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# Fertilizer application and chemical fertility of a lixisol in a crop rotation system in the southern Sudanian zone of Burkina Faso

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**Abstract**

The lack of organic matter in soils and the high cost of mineral fertilizers are constraints to the intensification of agricultural production in Burkina Faso. The aim of this study is to evaluate the effects of the joint application of organic and mineral matter on soil fertility under crop rotation conditions. The study was carried out at the research station in Farakoba, from 2018 to 2020. The system was a 4x4 split-plot factorial with 3 replications. The 4 treatments corresponded to 4 crop rotations used as the main factor and 4 manures as the secondary factor. We used 4 rotation sequences: Sorghum-Fonio, Soya-Fonio, Mung bean-fonio, Sorghum-Mung bean. The four secondary treatments corresponded to four fertilizers: control with no fertilizer application; NPK and urea; Compost+poultry manure; Compost+poultry manure+Burkina phosphate). Results showed that legume-cereal rotations resulted in a 2.3% drop in C/N ratio, while the total exchangeable base (TEB) and the cation exchange capacity (CEC) increased by 82.53% and 24.08% respectively compared to the soil at the start of cultivation. Compared to the soil at the beginning of the crop, the soya-fonio rotation resulted in CEC and TEB increases of 26.87% and 86.55% respectively. The Compost+poultry manure treatment recorded significantly higher TEB and CEC contents, followed by the Compost+poultry manure+Burkina Phosphate and Compost+NPK+Urea treatments. Compared to the Compost+NPK+Urea treatment, the Compost+Poultry manure +Burkina Phosphate treatment resulted in TEB and CEC increases of 18.7% and 5.06% respectively. The results showed a negative and non-significant correlation between C/N and the parameters Ca, Na, Mg, TEB, CEC and saturation level. On the other hand, the correlation between C/N and K was positive and non-significant (r=0.036). In a context of high mineral fertilizer costs, fertilization techniques and productivity of systems can therefore be improved by combining local fertilizing resources such as poultry manure, Burkina phosphate and legume rotations.

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## Introduction

The combination of climatic factors and current cropping practices (low restitution of mineral element exports) in the western zone explains the decline in soil fertility and its rapid degradation (Bado and Bationo, 2018). For most farmers, the use of mineral fertilizer is the only fertilization technique. In the long run, only-mineral fertilization leads to a decline in soil fertility and subsequently to lower crop yields. However, given the cost of inputs, the use of mineral fertilizer in Burkina remains very low, with an average of only 385.32 kg/ha of organic fertilizer, 32.24 kg/ha of NPK and 13.84 kg/ha of urea (MAAH, 2020). Producers are increasingly resorting to the use of organic manure or legume crops to restore soil fertility at lower cost. According to Hatfield et al., (2017), ensuring more stable and sustainable soil productivity helps reduce producers' dependence on external inputs such as mineral fertilizers. Nitrogen-fixing legume crops are very useful for improving soil fertility, land productivity and the incomes of smallholder farmers (Bado et al., 2012). Poultry manure is recognized as the most remarkable natural fertilizer, due to its high nitrogen content (Delgado et al., 2012). This fertilizer contains nitrogen in two main forms: ammoniacal nitrogen, which behaves like a conventional mineral fertilizer, and organic nitrogen, which needs to be degraded by soil microorganisms to mineralize (Gomgnimbou et al., 2019). Introducing local fertilizers into farming systems through poultry manures combined with legumes could further contribute to income generation and improve the productivity and resilience of farming systems, thereby improving food and nutrition security.

The present study is in this context and aims to provide information on the conditions for using organic manure (compost and poultry manure) and/or mineral manure (NPK, urea and Burkina phosphate) in combination with crop rotation to maintain plot productivity at lower cost in fonio- and sorghum-based cropping systems. This study aims to investigate the effects of different crop rotations and fertilizer formulas on soil chemical properties in the South Sudanian zone of Burkina Faso.

## Materials and Methods

### Presentation of the study area

The study was carried out at INERA's Farako-Bâ experimental station, located 10 km south of Bobo-Dioulasso (Burkina Faso) on the Bobo-Banfora route between longitude 04°20' West and latitude 11°06' North, at an altitude of 405 m. The Farako-Bâ research station is located in the southern Sudanian zone of Burkina Faso, which is characterized by two alternating seasons: a rainy season lasting 5 to 6 months from May to October, with rainfall ranging from 950 to 1200 mm, and a dry season from November to April (Guinko, 1998). The soils at INERA Farako-Bâ are mostly of the tropical ferruginous type.

