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

Int. J. Biol. Chem. Sci. 18(2): 326-337, April 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

# Agro-pedological impacts of different crop rotations on a ferric acrisol in Burkina Faso

Pouya Mathias BOUINZEMWENDÉ*, Zacharia GNANKAMBARY,
Innocent Delwendé KIBA, Nongma ZONGO and Michel SEDOGO

*Institute of Environment and Agricultural Research (INERA) of Burkina Faso.*
**Corresponding author; E-mail: pouyabmathias@gmail.com.*

Received: 27-02-2024 Accepted: 24-04-2024 Published: 30-04-2024

## ABSTRACT

Low crop yields are often explained by unfavourable rainfall conditions, the natural poverty of the soil in terms of nutrients and the low use of fertilisers. In order to find appropriate solutions for the sustainable management of soil fertility, a study was carried out on the Fertility Maintenance Trial (FTM), an experimental system established in 1960 in central western Burkina Faso, where organic and/or mineral fertilisation regimes combined with crop rotations have been tested. The approach of this study consisted of a synthesis of existing agronomic data from 2011-2019 on the three (03) crop rotations. Soil samples were taken from a depth of 0-20 cm for physico-chemical analysis. We also measured yields on the cotton and sorghum plots during the 2018 and 2019 seasons. The results show that yield variability can be attributed not only to fertilisation, but also to crop rotations and the annual rainfall recorded over the period. The sorghum-cotton and sorghum-cowpea rotations produced the highest average sorghum yields, at 547 kg.ha$^{-1}$ and 642 kg.ha$^{-1}$ respectively. Sorghum monoculture recorded the lowest sorghum production. Chemical analyses revealed higher phosphorus use in the sorghum-cowpea rotation compared with the other rotations. The study of cropping system efficiency also revealed the role of legumes in crop rotations in maintaining and preserving soil fertility. In addition, we can be recommending integrated soil fertility management (organic and mineral fertilisation, crop rotations, etc.) for sustainable management of productive capital on cotton farms in Burkina Faso.

**Keywords:** Impacts, Production, Crop rotations; Ferric Acrisol, Fertility Burkina Faso.

## INTRODUCTION

Strong demographic growth in recent years has led to high pressure on arable land resources. This high pressure on vegetation cover influences the capacity of soils to produce the biomass required to meet the needs of a growing population (Haddaway et al., 2014; FAO, 2018). By way of illustration, almost 60% of soil depletion has been attributed to various degrees of soil ecological processes, with agricultural practices becoming one of the main contributors (Affholder et al., 2013; Baize, 2017, Bolinder et al., 2020). Thus, research explores and takes a significant position in the overall resilience of agricultural objectives by transforming scientific information about soils into real techniques that increase farmers' understanding of the sustainability of their farming activities (Han et al., 2016; Borchard et al., 2019; Krauss

DOI : https://dx.doi.org/10.4314/ijbcs.v18i2.1

et al., 2020). One approach to sustainable agricultural management is to increase soil organic matter and reduce soil erosion through crop rotation (Laberge et al., 2011; Hopkins and Hansen, 2019; Krupnik et al., 2019; Rinot et al., 2019).

Crop rotation perturbs the reproduction of insects and pathogens, and therefore their life cycle. Plant nutrients are restored when certain plant species are included in the crop rotation, requiring less chemical fertiliser. Crop rotation is a useful technique in the practice of sustainable agriculture (Fontaine et al., 2011; Voisin et al., 2015; FAO, 2018; Guinet et al., 2019). Nevertheless, careful selection of a crop rotation pattern has the potential to reduce trade-offs between crop viability and environmental impacts, maintain long-term soil fertility and disrupt weed and disease cycling processes through intrinsic nutrient recycling (Bouthier and Trochard, 2015; Jeudy et al., 2016; Eva, 2019; Sierra et al., 2019).

The advantages of rotations including a legume in terms of food security and maintaining soil health are well established. After the rotation, the increasing heterogeneity of the agricultural production system will maintain or improve soil performance by increasing crop residues and various root systems, as well as increasing and developing agricultural activity (FAO, 2018; Bünemann et al., 2018; Eva, 2019; Chabert and Sarthou, 2020). To understand how soil fertility changes under crop rotations and to improve the sustainable management of soil fertility, an experiment was conducted at Saria, in the Centre-West region of Burkina Faso. Several research projects have been carried out on this experimental system, known as the Fertility Maintenance Trial (FTM). They focused on the impact of soil fertilisation options on carbon fractions, mineral balances, forms of phosphorus, soil organic matter and soil biology. Very little work has been done on the impact of the three (03) crop rotations on soil and crop productivity. This work will make it possible to evaluate the evolution of sorghum and soil production under the influence of the different crop rotations tested since 1960.

## MATERIALS AND METHODS

### Study site

The study was conducted in the long-term trial plots at the research station of the Institute of Environment and Agricultural Research (INERA) in Saria, a village located at 2°16'N, 2°9'W at an altitude of 300 m in central western Burkina Faso. The average rainfall in 2015, 2017 and 2019 was 964, 898 and 992 mm, corresponding to 67, 65 and 74 days of rain respectively in the area. The vegetation type was an open woody savannah and the main species were *Parkia biglobosa, Vitellaria paradoxa,* and *Tamarindus indica.* The herbaceous component was dominated by *Pennisetum pedicellatum, Andropogon sp., Loudetia togoensis* and *Schoenfeldia gracilis*.

