in many parts of the world. According to [25], these heavy agricultural machines could destroy up to a fifth of the world's agricultural land. Soil degradation caused by compaction can be estimated at 68 million hectares of arable land [26] [27]. Soil compaction also disrupts crop growth and development, resulting in a drop in yield of between 10% and 30% [28]. As far as weeds are concerned, turning over the soil buries the seeds at variable depths, so that some of them are placed in oxygenation or light conditions that are temporarily or permanently incompatible with their germination [29]. As for previously buried seeds, they can rise to the surface and germinate under favorable conditions. The machinery and type of tillage therefore have an impact on the vertical distribution of weeds in the soil profile. If the type of tillage is shallow, the seeds are mainly found on the surface (0 - 5 cm) and weeds proliferate. On the other hand, if ploughing is deep (10 - 15 cm), weed seeds will be found at depth and there will therefore be fewer weeds.

The lack of expertise in the use of motorized equipment and the problems of upkeep, maintenance and adaptation of equipment identified in the river valley are consistent with the constraints identified by [30]. In his work on the management and use of agricultural equipment, [30] identified a number of constraints, including a lack of expertise in the field of mechanization, maintenance and servicing problems, the difficulty of obtaining spare parts and a lack of mastery of management tools. [31] highlighted the poor use of machinery as the cause not only of frequent breakdowns but also of soil degradation. As for [32], he linked the failure to introduce agricultural machinery in Senegal to a lack of experience and a lack of training for service providers.

6. Conclusion

This study gathered farmers' perceptions of the major constraints associated with agricultural mechanization in rice production, and also determined its effect on the soil. The results showed that soil preparation work in the Saint-Louis region is largely carried out using tractors with accompanying implements such as offset, disc/Socs ploughs, cultivators, etc. Offset tillage was the most common tillage operation for 95.4% of growers, to the detriment of ploughing (3.6%). 78.3% of rice growers in the Saint-Louis region noted low machine efficiency due to several constraints. These constraints include: problems in adapting machinery to environmental conditions (12% of respondents), problems in maintaining and servicing machinery (57%) and a lack of skills in agro-equipment (31%) to optimize the tractor-tool linkage. All these difficulties have contributed to increasing soil degradation and the frequent appearance of weeds, which compete with rice. As a result, yields have fallen in the area in recent years. In the light of this diagnosis, it would be interesting to test adapted and more environmental friendly machinery as well as train farmers on machinery maintenance and utilization. It would also be important to carry out field trials to determine the effect of farm mechanization on rice production, soil characteristics and the appearance of weeds.

Authors' Contributions

C.A. Mane and S. Diedhiou were the principal investigators. C.A. Mane carried out the fieldwork. C.A Mane, S. Diedhiou and A.O.K. Goudiaby contributed to drafting the protocol, the acquisition, analysis and interpretation of the data, and drafting the manuscript. M. Sall and G. Gillet contributed to the revision of the protocol and the manuscript.

Acknowledgements

Our sincere thanks go to the French Embassy in Senegal, which funded this study through a grant awarded to the Université du Sine Saloum El Hadji Ibrahima NIASS.

Conflicts of Interest

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

References

[1] ANSD (2020) Senegal's Economic and Social Situation. Quincy, 17 p.

[2] Fall, A., Mbaye, B.B. and Sy, H. (2013) Agricultural Policy, Productivity and Long-Term Growth in Senegal. Senegal Ministry of Economic and Finance, Dakar, 14.

[3] Diatta, P.A. (2017) Growth in Agricultural Production and Economic Growth: The Case of Senegal. Master's Thesis, Assane Seck University of Ziguinchor.

[4] FAO (2007) Characterisation of Agricultural Production Systems in Senegal. Rome, 39 p.

[5] Khater, A., Fouda, O., El-Termezy, G., Abdel Hamid, S., El-Tantawy, M., El-Beba, A., Sabry, H. and Okasha, M. (2023) Modification of the Rice Combine Harvester for Cutting and Binding Wheat Crop. *Journal of Agriculture and Food Research*, **14**, Article 100738. https://doi.org/10.1016/j.jafr.2023.100738

[6] Al-Gezawe, A., Ottb, M., Abdel Gawad, F., Awad, M., Fouda, O. and Okasha, M. (2023) Manufacture of a Device for Pruning Fruit Branches. *INMATEH Agricultural Engineering*, **69**, 379-388. https://doi.org/10.35633/inmateh-69-35

[7] Ngom, C.A.B., Sarr, F. and Fall, A.A. (2016) Mesure de l'efficacité technique des riziculteurs du bassin du fleuve Sénégal. *Économie Rurale*, **5**, 91-105. https://doi.org/10.4000/economierurale.5021

[8] Dieye, M. (I994) Contribution to the Identification of and Research into Techniques for Improving Dirty Soils in the Delta and Mid-Valley. ISRA, Saint-Louis, 71 p.

[9] ANSD (2021) Regional Economic and Social Situation 2019. Quincy, 135 p.

[10] GRDR (2014) Study the Local Dimension of the Migration and Development Dialectic—The Case of France and Senegal. In: Monograph on the Senegal River Valley, Final Version, 75 p.

[11] Diop, P.D. (2005) A Market Gardening Area in Crisis in Northern Senegal: The Gandiolais and Toubé in the Rural Community of Gandon. Master's Thesis, Gaston Berger University.

