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Soil-root interface (RLD), porosity and density of earthworms in crop profile, under young agroforestry fallow-grassland (Green Mat), in Kisangani (DR Congo)

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An experiment was carried out in Kisangani (DR Congo) to examine, faced to the Slash-and-burn system, to what extent and what degree the cropping system in "Plates under Green Mat" would favorably affect the soil-root interface (RLD), porosity and soil macro-invertebrates including earthworms. A device plan with 5 completely randomized blocks, divided into 2 plots each, was chosen to test the factor "production system (single-factor ANOVA x Duncan's test)". It emerges from this study the following performance points:

- ✓ An improvement in root density and soil-root interface (13.4 versus 5.2 g/100 cm³ of soil and 22.2 versus 8.9 cm/cm³ at 0-5cm), the effects ranging up to a depth of 20cm ;
- ✓ A dense and more compact rooting board, suitable for mineral recycling and for the complete redistribution of edaphic bioagents for fertility improvement, both microbial and faunal ;
- ✓ An improvement in structure and organicmatter rate of the upper soil stretch (8 against 3.5% at 0-5cm and 4.5 against 1% at 5-20cm);
- ✓ An improvement in earthworm density of 200% (1693 against 581 /m²).

Cropping in Plates under Green Mat thus displays the essential features of Conservation Agriculture, being both ecological and sustainable.

Key words : Green Mat, Slash and Burn, rootingboards, morpho-edaphic charts, Soil-root Interface, Lombrics

INTRODUCTION

Conservation farming practices promote the safeguard and improvement of soil resources, ensuring sustainable management of agroecosystems (Mulatie, 2021). In this way, zero or reduced cultivation methods are used, which are there fore likely to promote both pore balance, humus content and microbial and faunalbiodiversity, through a considerably improved soil-root interface (Lal, 2010 ; Cooper *et al*, 2020). No-till, while promoting C sequestration and conservation of

soil resources over time, leads to increased resistance to root penetration (Arvidsson *et al*, 2013), affecting root development and the infiltration coefficient (Bayat *et al*, 2013), this being controlled with biochar incorporation (Obia *et al*, 2020).

Minimum tillagewith residue retention (Modak *et al*, 2020), on the other hand, makes it possible to relatively circumventthese limitations while safeguarding the essential advantages of no tillage (López-Fando and Pardo, 2012), more particularly an increase in microbial activity (López-Garrido *et al*, 2012) and the diversity of biological functionalities in the mycorrhizosphere (Nautiyal *et al*, 2010; Liet *al*, 2021). It also has significant potential in improving the physical and

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biological properties of the soil (Hartmann *et al*,2012) and the suppression of weeds; this without a formed plow sole or any detrimental effect on root growth (Vakaliet *al*, 2011).

Also, it has been found in Canada that the use of no-till does not always lead to improved yields. The effectiveness of the system being there fore linked to many factors including the climate, the history of land management, the nature of the soil, the topography and the position of the field on the water shed (Blaise, 2011;Rosolem and Calonogo, 2013).

In addition, it was pointed out that terraces and isohypse living hedges effectively counteract runoff on undulating and steeply sloping land so common in tropical environments. Erosion control is considered an essential condition for the establishment of efficient agriculture (Comino *et al*, 2010), sedentary and ecologically compatible with tropical conditions where the soils are rugged, undulating and always sloping (Rodenburget *al*, 2003)).

Establishing permanent isohypse grass bands, as old as 20 years, has been shown to be particularly effective in maintaining fertility under a diverse range of edaphic and topographic conditions (Kagaboet *al*, 2013).

The ecological disadvantage of conventional tillage is that it disturbs the soil structure, thus imposing restrictions on the movement and feeding of earthworms (Johnson *et al*, 2007).

This modifies the composition and structure of microbial communities, which are correlated with soil micromorphology (Gupta and Roper, 2010;Helgason *et al*, 2011 ; Jiang *et al*, 2011).

