

1 **Effect of the optimized *Guiera senegalensis* system on crop**  
2 **performance (millet, groundnut) in the northern Peanut Basin**  
3 **(Senegal).**

4 **CRedit authorship contribution statement**

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15 **ABSTRACT**

16 Agroforestry systems combining indigenous shrubs and crops are recognized as promising  
17 ways of restoring degraded soils and improving agricultural yields in the Sahel. Research is  
18 attempting to optimize these systems to maximize their benefits. In this context, the  
19 comparative effect of optimized (OSS) and traditional (TMS) *Guiera senegalensis*  
20 management systems on the performance of groundnut (*Arachis hypogaea* L.) and millet  
21 (*Pennisetum glaucum* L.) was studied in the Meckhé zone from 2019 to 2022 under farmer  
22 conditions. OSS involves increasing the density of *Guiera senegalensis*, cutting and chopping

23 the biomass, and incorporating it into the soil. This contrasts with TMS, where shrub density  
24 is low, and the cut shrub biomass is burned. The trial is a randomized block design with  
25 fifteen replications and two treatments. Measurements were taken of height, LAI, NDVI,  
26 yield components and rainwater use efficiency. The optimized system improved groundnut  
27 and millet growth. It also significantly improved yield components and crop rainwater use  
28 efficiency. Overall, compared with the traditional system on the farm, the optimized system  
29 increased crop performance.

30 **Key Words:** Peanut Basin, *Guiera senegalensis*, Optimized System, Millet, Groundnut, Crop  
31 Performance

32

33

## 34 **RESUME**

35 **Effet du système optimisé à *Guiera senegalensis* sur la performance des cultures (mil,**  
36 **arachide) dans le Nord Bassin Arachidier (Sénégal).**

37 Les systèmes agroforestiers associant arbustes autochtones et cultures sont reconnus comme  
38 prometteurs, pour restaurer les sols dégradés et améliorer les rendements agricoles au Sahel.  
39 C'est dans ce contexte que, cette étude a été menée de 2019 à 2022, pour déterminer l'effet du  
40 système optimisé à *Guiera senegalensis* sur la performance du mil et de l'arachide en milieu  
41 paysan. Le dispositif expérimental est en blocs complets randomisés avec deux traitements  
42 (système optimisé à *Guiera senegalensis* et système traditionnel à *Guiera senegalensis*) et  
43 quinze répétitions. Le système optimisé consiste à augmenter la densité des arbustes, à  
44 découper leur biomasse, et à l'incorporer au sol. Le système traditionnel consiste à maintenir

45 une faible densité d'arbustes dans la parcelle et à brûler leur biomasse quand ils sont coupés.  
46 Les mesures ont porté sur la hauteur, le LAI, le NDVI, les composantes du rendement,  
47 l'efficacité d'utilisation de l'eau de pluie par les cultures. Le système optimisé a amélioré la  
48 croissance de l'arachide et du mil. Également, il a amélioré significativement les composantes  
49 du rendement et l'efficacité d'utilisation de l'eau de pluie des cultures. Globalement,  
50 comparé au système traditionnel en milieu paysan, le système optimisé a augmenté la  
51 performance des cultures. **Mots clés** : Bassin Arachidier, *Guiera senegalensis*, Système  
52 Optimisé Mil, Arachide, Performance des Cultures.

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## 56 **1. Introduction**

57 In Senegal, over 15% of the population faces poverty and food insecurity due to the drop of  
58 crop yields combined with population increase (ANSD, 2014; Masson-Delmotte, 2020;  
59 Mbow et al., 2021).

60 This situation is due, among other things, to an agriculture dependent on erratic rainfall,  
61 coupled with the degradation of most arable land (Sacande, 2018; Sow et al., 2020). Indeed,  
62 the great drought of 1968 to 1985 was exceptional in its duration and intensity. This resulted  
63 in a 300 mm drop in rainfall, and a 200 km southward shift in isohyets, the consequences of  
64 which are regression of vegetation cover and denudation of land (Roquet, 2008; Diallo et al.,  
65 2022). As a result, soils in Senegal have become increasingly poor, and highly vulnerable to  
66 erosion (Badiane et al., 2000). This phenomenon particularly affects the Peanut Basin, the  
67 main millet and groundnut production area, where 47% of land is experiencing some form of

68 degradation (O.D.N.U, 2007; INP, 2013). Yields of these crops, which are of vital economic  
69 and social importance, are less than a quarter of world levels (Sow et al., 2018; Gérald et al.,  
70 2020).

71 A great deal of research has been devoted to combating the growing degradation of the soils  
72 of the Groundnut Basin. They have shown that the soils of the Peanut Basin, with their low  
73 organic matter content, make little use of mineral fertilization. It is organo-mineral  
74 fertilization that enables yields to be improved sustainably (Badiane et al., 2000).  
75 Unfortunately, the availability of organic matter poses a problem, as crop residues compete  
76 with animal feed and domestic uses, while livestock numbers have been considerably reduced  
77 (Badiane et al., 2000).

78 In this context, numerous studies have been devoted to the role of agroforestry species in  
79 improving and/or maintaining soil organic status and fertility (Ndour et al., 2000). On this  
80 path, growing interest is noted mainly in two agroforestry shrubs widely distributed in the  
81 Sahelian zone, notably *Guiera senegalensis* and *Piliostigma reticulatum* (Chapuis-Lardy et  
82 al., 2019).