### Experimental design: Fertility Maintenance Trial (FTM)

- The Fertility Maintenance Trial (FTM) was implemented in 1960 to study the fertility of a leached tropical ferruginous soil (ferric acrisol) under the influence of different cropping practices. These practices include mineral and organo-mineral fertilisation and three cropping systems: (i) sorghum monoculture *(Sorghum bicolor* L.*)*, (ii) sorghum-cotton *(Gossipium hirsutum)* rotation and (iii) sorghum-leguminous rotation (groundnut until 1973, cowpea *(Vigna unguiculate L.)* thereafter *cowpea*).

Six identical treatments were applied to each of the three systems. The dose of mineral fertiliser depended on the nature of the crop and was expressed in kg of N, $P_2O_5$ and $K_2O$.

The main treatments were :

- **te**: control without any fertilizer addition,
- **fmr**: low mineral fertilization (37-23-14-6S-1B) + recycling of sorghum residues once every two years,
- **fmo:** low mineral fertilization (37-23-14-6S-1B) + low rate of cow manure (5 t MS ha $^{-1}$ 2ans$^{-1}$),
- **fm:** exclusive low mineral fertilization (37-23-14-6S-1B),
- **FMO:** high mineral fertilization (60-23-44-6S-1B) + high rate of cow

manure (40 t MS ha $^{-1}$ 2ans$^{-1}$) + export of sorghum straw,

- **FM**: exclusive high mineral fertilization (60-23-44-6S-1B).

### Study approach

In this study, the available data on the three (03) rotations: sorghum-cotton, sorghum-cowpea and sorghum-sorghum from 1981 onwards, over a six-year period in the cotton-growing year (odd-numbered year) were used. Then, under this rotation systems based on sorghum, the agronomic and pedologic impact of the continuous application of mineral, organic and organic + mineral fertilisers we assessed. This enabled to assess the sorghum yield growth performance and soil chemical parameters evolution under the various soil fertilisation practices in sorghum-based rotations systems. In addition, to compare the agro-pedological efficiency of the three systems, we were considered the years in which the trial was cultivated with sorghum (even-numbered years since 1960). In principle, this comparison evaluates the after-effects of sorghum, cotton and cowpea cultivation respectively in the sorghum-sorghum (a), sorghum-cotton (b) and sorghum-cowpea (c) rotation systems. These cropping systems were compared to a fallowed field since 1961. As a result, the impact of each crop cultivation in the rotation could be assessed. Soil carbon, soil phosphorus and pH as chemical parameters and the sensitivity to soil degradation as physical property were the concerning studied parameters. The study focused on years when all the plots were cultivated with sorghum.

The efficiency of the systems was studied by considering the individual and cumulative effects of the six fertilisers applied.

The soil degradation sensitivity (St) is determined by the method of Pieri (1989):

**(St)= MO*100 / (A + Lf)**

where MO = organic matter, A = clay and Lf = fine silt.

- St < 5, the soil is physically degraded and highly susceptible to erosion;
- 5< St<7, the soil is at high risk of physical degradation;
- St >7, the soil is not at risk of degradation.

### Soil sampling and chemical analysis

Soil samples were taken at the end of the cropping season of 2011. That is three soil samples were taken per plot with an auger at 20 cm depth after harvest. The soil samples were then pooled and air dried and sieved at 2 mm. The soil organic carbon content was determined according to Walkley and Black (1934). The soil total N and P contents were determined after a wet digestion with $H_2SO_4$ solution, as described in Novozamsky et al. (1983) and an automatic colorimeter was used for measurements (SKALAR SAN plus SYSTEM). Available phosphorus was extracted according to the Bray and Kurtz (1945) and then, its content determined with the automatic colorimeter. Soil pH was determined, using the electrometric method, in a soil solution with soil and water ratio of 1/2.5.

### Statistical analysis

Rstudio was used for the Principal Component Analysis and to produce the boxplots. Genstat 9th edition was used for the analysis of variance of the data and the Newman Keuls test was applied for the separation of means at the 5% probability level.

## RESULTS

### Sorghum yield evolution over the five years under the various fertilisation practices and sorghum cropping rotation systems

The Table 1 shows a large variability in sorghum yields induced by different manures applied over time. The Newman Keuls test revealed a highly significant difference between the fertilisers, between years and the combined effects of fertilisers and years of cultivation. There was inter- and intra-annual variation between treatments.

Statistical analysis of average sorghum yields for the three crop rotations showed a highly significant difference between treatments (Table 1). The control had the lowest yields. It was followed respectively by the fm, fmr, FM, fmo and FMO manures. The organic+-mineral fertilisers had the highest annual yields. Annual increases of 31 to 56% of sorghum yields with mineral fertilisers application were reached by sorghum residues annual return to plots. However, the manure addition to mineral fertilised plots increases the sorghum yields by 25-39%, or at least double them. When higher rates of manure were applied to plots fertilised with higher rates of mineral fertilisers, the sorghum yield increase ranged from 10 to 44%. The increase of sorghum yield in sorghum-cotton rotation was 19.4% as compared to continuous sorghum-sorghum cropping system while in the case of sorghum-cowpea rotation, the yield increased by 40.2%.

Analyses of variance and probability on crop rotations revealed strong interactions between rotations and fertilisers on the one side, and their combined interaction with time on the other side. Thus, highly significant probabilities were recorded with these interactions.

### Agronomic efficiency of cropping systems on sorghum yield

Figure 1 shows the efficiency of the preceding cropping systems on sorghum yield. The Newman Keuls test revealed highly significant differences between sorghum, cotton and cowpea. The sorghum-cotton and sorghum-cowpea rotations had the highest average yields, at 547 kg.ha$^{-1}$ and 642 kg.ha$^{-1}$ respectively. Sorghum monoculture had the lowest yield, at 458 kg.ha$^{-1}$.