In a long-term trial to determine the role of earthworms in different cropping systems earthworm droppings played a major role in the mixing of horizons, the establishment of gas and material exchange galleries between horizons and the integration of the carbon of organic inputs with that of the mineral phase of the soil (Bottinelli *et al*, 2010 Zhang *et al*,2011; Arai *et al*, 2013).

According to Karlen *et al*. (2019), Soil biological properties and processes are the new frontiers in soil health. Mulching and no till develop a high potential in C sequestration (Fiorini *et al*, 2020).

Finally, soil structure largely affects productivity at the field level. Measurements of the hydraulic conductivity at saturation, also linked to the structural state of the soil, make it possible, with a view to precision agriculture, to quickly identify and locate, or even map, sectors of low primary productivity or low biological activity over the entire cropping landscape (Keller *et al*,2012; Kahle *et al*, 2013; Karlen *et al*, 2013; Thierfelder *et al*, 2013).

Ultimately, we are led to ask the following question : "to what extent and to what degree the Green Mat

system, through its dense permanent root structures and minimum plowing that does not disturb the soil, favorably impact soil-root interface (RLD), porosity and soil macro invertebrates including earthworms ? "

MATERIALS AND METHODS

Site Location

The experiments were carried out in the research station of the Faculty of Renewable Natural Resources Management of the University of Kisangani (Faculty of Sciences concession) located in the Municipality of Makiso, city of Kisangani.

The test site is located at 404m altitude, 00 ° 30'05 "North latitude and 25 ° 12'41" East longitude. The slope of the terrain, which is highly variable, is 8.5% upstream, 3.6% downstream and 16.1% at mid-slope. Also, the tests under taken extend from January 2008 to December 2012.

Vegetation

The vegetation of Kisangani is located in the central forest sector of the Guinean region, characterized by dense humid forests and various vegetation groups degraded as a result of human action (Mate, 2001). The hinterland of the city of Kisangani was initially covered up of evergreen rainforests which constituted its climax. Currently, under the effect of degradation due to increasing pressure, these forests have given way to highly disturbed recruits, low herbaceous fallows and crop fields.

The experimental site had a previous crop marked by the continuous cultivation of cassava associated with maize.

The short-lived fallow areas were dominated by *Cynodon dactylon* with sparse patches of very dense *Panicum maximum*, *Pueraria javanica* and *Calopogonium muconoides*. The lowland area along the stream was dominated by *Pennisetum purpureum*.

EDAPHO-CLIMATIC CONDITIONS

The soil of Kisangani (Fac. Des Sciences UNIKIS) carrying the agroforests evaluated presents, upstream, a heavy clay-silt-sandy texture with 42%, 30% and 28% of elementary particle content, respectively for clay, silt and sand.

The texture, downstream, is more variable but overall of a heavy to very heavy nature. The textural triangle used is from the Applied Pedology Problems Study Group, GEPPA. Table 1 below gives the chemical and physicochemical properties of the soil at the start of the study.

The city of Kisangani enjoys an equatorial climate of type Af according to the Koppen classification. It is a constantly hot and humid climate, thus identifying itself with a very high ecological productivity. The average annual precipitation is therefore around 1800 mm, with average daily temperatures varying between 24 and 25°C. However, a considerable increase has been observed over the past 5 years, with annual rainfall reaching 2000-2400 mm and the average monthly temperature reaching 27-28°C. Figure 1 below shows

the essential climatic data during the test period.

EXPERIMENTAL APPARATUS

The experimental device mounted in this study is given in figure. 2 below. The experimental sector, linked to the rain fed rice cultivation was practiced under the fallow-green manure of *Mucuna - Pennisetum*. It was established upstream of the water shed, on a sloping land (8-9%) with a direction slope from South to North.