### Plant material

The plant material used in our study consists of two improved varieties: The ICSV 1049 variety of sorghum (*Sorghum bicolor*) from the ICRISAT and INERA varietal selection units, with a cycle from sowing to maturity of 110 to 120 days with an average yield of about 4 t/ha (CNS, 2014). The fonio variety CVF 109 (Digitaria exilis Stapf). This variety was developed by INERA and has a 95-day cycle. This variety has a potential yield of 1.5 to 2 t/ha.

### Fertilizers used

The organic fertilizers used were poultry manure and compost. The compost was obtained after pile composting of natural biomass (straw). The poultry manure was taken from the poultry house of the *Centre Agricole Polyvalente de Matourkou/Burkina Faso*. The mineral fertilizers used were NPK (formula 14-23-14) and urea (46% nitrogen) from retailers approved by government technical structures.

The natural phosphates used come from the Kodjari deposit, located in eastern Burkina Faso, and contain an average of 25% $P_2O_5$ (of which only 0.03% is water-soluble) and 35% CaO. With a pH-water of 7.04, poultry manure has organic carbon, total nitrogen and total phosphorus contents of 32.05%, 2.128% and 9688.53 mg/kg respectively. The compost has a pH-water of 7.5 and organic carbon, total nitrogen and total phosphorus contents of 15.06%, 0.887% and 6543.86 mg/kg respectively.

### Methodology

#### *Soil preparation*

The soil is prepared by plowing with a disc plow to a depth of 20 cm followed by harrowing.

### *Experimental system*

The test was conducted over two seasons (2018 to 2021). The system is a split-plot factorial trial with 4 main treatments, 6 secondary treatments and 3 replications. The main plots measure 89.25 $m^2$ (8.5 m x 10.5 m) and are spaced one meter apart. The secondary plots each measure 20 $m^2$ (4 m x 5 m) and are spaced 0.5 m apart.

The total surface area of the trial is 1,237.5 $m^2$ (45 m x 27.5 m). The main treatments applied correspond to the crop sequencies (Sorghum-Fonio, Soya-Fonio, Mung bean-Sorghum, Mung bean-Fonio) and are presented in Table 1.

Secondary treatments were also randomized in each secondary plot (T0 = control, T1 = Compost+NPK + Urea, T2 = Poultry manure (7.5 t $ha^{-1}$) and T3 = Compost+Poultry manure (7.5 t/ha) + BP (Table 2).

### *Seeding and care*

Fonio was sown in continuous rows at 0.80 m row spacing. Sorghum was also sown with 0.80 m between rows and 0.40 m between seed holes.

NPK (150 kg $ha^{-1}$), Burkina Phosphate (500 kg $ha^{-1}$) and compost (2.5 t $ha^{-1}$) were used as background fertilizers, while urea was applied as a maintenance fertilizer (100 kg/ha: 50 kg/ha at tillering and 50 kg $ha^{-1}$ at bolting). Poultry manure (7.5 t $ha^{-1}$) was applied in two fractions: 2/3 (5 t $ha^{-1}$) before sowing and 1/3 (2.5 t $ha^{-1}$) 45 days after sowing.

### Methods of chemical analysis

The following chemical parameters were measured:

### Total carbon (Total C)

Total carbon (Total C) was determined using the Walkley-Black method (1934).

### Total nitrogen (Tota N)

Total nitrogen (Tota N) was determined by the Kjeldahl method (Hillebrand et al., 1953). Soil samples were subjected to Kjeldahl mineralization with sulfuric acid and salicylic acid ($C_7H_6O_3$) in the presence of hydrogen peroxide ($H_2O_2$) and selenium (Se) as a catalyst.

### Tota exchangeable bases (TEB)

Tota exchangeable bases (TEB). Exchangeable bases (Na+, K+, $Ca^{2+}$, $Mg^{2+}$) were extracted with ammonium acetate and determined by atomic absorption spectrophotometry for calcium and magnesium, and flame emission photometry for sodium and potassium (Houba et al., 1995).