83 In particular, in Senegal, research efforts devoted to these two shrubs between 1998 and 2016  
84 led to the development of an optimized shrub-crop system (OSS) (Chapuis-Lardy et al.,  
85 2019). The OSS sequesters more carbon in the soil (Lufafa et al., 2008a and 2008b), improves  
86 soil quality through nutrient recycling and increased biological activity (Dossa et al., 2008;  
87 Diedhiou et al., 2009; Diedhiou-Sall et al., 2013), achieves hydraulic redistribution and thus  
88 increases soil moisture thanks to this faculty (Kizito et al., 2006, 2007, 2012; Bogie et al.,  
89 2018). This has a positive impact on crops in terms of improved growth (Bogie et al., 2019;  
90 Bayala et al., 2022), shorter development cycles (Bayala et al., 2022) and higher yields  
91 (Bright et al., 2017; Bright et al., 2021). However, the results were obtained under

92 experimental conditions, where the OSS was compared with a system where the crop plots are  
93 bare (without any shrubs) and not the peasant system where there is a low density of shrubs.  
94 The main objective of this study is to highlight the effect of the optimized *G. senegalensis*  
95 management system (OSS) on the performance of groundnut and millet in the Northern  
96 Peanut Basin of Senegal. The specific objectives are: (i) to determine the effect of OSS on  
97 crop growth and yield; (ii) evaluate the effect of OSS on the efficiency of water use by crops  
98 (groundnut and millet).

## 99 **2. Materials and methods**

### 100 **2.1. Characteristics of study sites**

101 The study was carried out in seven villages (Koul, Lissar, Ndia, Femboule, Ngass, Ndiaye  
102 Thioro, and Risso) of Meckhé (16° 39' N and longitudes 15° 4'W) in Peanut Basin of Senegal.

103 The area's climate is tropical and semi-arid, with one wet season (July to October) and a long  
104 dry season lasting around eight months (November to June). Average annual rainfall is 470.87  
105 mm. The average annual temperature ranges between 17 and 35°C (ANACIM, 2021).

106 The soil is Rubic Arenosol (95% sand) with low content of carbon and nitrogen (0.2% C and  
107 0.15% N) low cation exchange capacity (0.7 meq/100 g) (Oldmen et al., 1993; Kouma,  
108 2002).

109 Fallow land is mainly shrub with dominant woody species like *Faidherbia albida* Del. A.  
110 Chev., *Vachellia tortilis* Forssk., *Balanites aegyptiaca* Del., *Zizyphus mauritiana* Lam. and  
111 *Adansonia digitata* L. The herbaceous cover is mainly composed of annual grasses, with a  
112 predominance of *Cenchrus biflorus* Roxb. (Dione et al., 2008).

113        **2.2. Plant materials**

114        **2.2.1. *Guiera senegalensis***

115        *Guiera senegalensis* J. F. Gmel is an indigenous shrub of *Combretaceae* family. It is found  
116        from Senegal to Ethiopia, in fallow land, light sandy soils and degraded soils (Kerharo and  
117        Adam, 1974; Sanogo, 2012). It generally occurs in bushy clumps rarely exceeding 3 m in  
118        height, branched from the stump (Kerharo and Adam, 1974; Reça, 2016). *G. senegalensis*  
119        leaves, roots, stem and galls are widely used in traditional pharmacopoeia and veterinary  
120        medicine (Tine et al., 2019). During a peak-season, the biomass of *G. senegalensis* could  
121        range from 0.9 to 1.4 Mg C ha<sup>-1</sup> (Lufafa et al., 2008).

122        **2.2.2. *Arachis hypogaea* L.**

123        Peanut variety used was 55-437. It has a short cycle (90 days). It is tolerant of water deficit,  
124        not very sensitive to photoperiod, resistant to aflatoxin and susceptible to acidity, salinity and  
125        Cercosporiosis diseases (Schilling, 2001). The crop development is subdivided into five  
126        phases: germination, which lasts 3 to 4 days after sowing (JAS), vegetative phase (5 JAS to  
127        25 JAS), flowering (25 JAS to 60 JAS), gynophorization (60 JAS to 90 JAS) and ripening (90  
128        JAS) (Mayeux, 2001; Schilling, 2001). The crop's water requirements are generally met when  
129        rainfall is between 500 and 1000 mm, albeit with a good distribution (Schilling, 2001). The  
130        crop is more sensitive to water stress during germination, flowering and gynophorization  
131        (Schilling, 2001). The potential yield of this variety is 2 T/ha, but its production in the real  
132        world hardly exceeds 800 kg/ha (Schilling, 2001; Bello et al., 2019). Shelling yield is 75%.  
133        The weight of 100 seeds is between 35 g and 38 g (Schilling, 2001).