Table N ° 1. Characterization of the soil at the end of the preliminary phase (morpho-edaphic optimization) in March 2011, before the start of the final phase of the experiment **

Systèmes de production	CO (%)	P assimilable + P organique (mg/kg sol)	Al ³⁺ +H ⁺ (cmole)	Saturation Al ³⁺ (%)	Saturation bases %	Bases totales (cmol/kg)	K ⁺ cmole / kg	Na ⁺ Cmole / kg	Ca ²⁺ Cmole / kg	Mg ²⁺ Cmole / kg	N (%)	pH au KCl	pH à l'ECCE	Ccm / k
Strate de sol de 0 à 15 cm de profondeur														
Tapis vert	4,5	86	5.2	47.3	52.7	5.80	2.20	0.10	2.10	1.40	0,3	4,4	5.3	11,0
Abattis-brûlis	1,5	37,2	15.6	<u>87.6</u>	12.4	2.18	0.30	0.06	1.34	0.48	0,16	3,5	4.3	17,8
hamps voisins	0,3	25,0	17.6	<u>90.8</u>	09.2	1.77	0.20	0.06	1.13	0.58	0,08	3,5	4.1	19,4
Strate de sol de 15 à 30 cm de profondeur														
Tapis vert	1,1	26	17.6	<u>91.6</u>	08.4	1.59	2.2	0.1	2.1	1.4	0,08	3,8	4.6	19,2
Abattis-brûlis	0,4	19	19.8	<u>94.3</u>	05.7	1.02	0.14	0.04	0.72	0.12	0,07	3,4	4.1	21,0
Champs voisins	0,2	13	23.0	<u>96.0</u>	04.0	0.94	0.10	0.03	0.69	0.12	0,05	3,3	4.1	23,9

* The underlined values of the aluminum saturation are those which do express the aluminum toxicity, the threshold of which is set at 60%.

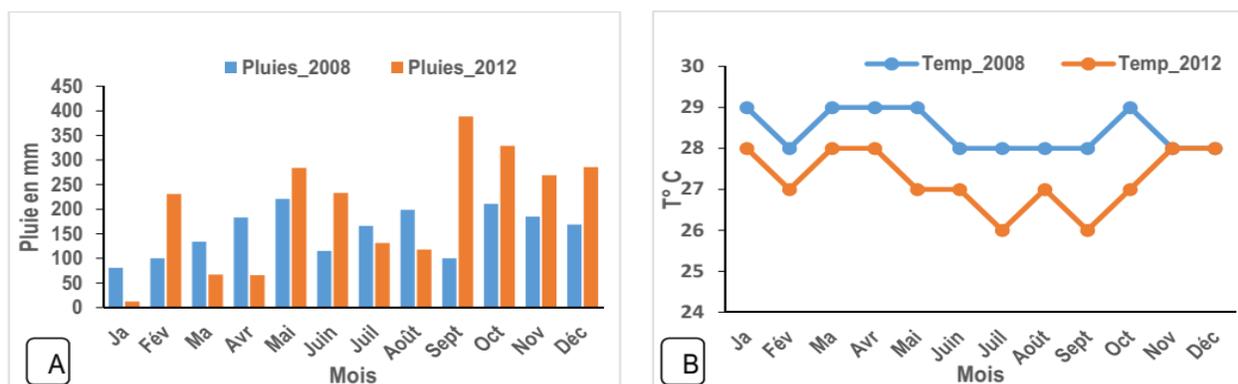


Fig. 1 (A, B). Evolution of monthly average temperatures and rains at the experimental site, between 2008 and 2012 (data from the first and last year of the study). Source: IFA, Department of Plant Science.