### Cation Exchange Capacity (CEC)

Cation Exchange Capacity (CEC) The determination was by the Metson method involved three stages: the sample was saturated with ammonium ions ($NH4^+$); after removal of excess ammonium ions by percolation with ethyl alcohol, the displaced ammonium ions were determined by spectro-colorimetry (AFNOR, 1981).

### Statistical analysis

Data collected and entered in Excel were subjected into an analysis of variance (ANOVA) using Genstat version 11.1 software. Averages were compared using the Newman-Keuls test at the 5% threshold.

## Results and Discussion

### Effect of rotations on soil chemical properties

Table 3 shows the initial soil properties at the beginning of cultivation and the effects of the cropping systems on the soil after three years of cultivation. Statistical analysis showed significant differences between rotations for potassium content. There were no differences between treatments for Ca, Mg, Na, TEB and CEC. The study showed that the legume-cereal rotation cropping systems resulted in a 2.3% decrease in C/N ratio, while SBE and CEC increased by 82.53% and 24.08% respectively.

The soya-fonio rotation increased K by 4.7 compared with the sorghum-fonio rotation. On the other hand, the sorghum-fonio rotation improved CEC and TEB, while the lowest SBE and CEC levels were recorded in the mung bean-fonio rotation. The sorghum-fonio rotation increased SBE and CEC by 7% and 4.3% respectively in the mung bean-fonio rotation. Compared to the soil at the beginning of the cultivation, the sorghum-fonio rotation and the soya-fonio rotation increased CEC by 26.87% and 25% respectively, and TEB by 86.55% and 85.49% respectively.

## Effect of treatments on soil chemical properties

Table 4 shows the properties of the initial soil at the beginning of cultivation (2018) and the effects of poultry manure and mineral fertilizers on the soil in 2021, after three years of cultivation (2019-2021). Statistical analysis showed that the treatments resulted in an increase of more than 100% in TEB and CEC content compared with the soil at the beginning of the test. The Compost+FV treatment recorded the highest SBE and CEC content, followed by Compost+FV+BP and Compost+NPK+Urea. Compared with the absolute control treatment, the Compost+FV treatment resulted in CEC and SBE increases of 16.56% and 87.74% respectively. The results showed that the Compost+FV+BP treatment resulted in TEB and CEC increases of 18.7% and 5.06% respectively, compared with the Compost+NPK+Urea treatment. Compared to the soil at the beginning of the season, the C/N ratio decreased by 2.01%. The greatest decrease in C/N ratio was observed in the Compost+FV and absolute control plots, by 3.09% and 2.25% respectively.

## Relationship between soil rotation parameters and fertilizers

Examination of the correlation circle between variables (soil chemical parameters) and individuals (treatments) in the main plane 1-2 (Fig. 1) shows the relationships between the different soil chemical parameters and the cropping system/fertilizer combinations. Some relationships are close. This is the case for treatments R2T2 and R4T2, which are related to TBE, CEC, Ca, Mg and saturation level. The treatments "R3T1", "R4T3", "R2T3" and "R1T3" are quite close and are related to the parameters C/N and K. Treatments R4T0, R4T1, R2T1, R1T1 and R2T1 are strongly related and weakly related to treatments R3T0, R1T0, R3T3.

Table 5 shows the correlation matrix between chemical parameters. Very close, statistically significant relationships exist between Ca and K (r=0.81) and Ca and SBE (r=0.95) and between Ca and CEC (r=0.89). There was a negative and non-significant correlation between the C/N parameter and Ca, Na, Mg, TEB, CEC and saturation level. However, the correlation between C/N and K (r=0.036) is positive and non-significant.

The soil fertility results showed a decrease in the C/N ratio and an increase in CEC and TEB. These two elements play an important role in the decomposition of OM and the availability of nutrients in the soil. The use of crop rotations and the application of organic fertilizers, especially Compost+poultry manure, has improved the availability of Na and Mg. This is due to the mineralization of organic matter, which initially increases the amount of humus in the soil, thereby improving the number of electronegative sites on the CEC and the number of nutrients in the soil, particularly $Ca^{2+}$ and $Mg^{2+}$.