134        **2.2.3. *Pennisetum glaucum* L.**

135 The variety of millet used was Souna 3 variety. The development cycle is 90 days. It is  
 136 drought tolerant and non-photoperiodic, and has a high tillering capacity (Sy et al., 2015). The  
 137 development cycle is subdivided into vegetative, productive and ripening phases (Kadri et al.,  
 138 2019). The favorable rainfall of this variety ranges between 350 and 500 mm and the optimal  
 139 yield is estimated at 2.5 T/ha, but under farmers practice, the yield rarely exceed 500 kg/ha  
 140 (Bamba et al., 2019; Sy and Kanfany, 2023). The average height of the Souna 3 variety is 245  
 141 cm at maturity, while the weight of 1,000 millet grains averages 7.98 g (Bekoye, 2014; Ndir  
 142 et al., 2014).

### 143 2.3. Experimental design

144 The trial was carried out on the farm for four years (2019 to 2022). The experimental design  
 145 is a randomized complete block design with fifteen (15) replicates (Table 1). The factor  
 146 studied is the *G. senegalensis* management system, with two (2) levels: optimized *G.*  
 147 *senegalensis* management system (OSS), traditional *G. senegalensis* management system  
 148 (TMS). The experimental unit is a 250 m<sup>2</sup> elementary plot, 10 m wide by 25 m long. Within a  
 149 block, the spacing between elementary plots is 3 m.

150

151 **Table 1.** Identification of trial blocks.

Block	Village
P1	Lissar
P2	
P3	
P4	
P5	
P6	Risso
P7	Ngass
P8	
P9	
P10	Femboule

<b>P11</b>	
<b>P12</b>	Ndiaye Thioro
<b>P13</b>	Koul
<b>P14</b>	Ndiaye Thioro
<b>P15</b>	Ndia

152 The TMS consists in maintaining the current density of shrubs in farmers' fields (120-520  
 153 shrubs per hectare). During soil preparing (June), the shrubs are cut and burned. Between the  
 154 end of July and August 15, shrub regrowth is cut again, and the biomass obtained is deposited  
 155 between the crop rows.

156 OSS involves increasing shrub density to 1,200 shrubs/ha, i.e. 30 shrubs per elementary plot.  
 157 Shrubs are cut as in the TMS treatment, and the biomass is chopped up and incorporated into  
 158 the soil. The total biomass added to the soil is around 3 T/ha.

#### 159 **2.4. Crop management**

160 The cropping system adopted during the trial is a millet/peanut rotation.

161 The groundnut trials were conducted in 2019 and 2021 during rainy season. Peanut fields  
 162 were sown early in August 2019, 2021 and 2022 at a 50 cm x 15 cm spacing. NPK fertilizer  
 163 (6-20-10) was applied at 150 kg/ha rate immediately after sowing. Weeding was carried out  
 164 whenever necessary.

165 Millet sowing was carried out manually, from July 14 to 17 in 2020 and from August 08 to 11  
 166 in 2022 at 1 m x 1 m spacing. Thinning at 3 plants per hole was carried out between 12 and  
 167 15 days after sowing (DAS). NPK fertilizer (15-10-10) was applied at the same time at a rate  
 168 of 150 kg/ha. Urea was applied with 50 kg/ha at thinning and 30 DAS. Weeding was carried  
 169 out whenever necessary.



## 170 **2.5. Measurements and observations**

### 171 **2.5.1. crop growth parameters**

172 Throughout the crop development cycle, the crop height, leaf area index and NDVI were  
173 measured on six plants per plot in 6 repetitions per farmers field (n=36 measurements per  
174 treatment). Measurements were made at 56 and 88 DAS in 2019; 40, 60 and 90 DAS in 2020;  
175 15, 25, 74 and 85 DAS in 2021; 30 and 90 DAS in 2022.

176 Height was measured using a tape measure. For groundnuts, it was measured from soil  
177 surface to the collar of the highest apical bud. For millet, it was measured from ground to the  
178 last point of ear insertion.

179 Leaf area index (LAI) was measured with an LP 80 ceptometer, below the canopy, on all four  
180 sides of the six plants sampled.

181 The normalized difference vegetation index was measured using a GreenSeeker. The device  
182 was placed 60 cm above the highest leaf of the plants monitored.

### 183 **2.5.2. Crop yield**

#### 184 **2.5.2.1. Groundnut (peanut)**

185 Three subplots of 2 m<sup>2</sup> were harvested randomly in each plot (treatment). Pods were removed  
186 from biomass and drying on the sun. Weight average of 100 grains of peanuts was measured  
187 in 3 repetitions per subplot.

188 (1) A sample of peanut biomass was  
189 simultaneously removed in each subplot and  
190 dried in oven at 105° C. Total of peanut

191 biomass was calculated through equation

192 
$$(1)PTs = \frac{PEms * PHT}{PEmh}$$

193 with *PTs*: Total weight of dry biomass; *PEms*: Average weight of dry samples; *PHT*: Total  
194 weight of wet biomass; *PEmh*: Average weight of wet samples.

#### 195 **2.5.2.2. Millet**

196 A subplot of 80 m<sup>2</sup> was established in each elementary millet plot for the yield.

197 Grain yield was measured after harvesting the ears at physiological maturity. Three samples  
198 of 1,000 grain were weighed to determine the average weight of 1,000 millet grains. The yield  
199 of straw was measured inner the subplot. Three samples of millet biomass were collected for  
200 oven-drying at 105°C for 48 hours. Total millet biomass was calculated using equation (1).