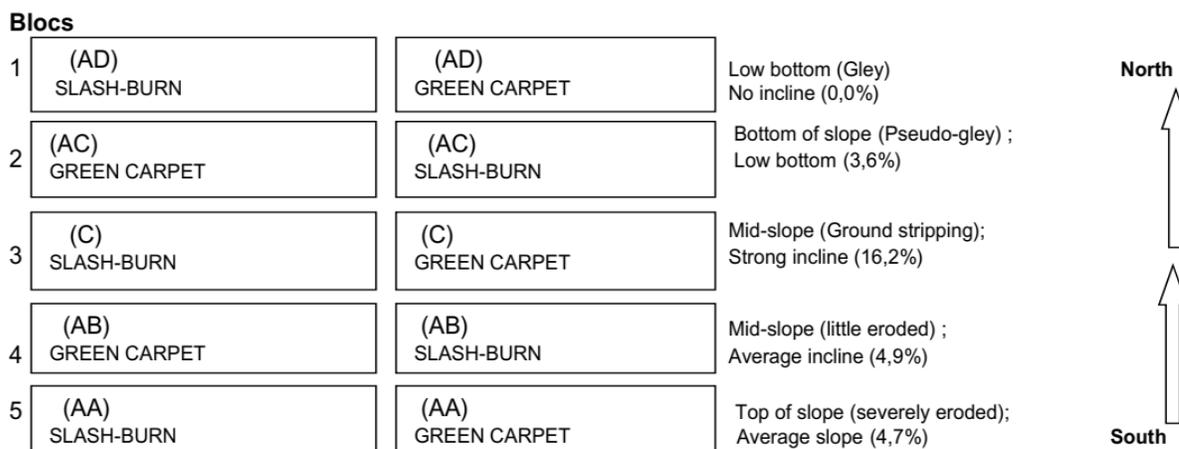


Fig. 1. Experimental device testing on soil-root interface, porosity and density of earthworms under agroforestry fallow-grassland, faced to slash-and-burn cultivation.

Legend: AA, AB, AC, AD and C designate the different experimental blocks. The plots form blocks perpendicular to the slope, the latter facing from South to North. The factor "morpho-edaphic properties" varying from one block to another (position, slope) was not taken into account at this scale of analysis. \Rightarrow Direction of slope.

SHORT APPROACH

The entire process to carry out this study took place in the field, on the one hand, and in the laboratory of soil analysis, on the other. It all started with the establishment of improved fallow to restore soil fertility.

Establishment of fallows with *Mucuna-Pennisetum* for green manure

Fallow fields with *Mucuna-Pennisetum* intercropping green manure were established on each of the plots of the device on the "Green Mat" system. Bush slash was carried out by clearing-stumping operation with a machete at ground level. Each plot was crossed by 8 lines of *Pennisetumpurpureum*, the latter being established at spacings of 50 x 50cm, thus observing a holes pace of 25 cm on either side. A line of *Mucunapruriens* was then inserted, established in pockets (2 grains) made with a hoe every 100 cm.

Manure (10t DM/ha) and microdoses of NPK fertilizer (50kg /ha) were applied. This ultimately produced "the raw mulch-compost" fertilized in situ which is the first stand for the "rhizo-bio-organic mat layer", used as the main strategy of mineral capitalization, maintaining a rapid setting in circuit and a continual mineral recycling. Root profile samples were used to assess root production by the treatment plot.

Evaluation of soil texture

The texture was determined for each of the stratified sectors, thus using composite samples addressing the soil slice 0 to 15 cm deep. It was determined by the successive sedimentation method, according to Baert and Van Ranst (1998), using sodium hypochlorite for

the removal of organic matter.

Spatial structure of the rooting of agroecosystems (RLD and RMD) under fallow

This investigation included 2 expected results, namely (1) the change in root density in the depth of the soil (the root density profile) and (2) the rooting board (root density reported on all elementary surfaces of the soil plot) characteristic for each of the fallow-pasture systems confronted. *P. purpureum* has a high potential for root production, to the point of forming a hairy mat, with very beneficial physical and biological properties in the restoration of severely degraded soils.

Slices or blocks of soil measuring 30 x 9 x 3 cm³, or 810 cm³, were carefully removed using a root auger, due to two quadrants of 1m² delimited at random, per experimental plot sampled in each of the 2 production systems, out of all 5 blocks in the device.

The blocks of soil brought back to the laboratory were wetted, subdivided into 5cm slices, sprayed manually and subjected to a laborious work of extraction, counting and measurement of the roots, according to the operating procedures followed by Lopez-Zamora *et al.* (2002) and Kashiwagi *et al.* (2006). After calibration and lath measurement (RLD), the extracted roots were subjected to drying in an oven at 105°C, to constant weight (RMD).