### Soil fertility impact of the various fertilisation practices in sorghum cropping based rotation systems

#### *Efficiency of crop rotations on soil organic matter, assimilable phosphorus and soil acidity*

Figure 2 shows the impact of fallow and crop rotations on soil organic matter. Soil organic matter content under set-aside and the sorghum-cowpea rotation is higher than under the other cropping rotations. The sorghum-cotton rotation had the lowest organic matter content.

A comparison of available phosphorus levels in the three crop rotations shows relatively higher levels in the sorghum-cotton and sorghum-sorghum rotations (Figure 2). The lowest levels were found on plots in set-aside and sorghum-cowpea rotations. The same observations were made regarding soil acidity (Figure 3) where pHwater 1:2.5 S-C > pH water 1:2.5 S-C > pH water 1:2.5 S-C > pH water 1:2.5 set-aside.

#### *Efficiency of fallow and crop rotations on soil granulometric fractions.*

The crop rotations led to a change in soil granulometric composition comparatively to the fallow (Figure 3). The clay content is higher on plots under sorghum-cowpea, sorghum-sorghum and sorghum-cotton rotations. The silt fraction is in increasing order on plots in sorghum-sorghum, sorghum-cowpea and sorghum-cotton rotations. The plots under sorghum-cotton and sorghum-sorghum rotations are very sandy. In most cases, these soils are predominantly silty-sandy. The clay fraction is low.

### Soil fertility management impacts on the sensitivity to soil degradation

The results on sensitivity to soil degradation (Table 2) show that most of the plots cultivated after 52 years are vulnerable to physical degradation. All the treatments are sensitive to soil degradation, except for the high rates application of organic + mineral fertilisers. (40 t.ha-1.2y$^{-1}$). The recommended dose of manure (5 t.ha-1.2y$^{-1}$), show a weak sensibility of soil degradation after 52 years of farming. This sensitivity to soil degradation is more pronounced with the continuous application of low and high mineral fertilisers and in mining agriculture practice (control).

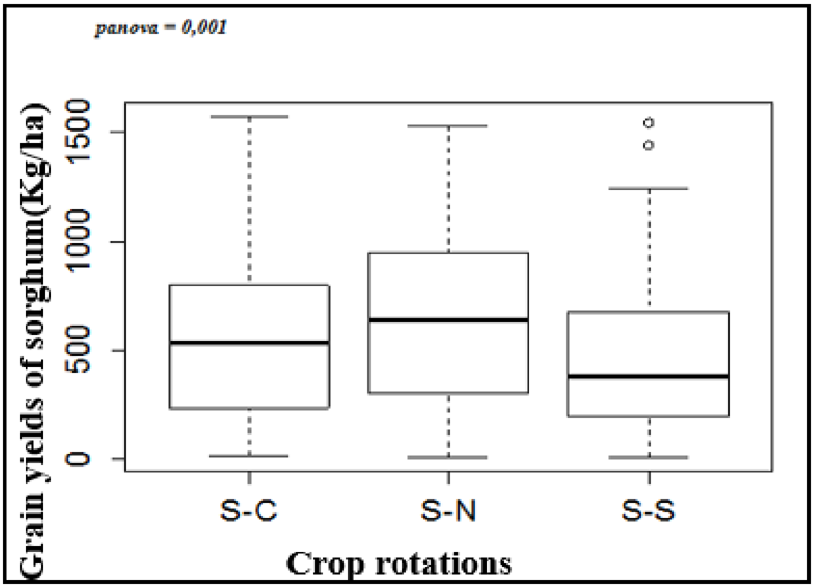
From another point of view, the soil degradation sensitivity induced by the Control, the low mineral fertiliser + sorghum residues and the low mineral fertiliser + low manure rate treatments under the three cropping rotations shows that the sorghum-cotton rotation has the lowest levels. That result to a relatively high sensitivity to degradation. As to sorghum-Cowpea rotation, the low values of soil degradation sensitivity were assessed with treatments high rate of mineral fertiliser and with high rates of mineral + organic fertilisers application. A comparison between crop rotations shows that plots in the sorghum-cotton rotation are more exposed to degradation.

**Table 1:** Average change in sorghum yield in cropping rotations under the impact of fertiliser options.

| **Years** | **te** | **fmr** | **fm** | **fmo** | **FMO** | **FM** |
|---|---|---|---|---|---|---|
| **2007** | 350 ± 45 | 840 ± 58 | 598 ± 37 | 833 ± 35 | 912 ± 56 | 781 ± 41 |
| **2009** | 389 ± 18 | 617 ± 27 | 757± 37 | 946 ± 64 | 1074 ± 35 | 955 ± 16 |
| **2011** | 290 ± 85 | 619 ± 57 | 398 ± 21 | 829 ± 14 | 911± 30 | 634 ± 11 |
| **2013** | 319 ± 98 | 648 ± 92 | 427 ± 12 | 858 ± 12 | 940± 31 | 663± 12 |
| **2015** | 393 ± 40 | 782 ± 107 | 597 ± 39 | 804 ± 30 | 810 ± 17 | 731 ± 34 |

| **Newman Keuls test at the 5% level** | **v.r.** | **p.r** |
|---|---|---|
| **Treatements** | **27,48** | **< 0,001** |
| **Years** | **13,52** | **< 0,001** |
| **Treatements * Years** | **2,27** | **< 0,001** |
| **Rotations* Treatements** | **3,82** | **< 0,001** |
| **Rotations * Treatements *Years** | **2,57** | **< 0,001** |