#### 201 **2.5.3. Determination of water use efficiency**

202 To determine rainwater use efficiency (kg/ha/mm), the method described by Bright *et al.*  
203 (2017) was used. This involved dividing the total biomass or the total amount of grain  
204 harvested by the total rainfall recorded during the crop season: 326.6 mm (2019), 661.98 mm  
205 (2020), 297.1 mm (2021) and 482.5 mm (2022).

#### 206 **2.5.4. Data analysis methods**

207 Statistical analyses were performed with R studio software (R Core Team, 2022), and Excel  
208 2016 spreadsheet (Microsoft Office) was used to produce all figures. The agricolae package  
209 (Mendiburu and Yaseen, 2020) was used to highlight the effect of treatments (OSS and TMS)  
210 on agro-physiological parameters, as well as millet and groundnut yield components, and crop  
211 nutrient and water use efficiency based on the general linear model:

212  $Y_{ij} = \mu + T_i + B_j + \epsilon_{ij}$ ,

213 where  $Y_{ij}$  is the analysed variable of crop  $ij$ ,  $\mu$  is the overall mean,  $T_i$  is the fixed effect of  
214 treatment  $i$ ,  $B_j$  is the fixed effect of the plot,  $\epsilon_{ij}$  represent the residual errors assumed to be  
215 independent and following a normal distribution  $(0, \sigma^2)$ .

216 Each plot represents a replicate or block. Significant differences were determined at  $p\text{-value} \leq$   
217 0.05. Assumptions about heterogeneity of variance and normality of residual errors were  
218 validated by residual and quantile plots. Analysis of the separation of means between the OSS  
219 and TMS treatments was performed using Tukey's test. Except for crop water use efficiency  
220 in 2022, the non-parametric Wilcoxon test was used, as the distribution of the variables did  
221 not follow a normal distribution. Pairwise comparisons of least squares means were presented  
222 with error bars representing 95% confidence intervals.

223

224

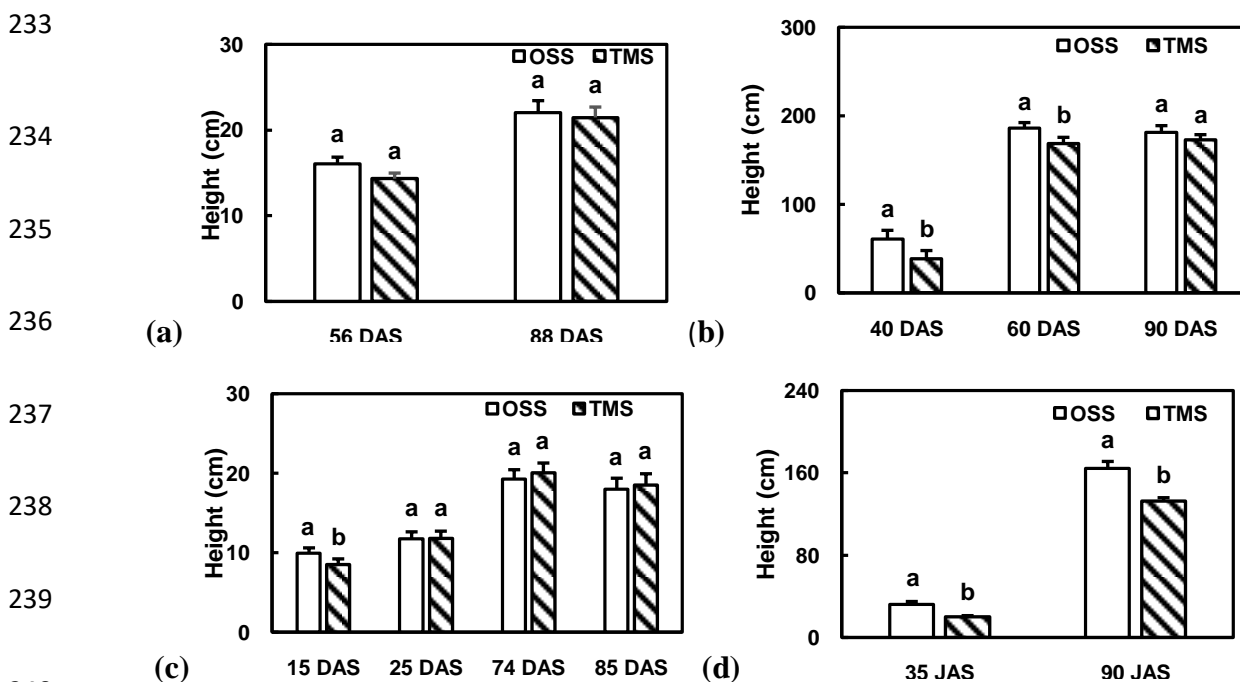
## 225 **3. Results**

### 226 **3.1. Effect of the optimized *Guiera senegalensis* system on crop growth** 227 **parameters**

#### 228 **3.1.1. Height**

229 OSS had a significant effect on millet height in 2020 and 2022. Thus, in 2020, OSS  
230 significantly ( $p\text{-value} \leq 0.005$ ) improved millet height by 59.07% and 10.28% during the

231 tillering and bolting phases respectively (Fig. 1c). In 2022, OSS significantly increased millet  
 232 height by 59.48% and 24.23% at tillering and ripening stages respectively (Fig. 1d).