These two positively charged cations replace $Na^{+}$ on the CEC, leading to a decrease in the latter and an increase in exchangeable cations. Our results confirm those found by Diallo et al., (2019) which indicated that organic fertilization leads to an increase in CEC. The joint use of poultry manure and mineral fertilizers has probably created favorable conditions for biological activities. This situation allows the release of nutrients, particularly exchangeable bases. The addition of 7.5 $t.ha^{-1}$ of poultry manure and 5 $t.ha^{-1}$ of compost almost doubled the calcium content of the soil. Combined, these two types of manure appear to be more conducive to establishing good soil condition for calcium fixation conditions. Kiba et al., (2020) showed that poultry manure has a higher nutrient content, including base cations (Ca, Mg and Na).

The application of poultry manure in cropping systems has helped to increase base cations in the soil. It is generally accepted that poultry manure can be used as liming material (Munir et al., 2019). Furthermore, during microbial decomposition of applied poultry manure and compost, base cations are released (Donatus et al., 2014). Similar results were obtained by Benouadah et al., (2020) and Sanon et al., (2021).

The increase in TEB and CEC of 82.53 and 24% due to leguminous precedents. All these increases in chemical parameters confirm the importance of legume cultivation over the subsequent cultivation of fonio and sorghum. The beneficial effect observed can be attributed to the nitrogen fixed by the legume, the N saved under the legume crop, and the liberation of N from the decomposition of legume residues (Bado et al., 2018) resulting in an increase in nitrogen and a decrease in carbon. This situation probably explains the decrease in the C/N ratio, since the use of crop rotations led to a 2.3% decrease in the C/N ratio. The negative correlation between C/N ratio and soil CEC and TEB content indicates a certain relationship between these parameters.

**Table 1.** List of main treatments (rotations).

| **Rotations** | **Years** | | | |
|---|---|---|---|---|
| | **2018** | **2019** | **2020** | **2021** |
| **R1** | Fonio | Sorghum | Fonio | Sorghum |
| **R2** | Soya | Fonio | Soya | Fonio |
| **R3** | Sorghum | Mung bean | Sorghum | Mung bean |
| **R4** | Mung bean | Fonio | Mung bean | Fonio |

**Table 2.** List of secondary treatments (manures) in secondary plots.

| **Treatments** | **Description** |
|---|---|
| **T0** | Absolute control |
| **T1** | Compost (2.5 t $ha^{-1}$) + NPK (150 kg $ha^{-1}$) + Vulgarized urea (100 kg $ha^{-1}$) |
| **T2** | Compost (2.5 t $ha^{-1}$) + Poultry manure (7.5 t $ha^{-1}$) |
| **T3** | Compost (2.5 t $ha^{-1}$) + Poultry manure (7.5 t $ha^{-1}$) + BP (500 kg $ha^{-1}$) |

BP: Burkina Phosphate

**Table 3.** Initial soil properties at the beginning of cultivation (2018) and effects of cropping systems on soil after two years of cultivation (2019-2020).

| **Rotations** | **C/N** | **Ca** | **Mg** | **K** | **Na** | **TEB** | **CEC** | **SL (%)** |
|---|---|---|---|---|---|---|---|---|
| | | **cmolc.kg$^{-1}$** | | | | | | |
| Initial soil | 11.77 | 0.611 | 0.47 | 0.14 | 0.001 | 1.22 | 3.23 | 37.84 |
| Sorghum-Fonio | 11.452±0.6 | 1.497±0.66 | 0.564±0.16 | 0.211±0.06$^{b}$ | 0.004±0.02a | 2.276±0.85 | 4.098±1.08 | 55.01±12.6 |
| Soya-Fonio | 11.546±0.9 | 1.485±0.57 | 0.556±0.15 | 0.221±0.06$^{a}$ | 0.001±0.001b | 2.263±0.71 | 4.035±0.89 | 55.48±10.22 |
| Mung-bean-Sorghum | 11.420±0.7 | 1.479±0.62 | 0.562±0.15 | 0.198±0.05$^{bc}$ | 0.001±0.001b | 2.239±0.79 | 3.969±0.99 | 55.04±8.64 |
| Mung bean-Fonio | 11.591±0.7 | 1.378±0.48 | 0.550±0.12 | 0.201±0.05$^{bc}$ | 0.0001±0.01b | 2.129±0.60 | 3.930±0.72 | 53.72±9.84 |
| *Treatment average* | *11.503* | *1.460* | *0.558* | *0.208* | *0.002* | *2.227* | *4.008* | *54.81* |
| *Variation* | *-2.3* | *138.90* | *18.71* | *48.33* | *61.57* | *82.53* | *24.08* | *44.85* |
| ***Pr > F*** | ***0.1*** | ***0.05*** | ***0.24*** | ***0.009*** | ***0.017*** | ***0.05*** | ***0.73*** | ***0.9*** |