**te** :control without any fertilizer addition, **fmr** :low mineral fertilization (37-23-14-6S-1B) + recycling of sorghum residues once every two years, **fmo :**low mineral fertilization (37-23-14-6S-1B) + low rate of cow manure (5 t MS ha $^{-1}$ 2ans$^{-1}$), **fm :** exclusive low mineral fertilization (37-23-14-6S-1B), **FMO :** high mineral fertilization (60-23-44-6S-1B) + high rate of cow manure (40 t MS ha $^{-1}$ 2ans$^{-1}$)+ export of sorghum straw, **FM** : exclusive high mineral fertilization (60-23-44-6S-1B).



S-C: sorghum-cotton rotation; S-N: sorghum-cowpea rotation; S-S: pure sorghum.

**Figure 1:** Soil fertility impact of the various fertilisation practices in sorghum cropping based rotation systems.

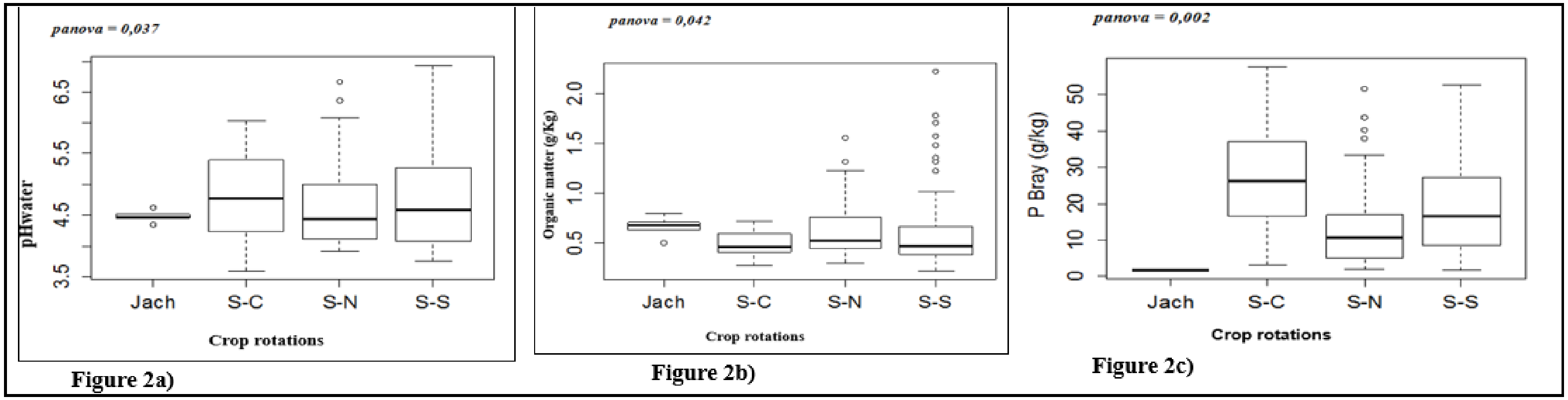


**Figure 2a)** **Figure 2b)** **Figure 2c)**

Jach: Fallow; S-C: sorghum-cotton rotation; S-N: sorghum-cowpea rotation; S-S: pure sorghum. The horizontal line inside the box plot represents the median.

**Figure 2:** Impact of cropping systems on soil organic matter, available phosphorus and pH$_{\text{water 1:2. 5}}$.

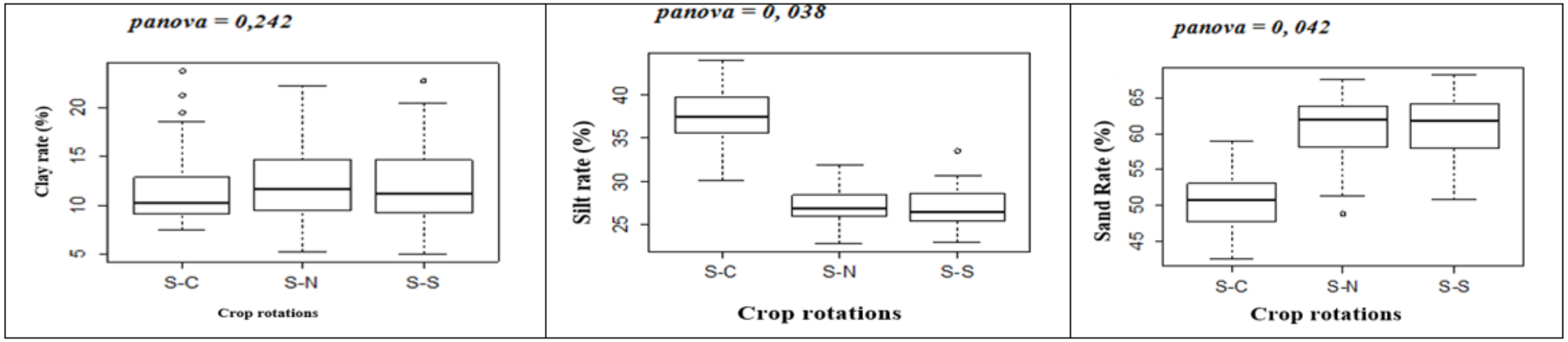


**Figure 3a)** **Figure 3b)** **Figure 3c)**

S-C: sorghum-cotton rotation; S-N: sorghum-cowpea rotation; S-S: pure sorghum. The horizontal line inside the box plot represents the median.