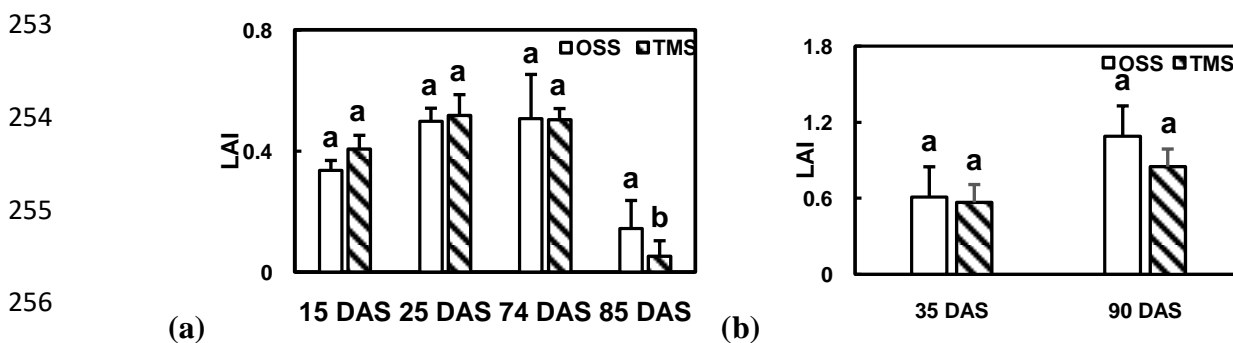
241 **Figure 1.** Effect of *G. senegalensis* optimized system on crop height evolution (a: groundnuts  
 242 in 2019; b: millet in 2020; c: groundnuts in 2021; d: millet in 2022).

243 OSS: Optimized *G. senegalensis* management system, TMS: Traditional *G. senegalensis*  
 244 management system; n = 36 per treatment and per measurement date; DAS: Days after  
 245 sowing. For each measurement date, the means of the treatments assigned the same letter are  
 246 not statistically different at the 5% threshold with Tukey's test.

### 246 3.1.2. Leaf Area Index (LAI)

247 Shrub management had no significant influence on LAI for groundnut in 2021 and millet in  
 248 2022 for all crop development stages except ripening in 2021 (Figs. 2a and 2b). At this last  
 249 stage, OSS improved LAI by 178.85% compared with TMS (Fig. 2a).

250 Millet leaf area index was not significantly improved by OSS in 2022. However, maxima  
 251 were recorded in plots receiving OSS, with an increase of 7.01% and 28.24% during the  
 252 tillering and ripening phases respectively (Fig. 2b).



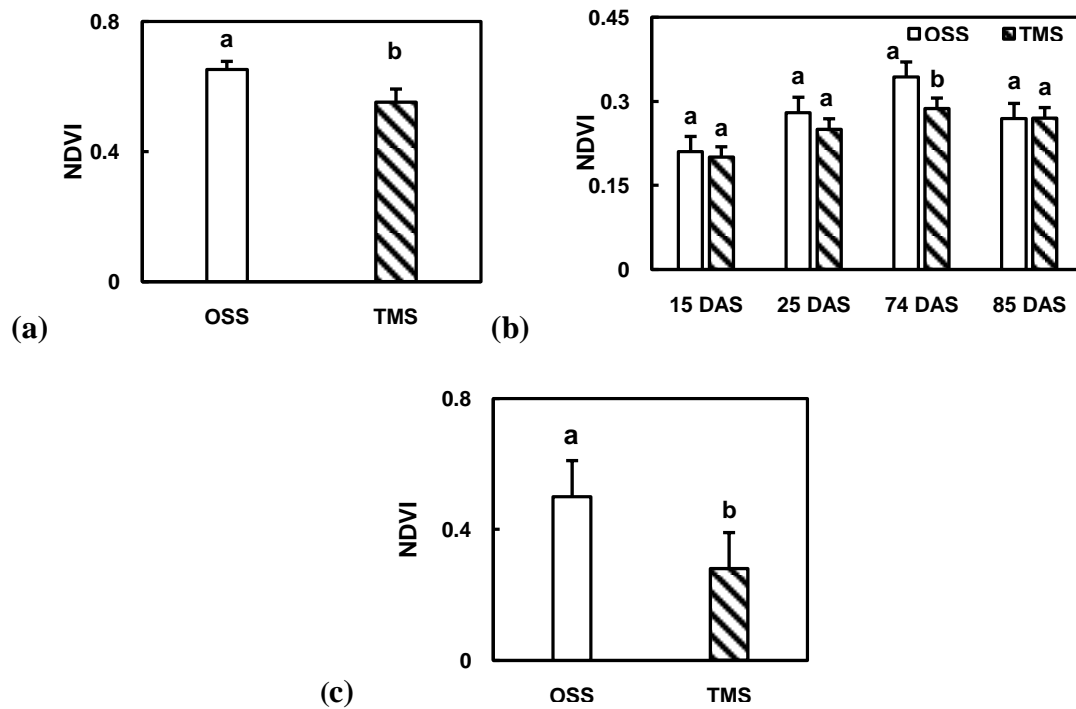
257 **Figure 2.** Effect of the optimized *G. senegalensis* system on changes in leaf area index  
 258 (LAI) of groundnut in 2021 (a) and millet in 2022 (b).