**Table 4.** Properties of the initial soil at the beginning of cultivation (2018) and effects of fertilizers on the soil after two years of cultivation (2019-2020).

| | **C/N** | **Ca** | **Mg** | **K** | **Na** | **TEB** | **CEC** | **SL (%)** |
|---|---|---|---|---|---|---|---|---|
| | | **cmolc.kg$^{-1}$** | | | | | | |
| Initial soil | 11.77 | 0.611 | 0.47 | 0.14 | 0.001 | 1.22 | 3.23 | 37.84 |
| Cpt + FV | 11.406±0,7 | 1.790±0.58$^{a}$ | 0.611±0.13$^{a}$ | 0.232±0.04$^{a}$ | 0.005± 0.02$^{a}$ | 2.638±0.7$^{a}$ | 4.286±0.86$^{a}$ | 61.01±8$^{a}$ |
| Cpt + FV + BP | 11.539±0,8 | 1.595±0.49$^{ab}$ | 0.593 ±0.14$^{a}$ | 0.217 ±0.05$^{a}$ | 0.001±0.001$^{ab}$ | 2.406± 0.6$^{ab}$ | 4.133± 1.02$^{ab}$ | 58.26±7.4$^{a}$ |
| Cpt + NPK + urea | 11.561±0,8 | 1.274±0.51$^{bc}$ | 0.542±0.15$^{ab}$ | 0.210±0.04$^{a}$ | 0.0001 ±0.001$^{ab}$ | 2.027±0.6$^{bc}$ | 3.934 ±0.81$^{ab}$ | 50.91±9.6$^{b}$ |
| Control | 11.504±0,7 | 1.179±0.54$^{bc}$ | 0.485±0.14$^{b}$ | 0.171±0.05$^{b}$ | 0.001±0$^{ab}$ | 1.836±0.6$^{c}$ | 3.678±0.9$^{ab}$ | 49.14±11$^{b}$ |
| *Treatment average* | *11.503* | *1.460* | *0.558* | *0.208* | *0.002* | *2.227* | *4.008* | *54.83* |
| *Variation* | *-2.01* | *-8.7* | *-55.8* | *-98.8* | *222591.5* | *222591.5* | *228.5* | *44.9* |
| ***Pr > F*** | ***0.100*** | ***0.050*** | ***0.247*** | ***0.009*** | ***0.178*** | ***0.051*** | ***0.735*** | ***0.01*** |

MTR : Treatments average ; FV : Poultry manure, BP : Burkina Phosphate, C/N : Carbon/Nitrogen ratio, TEB : Total exchangeable bases, CEC : Cation Exchange Capacity ; SL : Saturation level; Treatments with the same letter in the same column are not significantly different.

**Table 5.** Correlation matrix between soil chemical parameters.

| **Variables** | **Ca** | **Mg** | **K** | **Na** | **SBE** | **CEC** | **SL** | **C/N** |
|---|---|---|---|---|---|---|---|---|
| Ca | **1** | | | | | | | |
| Mg | **0.824** | **1** | | | | | | |
| K | **0.815** | **0.678** | **1** | | | | | |
| Na | **0.610** | 0.378 | 0.386 | **1** | | | | |
| SBE | **0.995** | **0.874** | **0.836** | **0.583** | **1** | | | |
| CEC | **0.895** | **0.896** | **0.768** | **0.567** | **0.921** | **1** | | |
| TS | **0.957** | **0.788** | **0.824** | 0.473 | **0.954** | **0.772** | **1** | |
| C/N | -0.097 | -0.046 | 0.036 | -0.281 | -0.084 | -0.007 | -0.120 | **1** |

Values in bold are different from 0 at significance level alpha=0.05; SL : Saturation Level ; CEC : Cation Exchange Capacity, TEB : Total exchangeable bases, C/N : Carbon / Nitrogen ratio.