**Figure 3:** Impact of crop rotations on soil granulometric fractions.

**Table 2:** Sensitivity to soil degradation under different fertilization and cropping rotations.

| Treatements | Sorghum-Sorghum | Sorghum-Cotton | Sorghum-Cowpea | Cumulative effects of fertilisation |
|---|---|---|---|---|
| **Te** | 2.33 ± 0.63 a | 2.26 ± 0.79a | 2.63 ± 0.36 a | 2.48 ± 0.9 a |
| **Fmr** | 2.47 ± 0.02 a | 2.13 ± 0.91a | 3.45 ± 0.8 a | 3.04 ± 0.34 ab |
| **Fmo** | 4.88 ± 0.39 a | 3.44 ± 0.60a | 4.42 ± 0.16 a | 4.65 ± 0.28 ab |
| **Fm** | 2.37 ± 0.12 a | 3.65 ± 0.36a | 3.70 ± 0.56 a | 2.96 ± 0.41 ab |
| **FMO** | 11.83 ±3.84 b | 8.60 ± 3.55b | 8.53 ± 2.27 b | 10.18 ± 2.81 c |
| **FM** | 3.08 ±0.42 a | 3.40 ±0.65a | 2.81 ± 0.45 a | 2.94 ± 0.43 a |
| **Probability** | ***< 0,001*** | ***< 0,005*** | ***< 0,001*** | ***< 0,001*** |
| **Newman keulhs** | ***S*** | ***S*** | ***S*** | ***S*** |
| **Crop rotations** | 4,49 ± 0,54 | 4,05 ± 0,25 | 4,26 ± 0,29 | …… |
| **Probability** | | ***0, 124*** | | …… |

**te**: control without any fertilizer addition, **fmr**: low mineral fertilization (37-23-14-6S-1B) + recycling of sorghum residues once every two years, **fmo :**low mineral fertilization (37-23-14-6S-1B) + low rate of cow manure (5 t MS ha $^{-1}$ 2ans$^{-1}$), **fm :** exclusive low mineral fertilization (37-23-14-6S-1B), **FMO :** high mineral fertilization (60-23-44-6S-1B) + high rate of cow manure (40 t MS ha $^{-1}$ 2ans$^{-1}$)+ export of sorghum straw, **FM** : exclusive high mineral fertilization (60-23-44-6S-1B).

## DISCUSSION

### Agronomic and soil efficiency of cropping systems (sorghum-sorghum, sorghum-cotton, sorghum-niebe, fallow)

By studying the agronomic and soil efficiency of cropping systems, it is possible to assess their potential for sustainable fertility management. This efficiency depends on the practices intrinsic to each system.

### *Agronomic efficiency of the three (3) crop rotations*

The average yields obtained over time with sorghum cropping rotation systems comparatively to pure cropping sorghum system show a higher performance The sorghum-cowpea and sorghum-cotton rotations largely contributed to improving sorghum yields. Similar performance of cereal yields are found in rotations and associations cropping systems that include cowpea (Zingore et al., 2008 ; Tittonell et al., 2013 ; Ripoche et al., 2015). Effect and residual effect of N symbiotic fixation by the leguminous crops in the rotation or association (cowpea and groundnut) are advanced to explain the cereal yields increase. Bado (2002) and Bado et al. (2006) in Burkina Faso have shown that groundnut and cowpea are able to cover 27-34% and 52-56% of their N requirements respectively through symbiotic nitrogen fixation process. This fixed nitrogen makes a greater contribution to plant growth than nitrogen fertilisers application (Bado et al., 2006; Carroué et al., 2012; Guinet et al., 2019). Leguminous crop residues are richer in nitrogen and help to enrich the soil in this element (Asimi, 2009; Haddaway et al., 2014; Jeudy et al., 2016).

Sorghum following cowpea and cotton can benefit indirectly from nutrients through the residues left by the two crops or residual fertilisers applied (Beillouin et al., 2015; Voisin et al., 2015; Sierra and Tournebize, 2019). These effects identified as "rotational effects" are explained by the improvement of soil chemical and biological properties by the leguminous crops which later can enable the physical one. Crop rotation also has other advantages, such as reducing pest attacks (Constantin et al., 2012; Ouandaogo et al., 2016; Guinet et al., 2019). However, crop rotation is not practised systematically by farmers, no doubt because of the limited available land. Combining cereal crops with leguminous plants is the most common practice. In Burkina Faso, more than 80% of sorghum and cowpea are grown in association.

### *Soil efficiency of cropping systems*

The fallow and the sorghum-cowpea rotation contributed to maintaining the organic status of the soil compared to the pure sorghum cultivation and sorghum-cotton rotation. Improving soil organic status in fallow could be explain by the presence of plant biomass, which turned to increase the soil organic carbon content. In the case of the sorghum-cowpea rotation, the improved soil organic status is the result of cowpea biomass residual stock and the increase of soil N content due to symbiotic fixation. Otherwise, soil N content is always linked to that of C. The contribution of fallow and crop rotations can be attributed both to carbon sequestration through the roots and to various crop exports. Somé et al., (2007), in the case of improved fallows, recorded a significant increase in soil organic matter stock of over 40% due to litter. They asserted that, given that the spiked biomass of fallow is mown and exported at the end of each season, its contribution to observed variations in soil chemical elements is low. The subsurface litter parts of the grasses largely contribute to the increase in fallow soil C content (Craheix et al., 2012; Krupnik et al., 2019; Krauss et al., 2020). Subsurface litter parts (root) can vary between 2 and 7 t C ha$^{-1}$ year$^{-1}$ (Garay et al., 2000; Douxchamps et al., 2010; Fontaine et al., 2011). That probably explains the difference in organic matter content between the fallow and the three rotations. The difference can be attributed to the difference in root biomass ploughed in by each cropping system. In addition, the different manures influence crop nutrient uptake at different levels. This explains the differences in nutrient reserves within each fertilisation regime. Added to this are the biological processes under the impact of these fertilisation practices, on which depend the degree of mineralisation and the capacity of each system to store carbon in the soil.