259 OSS: Optimized *G. senegalensis* management system, TMS: Traditional *G. senegalensis*  
 260 management system; n = 36 per treatment and per measurement date. DAS: Days after  
 261 sowing. For each measurement date, the means of the treatments assigned the same  
 262 letter are not statistically different at the 5% threshold with Tukey's test.

### 262 3.1.3. NDVI

263 In 2020 and 2022, OSS had a significant effect on millet NDVI during the tillering phase (40  
 264 DAS in 2020 and 35 DAS in 2022) ( $p\text{-value} \leq 0.01$ ). This parameter increased by 18.71% in  
 265 2020 and 78.57% in 2022 (Fig. 3a and Fig. 3c).

266 Groundnut NDVI was not significantly affected by OSS ( $p\text{-value} \geq 0.35$ ) during the  
 267 vegetative (15 DAS), flowering (25 DAS) and ripening (85 DAS) phases. However, at  
 268 gynophorization (74 DAS), this effect was significant ( $p\text{-value} = 0.008$ ), with NDVI rising  
 269 from 0.287 to 0.343 (Fig. 3b).



**Figure 3.** Effect of the optimized *G. senegalensis* system on changes in normalized difference vegetation index (NDVI) for millet in 2020 (a) and 2022 (c), and for groundnut in 2021 (b).

OSS: Optimized *G. senegalensis* management system, TMS: Traditional *G. senegalensis* management system; n = 36 per treatment and per measurement date. DAS: Days after sowing. For each measurement date, the means of the treatments assigned the same letter are not statistically different at the 5% threshold with Tukey's test.

270  
271  
272  
273  
274

### 3.2. Effect of the optimized *Guiera senegalensis* system on crop yields

#### 3.2.1. Effect of optimized *Guiera senegalensis* system on peanut yield

In both 2019 and 2021, there were no significant differences between the OSS and TMS treatments for any of the yield parameters measured, including pod yield, haulm yield and 100-seed weight (Table 2).

**Table 2.** Effect of *G. senegalensis* optimized system on peanut yield components (n=15).

	Peanut Yield			
	2019			2021
	Biomass (kg/ha)	Pod (kg/ha)	100-seeds Weight (g)	Biomass (kg/ha)
OSS	290.3 <sup>a</sup> ± 122.15	123.9 <sup>a</sup> ± 81.13	27.5 <sup>a</sup> ± 3.32	2278.8 <sup>a</sup> ± 1088.279
TMS	292.8 <sup>a</sup> ± 165.44	108.5 <sup>a</sup> ± 76.58	27.4 <sup>a</sup> ± 3.25	2186.1 <sup>a</sup> ± 1111.684
Treatment	0.93	0.17	0.89	0.65
Block + Treatment	0.001 **	1.4e-5 ***	8.4e-5 ***	0.0005 ***

OSS: Optimized *G. senegalensis* management system, TMS: Traditional *G. senegalensis* management system. Values ± standard deviation.

Means marked with the same letter are not statistically different at the 5% level using Tukey's test. \* : significant difference. \*\* : highly significant difference. \*\*\* : highly significant difference.

### 3.2.2. Effect of optimized *Guiera senegalensis* system on millet yield

By 2020, OSS had improved all millet yield except 1000-kernels weight. Straw increased by 17.23% (1840.71 kg/ha vs. 1570.08 kg/ha). Grain weight improved by 32.3% ( $p$ -value = 0.01). The maximum weights of 1,000 millet kernels were recorded on plots receiving the OSS treatment, representing an improvement of 2.86%. In 2022, OSS improved harvested straw by 32.4% ( $p$ -value = 0.02), total grain weight by 30% ( $p$ -value = 0.28), and weight of 1,000 millet kernels by 19.87% (Table 3).

**Table 3.** Effect of *G. senegalensis* optimized system on millet yield (n=15).

Millet Yield						
	2020			2022		
	Straw (kg/ha)	Grain weight (kg/ha)	Weight of 1,000 kernels (g)	Straw (kg/ha)	Grain weight (kg/ha)	Weight of 1,000 kernels (g)
OSS	1840.71 <sup>a</sup> ± 446.93	697.51 <sup>a</sup> ± 285.22	6.83 <sup>a</sup> ± 0.48	1145.88 <sup>a</sup> ± 1019.9	96.98 <sup>a</sup> ± 77.29	7.18 <sup>a</sup> ± 1.03
TMS	1570.08 <sup>b</sup> ± 453.8	527.22 <sup>b</sup> ± 216.35	6.64 <sup>a</sup> ± 0.76	866.09 <sup>b</sup> ± 1222.5	74.5 <sup>a</sup> ± 64.69	5.99 <sup>b</sup> ± 3.2
Treatment	0.02 *	0.01 *	0.187	0.0231 *	0.2814	0.01961 *
Block + Treatment	0.008 **	0.00526 **	0.003**	3.96e-05 ***	0.0181 *	0.18



*OSS: Optimized G. senegalensis management system, TMS: Traditional G. senegalensis management system. Values  $\pm$  standard deviation.*