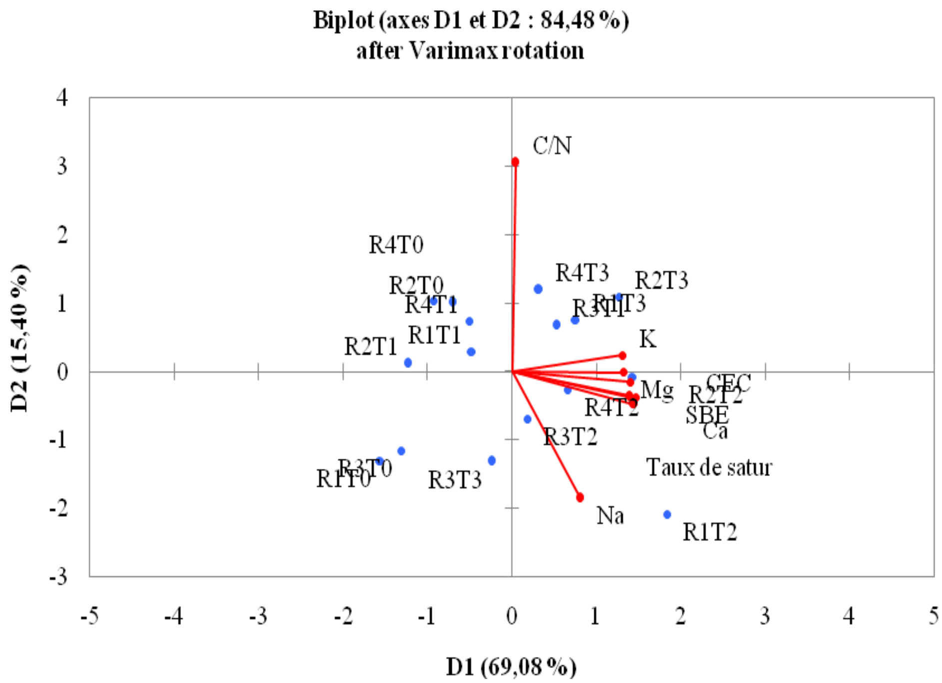


**Fig. 1:** Correlation circle between soil-cropping system parameters and fertilizers in the main plane. Carbon/Nitrogen ratio, TBE: Total exchangeable bases, CEC: Cation Exchange Capacity; Na: Sodium, K : Potassium, Ca : Calcium, Saturation Level. R : Rotation, T : treatments.

This shows that soil SBE and total CEC content are among the soil variables that best explain the decrease in C/N ratio, and consequently the mineralization of legume residues. Considering the correlation circle in the main plane of figure 1, a strong relationship can be seen between the "R2T2" and "R4T2" treatments and soil TEB, CEC and saturation levels. A treatment based on compost and poultry manure combined with a legume-fonio rotation is expected to produce a significant number of CEC, TEB and saturation levels, resulting in improved yields of subsequent crops.

The nitrogen balance can be improved when legume is included in the rotation system, and this helps to boost the productivity of the other crops over the years. This is because legumes fix a certain amount of nitrogen in the atmosphere. According to Bado et al., (2006), in cropping systems, legume residues enrich the soil with nitrogen. A crop rotation that includes a nitrogen-fixing legume may be better able to enrich the soil with nitrogen through the legume residues, and the mineralization of these residues can help supply nutrients to the soil and improve soil fertility. As a result, other crops in the rotation can benefit from these nutrients through residue mineralization. This work confirms that of Bado et al., (2012) and Zeinabou et al., (2014) on the importance of rotation in cereal-legume cropping systems, and more specifically the major role played by the interaction of organic matter and mineral fertilizers associated with legume rotation on agricultural production in Sahelian zones.

## Conclusions

The present study has shown that the combined use of local fertilization resources and crop rotations improves soil fertility. The proposed cropping system has several advantages. It is a low mineral input system that can be offered to vulnerable farmers while ensuring sustainable soil fertility management. This study paves the way for the valorization of locally available organic matter in agro-ecosystems, and may help reduce the costs of agricultural production.

## Conflict of interest statement

Authors declare that they have no conflict of interest.

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