As regards available phosphorus under these cropping systems, the biennial sorghum-cotton rotation and continuous sorghum-cultivation provide a better supply of available phosphorus. This is due to the yields obtained in these cropping systems, which imply relatively low Phosphorus or nutrients? exports compared with those obtained in the sorghum-cowpea rotation. It should be noted that cowpea allows good use of phosphorus (P) by the subsequent cereal crop. In Burkina Faso, Bado (2002) showed that after groundnut and cowpea precedents, sorghum took up 2 to 3 times more nitrogen and twice as much P to enhance the yield increases by about 60 to 300% respectively. This explains the lower P content and higher yields of sorghum in this rotation, compared with the continuous sorghum cropping and sorghum-cotton rotation systems.

Crop rotations influenced the soil granulometric composition. The fine fractions (0-50 µm), (50-200 µm) shows that the plots under sorghum-cowpea and sorghum-cotton rotations were more clayey and siltier respectively.

With total sand content (200-2000 µm), the same trend as that on soil organic matter content (Sorghum-Cotton Sands < Sorghum-Sorghum Sands < Sorghum-Cowpea Sands) was observed. This confirms once again the close relationship between the coarse fraction and soil organic matter content. This difference can be justified by the soil protection function provided by each crop in the rotation. In the sorghum-cowpea rotation, the cowpea, as it develops, acts as a biological cover, and thus protects the soil against erosion factors (wind, run-off). It also acts as an anti-erosion agent by retaining fine fractions. When comparing the biomass of continuous sorghum cropping system and sorghum-cotton rotation over one rotation cycle, we obtain a higher production under the continuous sorghum cropping system is obtained. Sorghum often has a branched surface structure, which reduces runoff and hence the loss of the fine fraction.

### Sensitivity to soil degradation

The study on soil sensitivity to degradation argues in favour of integrated soil fertility management strategies. The mining agriculture and the continuous application of mineral fertilisers are not recognised for sustainable soil use. In the long term, these agricultural practices expose soils to degradation (Luo et al., 2010; Kiba, 2012; Pouya et al., 2013b). Only the high-rate input of organic and mineral fertilisers has been able to conserve the soil better. Low rate of organic and-mineral fertilisers reduced the soil degradation. The present results confirm the benefits of crop rotations for soil fertility management. A rational crop rotation balances in nutrients exports and is an excellent farm management plan (Ly et al., 2020; Young et al., 2021).

## Conclusion

After 50 years cultivation, the lixisol in the West-central part of Burkina Faso leads to a general fluctuation of crop yields linked not only to rainfall patterns but above all to different fertilisation practices. The risks of the mining agriculture on the decreasing cotton yields and on soil fertility depletion have been demonstrated. Fertilisation practices that combine organic matter and mineral fertilisers are recognised to enhance sustainable production. Therefore applying manure or compost at the rate of 6 $t.ha^{-1}.2y^{-1}$ plus an annual input of 100 Kg.ha-1 of NPK and 50 $Kg.ha^{-1}$ of urea to the cotton plant can be recommended. The dose of 5 $t. ha^{-1}.2y^{-1}$ of organic matter seems unsuitable to maintain the soil fertility. Crop diversification through rotations, especially by the incorporating of leguminous (cowpea or groundnut), offers definite agronomic and soil-related advantages over the continuous sorghum cultivation. Finally, a triennial sorghum-cotton-cowpea rotation for cotton cultivation is recommended. In this case, an annual input of 3 $t.ha^{-1}$ of compost or manure is suitable. In addition, the cotton residues can be transformed into compost by using an appropriate and proven technic to, thereby help diversify the sources of organic soil improvers.

## ACKNOWLEDGEMENTS

The authors are grateful to the "Laboratoire Sol-Eau-Plante" of the "Institute of the Environment and Agricultural Research (INERA)", Burkina Faso, for supporting this research. We are grateful to the field technician Sanon Martin for their assistance during the fieldwork, and to Moyenga Momini, Ramdé Martin and Kaboré Jean-Paul for the lab analysis.

## COMPETING INTERESTS

The authors declare that they have no competing interest concerning this article.

## AUTHORS' CONTRIBUTIONS

All authors contributed to the realization of the work and to the manuscript preparation.

## REFERENCES

Affholder F, Poeydebat C, Corbeels M, Scopel E, Tittonell P. 2013. The yield gap of major food crops in family agriculture in the tropics: Assessment and analysis through field surveys and modelling. *Field Crops Research,* **143**: 106–118. DOI: http://doi.org/10.1016/j.fcr.2012.10.021.

Asimi S. 2009. Influence des modes de gestion de la fertilité des sols sur l'activité microbienne dans un système de cultures de longue durée au Burkina Faso. Thèse de Doctorat d'Etat. Université Polytechnique de Bobo-Dioulasso/ Institut du Développement Rural, 159 p.