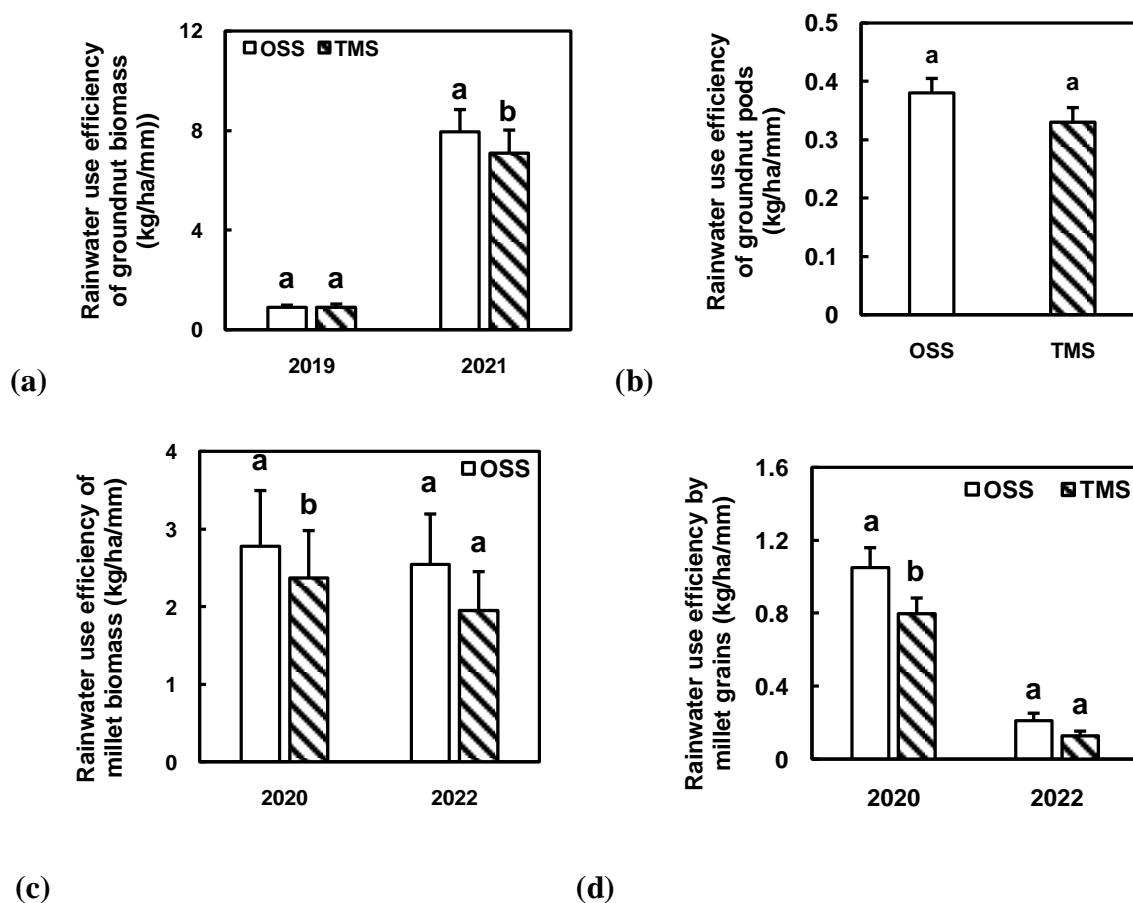
*Means marked with the same letter are not statistically different at the 5% level using Tukey's test. \* : significant difference. \*\* : highly significant difference. \*\*\* : highly significant difference.*

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### 3.3. Effect of optimized *Guiera senegalensis* system on rainwater use efficiency of mature crops

In 2019, rainwater use efficiency by groundnut biomass is improved by 31.25% ( $p$ -value = 0.171), while in 2021 this improvement is 12.11% ( $p$ -value = 0.0347) (Fig. 4a). The efficiency of rainwater use by peanut seeds was only achieved in 2019, so OSS increased the value by 15.15% (Fig. 4b). In 2020 and 2022, rainwater use efficiency by millet biomass is improved by 17.3% and 30.26% respectively (Fig. 4c). Millet grain rainwater use efficiency increased by

56.25% and 61.54% between 2020 and 2022 (Fig. 4d).



**Figure 4.** Effect of *G. senegalensis* optimized system on rainwater use efficiency by groundnut biomass (a) and seeds (b) in 2019 and 2021; and millet biomass (c) and seeds (d) in 2020 and 2022.

## 4. Discussion

The main aim of this study was to determine the effect of the optimized *G. senegalensis* system (OSS) on crop performance (millet and groundnuts) in the farming environment of the Northern Peanut Basin.

It revealed that, compared with the traditional *G. senegalensis* management system (TMS), the OSS improves rainwater use efficiency by mature groundnut and millet.

The rainwater use efficiency of mature groundnut biomass improved by 21.68%. For millet, it increased by 23.78% for biomass and 58.9% for grain.

Bright *et al.* (2021) obtained similar results, comparing OSS with treatments without shrubs on the Keur Matar Aram site (Senegal) under soil-climatic conditions similar to those in our study area. Rainwater use efficiency by millet increased by 50% for millet grains and 107% for groundnut pods.