Physical and morpho-edaphic properties of agroecosystems

Morpho-edaphic charts were produced, based on the development, description and interpretation of 20 crop profiles in the field, 10 for each of the 2 systems. This, while using a magnifying glass and a camera sparingly

to bring out the details better and continue the work calmly in the laboratory. The description of the crop profile and the development of morpho-edaphic picture were carried out according to Jones (2006). From each crop profile was determined a morpho-edaphic board and a root board from which the global average was identified.

Earthworm count in the fallow crop profile

The operation began by taking the temperature of the soil under the litter at the various sites. The samples were taken according to Mulotwa (2001), in accordance with the manual sorting method recommended by the Tropical Soil biology and Fertility (TSBF) program.

Twenty crop profiles, of which ten per cropping system have been developed (2, diagonally, per plot), each highlighting, in its center, a monolith (block of earth) of 25 cm x 25 cm x 30 cm equivalent approximately to 30 kg of soil. The monolith was subdivided into four quadrants, the results of which were counted separately. Three 10 cm slices of soil were distinguished on each of the quadrants to facilitate the subsequent manual sorting.

The monolith was thus explored from top to bottom, passing successively through 4 strata, namely (1) > 0 cm, (2) 0 to 10 cm, (3) 10 to 20 cm and (4) 20 to 30 cm. From there, a total per quadrant, then per m² of floor area was produced at the end of each operation.

Evaluation of bulk density and porosity at harvest of rice

The bulk density and the porosity of the soil, on the different plots, were determined for the first 2 slices of 5 cm of soil. The operation was carried out according to the harvest scheme, using several sets of 100cc Koppéký cylinders and a cylindrical mount with a piston to drive it into the ground. The current operations involved drying these samples at 105°C in an oven,

The related data are illustrated in Figures 3, below.

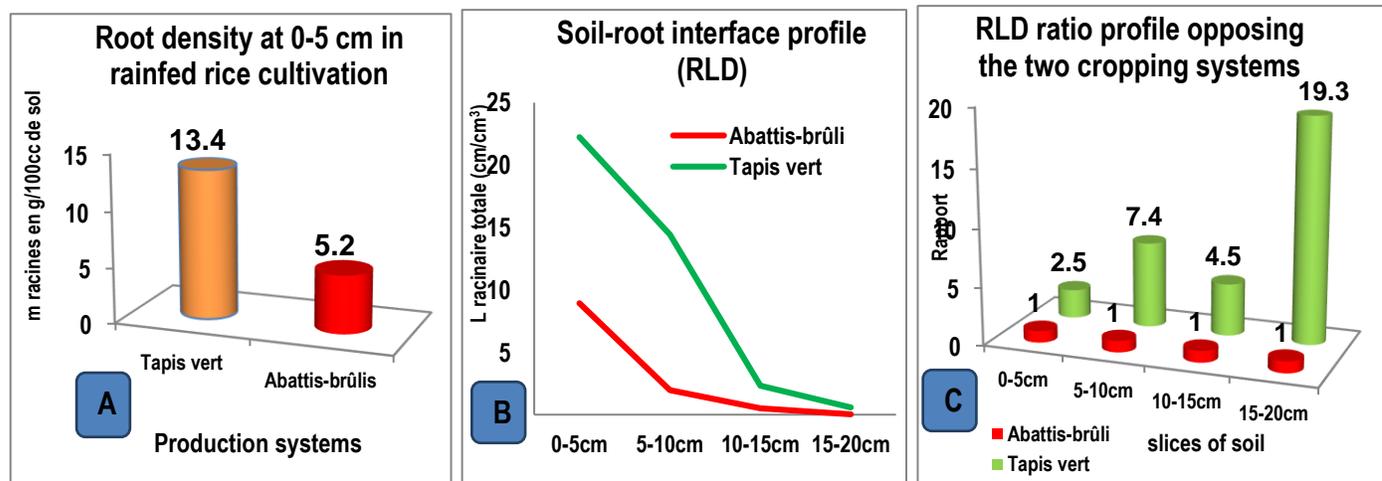


Figure. 3 (A, B, C). Root density at 0-5 cm (A), soil-root interface profile (RLD) (B) and RLD ratio profile (C) in rainfed rice cultivation (average) opposing the cultivation system under green mat and slash-and-burn cultivation. PA = 0.0000; PB = 0.0000; PC = 0.0000.

punctuated by several weighing up to constant weight.