Bado BV. 2002. Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéenne et soudanienne au Burkina- Faso. Thèse de doctorat de troisième cycle, université Laval Québec, 148p.

Bado BV, Bationo A, Cescas MP. 2006. Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa). *Biology and Fertility of Soils,* **2**: 171-176.

Baize D. 2017. Du taux de carbone à celui de matières organiques dans les sols — Les Mots de l'agronomie [WWW Document]. URL https://lorexplor.istex.fr/motsagronomie.fr/index.php/Du_taux_de_carbone_%C3%A0_celui_de_mati%C3%A8res_organiques_dans_les_sols (accessed 6.6.22).

Bolinder MA, Crotty F, Elsen A, Frac M, Kismányoky T, Lipiec J, Tits M, Tóth Z, Kätterer T. 2020. The effect of crop residues, cover crops, manures and nitrogen fertilization on soil organic carbon changes in agroecosystems: a synthesis of reviews. *Mitig. Adapt. Strateg. Glob. Chang.*, **25**: 929-952. DOI: 10.1007/s11027–020-09916–3.

Borchard M, Schirrmann ML, Cayuela C, Kammann N, Wrage-Mönnig JM, Estavillo T, Fuertes-Mendizábal G, Sigua K, Spokas JA, Ippolito JN. 2019. Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: a meta-analysis. *Sci. Total Environ.,* **651** : 2354-2364. DOI : 10.1016/j.scitotenv.2018.10.060.

Beillouin D, Schneider A, Carrouée B, Champolivier L, Le Gall C, Jeuffroy MH. 2014. Short- and medium-term effects on nitrogen leaching of the introduction of a pea or an oilseed rape crop in wheatbased successions Poster avec extended abstract, 18th Nitrogen Workshop Lisbon, 30 June - 3 July 2014.

Bouthier A, Trochard R. 2015. Incidence d'apports répétés d'engrais de ferme sur la fertilité physique, chimique et microbiologique des sols sous rotation de cultures annuelles et sous prairie temporaire. *Fourrages,* **223**: 211-219.

Bray RH, Kurtz LT. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science,* **59**(1): 39-45.

Bünemann EK, Bongiorno G, Bai Z, Creamer RE, De Deyn G , Goede R , Fleskens L , Geissen V , Kuyper TW , Mäder P , Pulleman M, Sukkel W , van Groenigen JW, Brussaard L ,2018. Soil quality – a critical review. *Soil Biol. Biochem.,* **120**: 105-125. DOI: 10.1016/j.soilbio.2018.01.030.

Carroué B, Scheider A, Flénet F, Jeuffroy MH, Nemecek T. 2012. Introduction of dry pea crop in rotation of cereals and rapeseed: impacton the economic and environmental performances. *Innovations. Innov Agronomiques,* **25**: 125–142.

Chabert A, Sarthou JP. 2020. Conservation agriculture as a promising trade-off between conventional and organic agriculture in bundling ecosystem services. *Agric. Ecosyst. Environ.,* **292**: 106815. DOI: https://doi.org/10.1016/j.agee.2019.106815.

Constantin J, Beaudoin N, Launay M, Duval J, Mary B. 2012. Long-term nitrogen dynamics in various catch crop scenarios: Test and simulations with STICS model in a temperate climate. *Agriculture, Ecosystems & Environment,* **147**: 36-46.

Craheix D, Angevin F, Bergez JE, Bockstaller C, Colomb B, Guichard L, Reau R, Doré T. 2012. MASC 2.0, un outil d'évaluation multicritère pour estimer la contribution des systèmes de culture au développement durable. *Innovations Agronomiques,* **20**: 35-48.

Douxchamps S, Humbert FL, Hoek R, Mena M, Bernasconi SM, Schmidt A, Rao I, Frossard E and Oberson A. 2010. Nitrogen balances in farmers fields under alternative uses of a cover crop legume: a case study from Nicaragua. *Nutr Cycl Agroecosyst,* **88**: 447-462.

Eva T. 2019. Effet de la diversification spatiale et temporelle des cultures à l'échelle du paysage agricole sur le biocontrôle et les ravageurs de culture. Sciences agricoles. COMUE Université Côte d'Azur (2015 - 2019), 2019. Français. ffNNT : 2019AZUR6032ff. fftel-03135557f

FAO. 2018. Etat de la situation alimentaire et de la nutrition dans le monde, renforcer la résilience face aux changements climatiques pour la sécurité alimentaire et la nutrition, Rome (Italie).

Fontaine L, Garnier JF, Bonte JB, Aubert C, Fourrié L, Colomb B, Glachant C, Maurice R, Gouraud JP, Morand P, Perret C. 2011. Rotations en grandes cultures biologiques sans élevage, 8 ferme-types, 11 rotations. Repères agronomiques, économiques, techniques et environnementaux. Restitution du projet RotAB, ITAB, 132 p. + annexes.

Guinet M, Nicolardot B, Durey V, Revellin C, Lombard F, Pimet E, Bizouard F, Voisin AS. 2019. Fixation symbiotique de l'azote et effet précédent : toutes les légumineuses à graines se valent-elles ? *Innovations Agronomiques,* **74**: 55-68. DOI: ff10.15454/jj5qvvff.ffhal-02158172f.

Haddaway NR, Söderström B, Hedlund K, Jackson LE , Kätterer T, Lugato E, Thomsen IK, Bracht Jorgensen H. 2014. What are the effects of agricultural management on soil organic carbon (SOC) stocks? Environ. Evid., **3**: 2. DOI:10.1186/2047-2382-3-2.