The increase in rainwater use efficiency by mature crops may be due to the improvement in soil physical properties induced by the addition of *G. senegalensis* biomass. The latter should increase the amount of particulate organic matter in the soil, which promotes soil aggregation; this in turn leads to increased porosity and improved water storage and availability for crops (Kizito *et al.*, 2007; Dossa *et al.*, 2012; Bright *et al.*, 2021). The presence of shrubs has also been shown to reduce drainage losses and evapotranspiration by 50% (Kizito *et al.*, 2007). In addition, *G. senegalensis* provides favorable moisture conditions for crop development, even before sowing, due to the hydraulic redistribution capacity assigned to *G. senegalensis* (Kizito *et al.*, 2012; Bogie *et al.*, 2018).

It has shown that, compared with the traditional *G. senegalensis* management system (TMS), OSS improves crop growth and yields, most notably in millet, even under conditions of low rainfall.

OSS improved millet height growth by 33.26% in 2020 and 2022, and groundnut height growth by 2.35% in 2021. It has improved groundnut yields to a lesser extent in 2019 (pod weight) and 2021 (haulm weight). It has increased all millet yield components by at least 2.86%.

These on-farm results corroborate those of Dossa et al. (2012), Bright et al. (2021) and Bayala et al. (2022) obtained under semi-controlled conditions in the same agro-ecological zone in Senegal. These authors have shown that the presence of *G. senegalensis* promotes the growth of millet and groundnuts and improves their yields. For example, Bayala et al. (2022) showed that OSS increased millet height by 230% during the vegetative phase, compared with treatments without shrubs. Also, in a long-term study (2004 to 2016) by Bright et al. (2021), an increase in millet yield by OSS of 126% was observed. The improvement in crop growth and yields would thus be due to a combination of several factors. *G. senegalensis* does not compete with crops for water and mineral nutrition, as 95% of the shrub's roots are located between 0.2 and 0.5 m, and the shrub preferentially uses water located above 0.9 m (Kizito et al., 2006). In addition, this system is also able to improve the water and mineral nutrition of crops. Thus, OSS has the capacity to provide a significant amount of organic matter, in the order of 2.9 to 8.3 Mg/ha/year (Lufafa et al., 2008a; Bright et al., 2021). This organic matter is the most limiting factor in Sahelian agroecosystems (Lahmar et al., 2012). Thus, its increase favors microbial activity, which induces nutrient mineralization and aggregate formation (Diedhiou et al., 2009; Dossa et al., 2012; Diedhiou-Sall et al., 2013); leading to increased availability of nutrients (N, P, K) to plants through their release, storage and

retention. Aggregate formation thus improves soil structure, and increases water availability for plants (Dossa et al., 2012; Lahmar et al., 2012; Bright et al., 2021).

*G. senegalensis* also is able to redistribute water, as 5% of its roots can reach the water table (Kizito et al., 2006; Bogie et al., 2018). In addition, the reduction in soil surface temperature, due to the mulch effect of undecomposed *G. senegalensis* biomass and the cooling effect induced by water redistribution, improves the germination rate and also prevents the denaturation of certain proteins; this leads to better development during the vegetative phase (Bright et al., 2021).

To these factors can be added the improvement in rainwater and nutrient use efficiency by crops, induced by the improved availability of nutrients, as well as of soil water, the increase in carbon sequestration potential, particularly of carbon derived from particulate organic matter, which are strongly linked to improved crop productivity (Bright et al., 2021).

On the farm, OSS was found to be better than the traditional *G. senegalensis* management system for supporting millet and groundnut productivity under Sahelian conditions; this is due to the high density of *G. senegalensis* shrubs and the way these shrubs are managed. However, the effect of OSS on these crops noted in this study, is less conclusive than that reported by previous work (Dossa et al., 2012, Bright et al., 2021 Bayala et al., 2022). Unlike these works, where OSS is compared with treatments without shrubs, in the present work, the traditional management system features a low shrub density (120 to 520 shrubs/ha).

## **5. Conclusion**

This study showed the effect of the optimized *Guiera senegalensis* management system (OSS) on the performance of groundnut and millet under farmer conditions, in the northern

Peanut Basin, compared with the traditional *Guiera senegalensis* management system (TMS). OSS improved the growth, yield and rainwater nutrition of peanuts and millet at maturity.

OSS significantly improved groundnut height, except during periods of water stress. OSS also increased LAI from the flowering phase onwards, as well as the rainwater use efficiency of the peanut, and accentuated the NDVI of the peanut during the first three phases, particularly at gynophorization. In addition, groundnut yield components such as pod weight and weight of 100 groundnut seeds in 2019, and straw weight in 2021, were also improved thanks to OSS.

For millet, OSS induced better millet height growth, improved NDVI during the tillering phase, and LAI during the tillering and ripening phases in 2020 and 2022. Grain and straw yields, as well as the weight of 1,000 millet kernels, were improved by OSS, even in years of low rainfall (2022). In addition, OSS has improved rainwater use efficiency, particularly for grain.

By improving soil quality, OSS has succeeded in improving the performance of peanuts and millet on the farm, and in supporting crop growth and yield. In this way, the sustainability of Sahelian agro-ecosystems has been enhanced, and the food security of local populations strengthened.

However, further research is needed to determine the economic performance taking into account the additional labour time of the optimized *G. senegalensis* management system.

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