[12] Gaye, D. (2017) Monitoring Rainfall in North Senegal from 1954 to 2013: Case Study of the Synoptic Stations in Matam, Podor and Saint-Louis, Norois. *Environment, Development, Society*, **244**, 63-73. http://journals.openedition.org/norois/6165

[13] Ba, D.D., Ndiaye, P.M. and Faye, C. (2018) Rainfall Variability and Evolution of Climatic Drought in the Senegal River Valley. *Revue Togolaise des Sciences*, **12**, 1-71. http://www.researchgate.net/publication/334049360

[14] Dirk, R. (1993) The Salty Soils of the Senegal River Delta: Physical and Chemical Properties. SAED, Saint Louis, 84 p.

[15] Van Lavieren, L.P. and Van Wetten, J.C.J. (1988) Profil de l'environnement de la vallée du fleuve Sénégal. *Research Institute for Nature Management*, **3**, 157 p. https://edepot.wur.nl/387981

[16] Barthélémy, P., Boisgontier, D. and Lajoux, P. (1992) Choosing Soil Preparation Tools. Technical Institute for Cereals and Forages, 200 p.

[17] Mballo, R. (2018) Weed Communities in Irrigated Rice in the Senegal River Valley:

Flora Structure, Habitat Amplitude and Degrees of Infestation of Species and Improved Weed Management. Ph.D. Thesis, Cheikh Anta Diop University of Dakar.

[18] Kouelo, A.F., Badou, A., Houngnandan, P., Francisco, M., Michée, F., Jean-Brice, G.C. and Sochime, D.J. (2012) Impact of Tillage and Mineral Fertilisation on the Productivity of *Macrotyloma geocarpum* (Harms) Maréchal & Baudet in Central Benin. *Journal of Applied Biosciences*, **51**, 3625-3632.

[19] Askari, M., Abbaspour-Gilandeh, Y., Taghinezhad, E., El Shal, A.M., Hegazy, R. and Okasha, M. (2021) Applying the Response Surface Methodology (RSM) Approach to Predict the Tractive Performance of an Agricultural Tractor during Semi-Deep Tillage. *Agriculture*, **11**, Article 1043. https://doi.org/10.3390/agriculture11111043

[20] Abo-Habaga, M., Imara, Z. and Okasha, M. (2018) Development of a Combine Hoeing Machine for Flat and Ridged. *Journal of Soil Sciences and Agricultural Engineering*, **9**, 817-820.

[21] Daouze, J.P. and Estrade, R.J. (2022) Soil Management and Machinery. Choosing the Right Tools. 2nd Edition, France Agricole, 171 p.

[22] CEMA (2014) European Agricultural Machinery. Brussels, 6 p.

[23] Nodiet Zokpodo, B.K.L. and Kakai, R.G. (2017) Analysis of the Determinants Linked to the Operation of Agricultural Machinery Operating Centres (CEMA) in Benin. *Annales des Sciences Agronomiques*, **21**, 181-202. https://www.researchgate.net/publication/332030696

[24] Das, T.K., Kabir, A., Zhao, W., Stenstrom, M.K., Dittrich, T.M. and Mohanty, S.K. (2023) A Review of Compaction Effect on Subsurface Processes in Soil: Implications on Stormwater Treatment in Roadside Compacted Soil. *Science of the Total Environment*, **858**, Article 160121. https://doi.org/10.1016/j.scitotenv.2022.160121

[25] Keller, T., Sandin, M., Colombi, T., Horn, R. and Or, D. (2019) Historical Increase in Agricultural Machinery Weights Enhanced Soil Stress Levels and Adversely Affected Soil Functioning. *Soil and Tillage Research*, **194**, Article 104293. https://doi.org/10.1016/j.still.2019.104293

[26] Hamza, M.A. and Anderson, W.K. (2005) Soil Compaction in Cropping Systems: A Review of the Nature, Causes and Possible Solutions. *Soil Tillage Research*, **82**, 121-145. https://doi.org/10.1016/j.still.2004.08.009

[27] Batey, T. (2009) Soil Compaction and Soil Management—A Review. *Soil Use and Management*, **25**, 335-345.

[28] Tsague, G.E. (2022) Soil Compaction: Causes and Solutions. https://www.agrireseau.net/agroenvironnement/documents/Tsague_La%20compaction%20des%20sols.pdf

[29] Hamadache, A. (2005) Soil Preparation for Winter Cereals in Algeria. Information Day on Cereals, Syngenta, Basel, 7 p.

[30] Mall, S. (2021) Constraints in the Management and Use of Motorised Agricultural Equipment Distributed by the State to Farms in the Department of Bambey in the Groundnut Basin: Proposed Strategies and Solutions. Ph.D. Thesis, Université Gaston Berger de Saint-Louis.

[31] Dieye, M. (2017) Evaluation of Motorised Services at SODEFITEX and Proposal for an Appropriate Implementation Strategy. National College of Agriculture (ENSA).

[32] Diakhate, D. (2009) Analysis of Supply and Demand for Agricultural Motorisation with a View to Intensifying the Development of Hydro-Agricultural Schemes in the Anambé Basin: The Case of Tractors and Combine Harvesters. National College of Agriculture (ENSA).

Abbreviations List

ANSD: National Agency for Statistics and Demography
CEMA: Center for Mechanized Services
FAO: Food and Agriculture Organization
GRDR: Research and Development Group for Rural Development
SAED: Company for the Development and Exploitation of the Senegal River Delta