Han P, Zhang W, Wang G , Sun W , Huang Y. 2016. Changes in soil organic carbon in croplands subjected to fertilizer management: a global meta-analysis. *Sci. Rep.,* **6**: 27199. DOI: 10.1038/srep27199.

Hopkins BG, Hansen NC. 2019. Phosphorus management in high-yield systems. *J. Environ. Qual.,* **48**: 1265-1280. DOI: 10.2134/jeq2019.03.0130.

Jeudy C, Adrian M, Baussard C, Bernard C, Bernaud E, Bourion V, Busset H, Cabrera-Bosquet L, Cointault F, Han S. 2016. RhizoTubes as a new tool for high throughput imaging of plant root development and architecture: test, comparison with pot grown plants and validation. *Plant Methods,* **12** : 1-18.

Kiba DI. 2012. Diversité des modes de gestion de la fertilité des sols et leurs effets sur la qualité des sols et la production des cultures en zones urbaine, péri-urbaine et rurale au Burkina Faso. Thèse de doctorat unique, Université Polytechnique de Bobo-Dioulasso, Burkina Faso, 172 p.

Krupnik TJ, Andersson JA, Rusinamhodzi L, Corbeels M , Shennan C , Gérard B. 2019. Does size matter? A critical review of meta-analysis in agronomy. Exp. Agric., **55**: 200-229. DOI: 10.1017/S0014479719000012

Krauss M, Berner A, Perrochet F, Frei R, Niggli U, Mäder P. 2020. Enhanced soil quality with reduced tillage and solid manures in organic farming – a synthesis of 15 years. *Sci. Rep.,* **10**: 1-12. DOI: 10.1038/s41598-020-61320-8

Laberge G, Haussmann RIG, Ambus P, HoghJensen H. 2011. Cowpea N rhizodeposition and its below-ground transfer to a co-existing and to a subsequent millet crop on a sandy soil of the Soudano-Sahelian eco-zone. *Plant and Soil,* **340**: 369-382.

Luo Z, Wang E, Sun OJ. 2010. Soil carbon change and its responses to agricultural practices in Australian agro-ecosystems: a review and synthesis. *Geoderma,* **155**: 211–223. DOI: https://doi.org/10.1016/j.geoderma.2009.12.012

Lv F , Song J, Giltrap D, Feng Y, Yang X, Zhang S. 2020.Crop yield and N2O emission affected by long-term organic manure substitution fertilizer under winter wheat-summer maize cropping system. *Sci. Total Environ.,* **732**: Article 139321, DOI: 10.1016/j.scitotenv.2020.139321.

Ouandaogo N, Ouattara B, Pouya BM, Gnankambary Z, Nacro BH, Sedogo PM. 2016. Effets des fumures organominérales et des rotations culturales sur la qualité des sols. *Int. J. Biol. Chem. Sci.,* **10**(2): 904-918.

Pieri C. 1989. Fertilité des terres de savanes. Bilan de 30 ans de recherche et de développement agricoles au Sud du Sahara. CIRAD/Ministère de la Coopération et du Développement, 444 p.

Pouya M, Bonzi M, Gnankambary Z, Traore K, Ouédraogo J, Somé A, Sédogo M. 2013. Pratiques actuelles de gestion de la fertilité des sols et leurs effets sur la production du cotonnier et sur le sol dans les exploitations cotonnières du Centre et de l'Ouest du Burkina Faso. *Cahier d'Agriculture,* **22**(4) : 282–292. DOI : http://doi.org/10.1684/agr.2013.0643

Rinot O, Levy GJ, Steinberger Y, Svoray, Eshel G.2018. Soil health assessment: a critical review of current methodologies and a proposed new approach. *Sci. Total Environ.,* **648**: 1484-1491. DOI: 10.1016/j.scitotenv.2018.08.259.

Ripoche A, Crétenet M, Corbeels M, Affholder F, Naudin K, Sissoko F, … Tittonell P. 2015. Cotton as an entry point for soil fertility maintenance and food crop productivity in savannah agroecosystems–Evidence from a long-term experiment in southern Mali. *Field Crops Research,* **177**: 37–48. DOI: http://doi.org/10.1016/j.fcr.2015.02.013.

Sierra J, Tournebize R. 2019. Fixation symbiotique d'azote par les légumineuses en association. Résultats obtenus en Guadeloupe. [0] 9, Inconnu. 2019, 12 p. ffhal-02373208.

Somé NA, Traoré K, Traoré O, Tassembedo M. 2007. Potentiel des jachères artificielles à Andropogon spp. Dans l'amélioration des propriétés chimiques et biologiques des sols en zone soudanienne (Burkina Faso). *BASE,* **11** (3): 245–252.

Tittonell P, Giller KE. 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research,* **143**: 76–90. DOI: http://doi.org/10.1016/j.fcr.2012.10.007.

Voisin AS, Pierre Cellier, Jeuffroy MH. 2015. Fonctionnement de la symbiose fixatrice de N2 des légumineuses à graines : Impacts agronomiques et environnementaux. *Innovations Agronomiques,* **43** : 139-160. ffhal-01173363f

Young MD, Ros GH, de Vries W. 2021. Impacts of agronomic measures on crop, soil, and environmental indicators: A review and synthesis of meta-analysis. *Agric. Ecosyst. Environ.,* **319**: 107551. DOI: https://doi.org/10.1016/j.agee.2021.107551.

Walkley A, Black A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* **37**: 29-38.

Zingore S, Murwira HK, Delve RJ, Giller KE. 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems and Environment*, **119**: 112-126.