Assessment of root density (RMD) and soil-root interface (RLD) at harvesting of rice

The two investigations were coupled. The same 100cc Koppéký cylinder mounted on an auger was thus used both to take the soil and the rice roots distributed over the 4 slices of soil, namely 0 to 5 cm, 5 to 10 cm, 10 to 15 cm and 15 to 20 cm deep. Root extraction and weighing were performed after assessment of bulk density.

Thus, 20 profiles were drilled per cropping system, therefore 4 in diagonal per plot, or a total of 80 cylinders of soil sampled for the system of "Cropping in Plates under Green Mat" and as many for the system of Slash-and-Burn. The root profile data (RMD) being expressed in g of DM per 100cm³ (5 cm strata) of soil, the root productivity of rice in t of DM per hectare and the root density profile (change in root density with successive soil strata) had to be converted by calculation.

Statistical analyzes

The data collected on cards, in the various tests described below, were organized and processed first on Excel software sheets. The statistical processing which followed made use of Statgraphics software. The majority of parameters that have been studied in this device have recourse, in turn, to two-factor ANOVA, for the significance of the differences between treatments, coupled to the Duncan's test for their discrimination.

RESULTS AND DISCUSSION

The root density and the soil-root interface (RLD) of the agrosystems

It emerges from figures 3A and 3B that "Green Mat" (Tapis Vert) presents versus "Slash-and-burn" (Abattis-brûlis), for the 0-5 cm slice of soil, a much higher root density and soil-root interface ($p < 0, 0001$), respectively 13.4 versus 5.2 g/100 cm³ of soil and 22.2 versus 8.9 cm/cm³.

Figure. 3C, for its part, reveals that Green Mat presents a soil-root interface 2.5, 7.4, 4.5 and 19.3 times higher, compared to Slash-and-Burn, respectively for strata 0-5, 5-10, 10-15 and 15 -20 cm deep. This would justify the high performance of the "Green Mat system" in that the 2nd and 4th stratum play a crucial role in plant nutrition during dry episodes, for the relative availability of nutrients and water they display, respectively. Below are the performance factors mentioned by different authors.

1 The grassland effect specific to Conservatory Agriculture :crops and meadows managed under zero tillage develop high root densities and hydro mineral demands, often creating stressful conditions (Herold *et al*, 2014) and proving to be more exhaustive, more efficient in the use of nutrients(Carvalho *et al*, 2012), specifically recycling of phosphorus (Yang *et al*, 2020) than those under plowing ;

2 The prevalence of a more increased mycorrhizal colonization under marginal conditions, in conservation agriculture, giving rise to a higher

phosphatase activity in response to increasing metabolic needs (Stover *et al*, 2012);

3 The role of the fallow root system as a factor of pedogenesis (Lehman and Rillig, 2013): porosity, structural development and biological activity are thus strongly correlated with root density (Lehmann *et al*, 2013; Uteau *et al*, 2013; Mc Kenzie, 2013 ; Parihar *et al*, 2020);

4 Root growth is accelerated by the methods of balanced fertilization applied to the base of the crop, in the immediate vicinity of the roots (Peigné *et al*, 2013) or incorporating rock fragments (Ceacero *et al*, 2020);

5 The primordial role of root exudates as a factor for sequestering Al³⁺ ions and attenuating toxicity, stimulating biological activity and desorption of inorganic phosphorus, in conjunction with the rhizospheric microflora (Ayoubiet *al*, 2012 ;Castellany *et al*, 2012).

The fallow-green manure has thus played a capital role in improving the physical, chemical and biological properties of the soil, according to the multi-functional activity of the vigorous and multi-branched root system of *Pennisetum purpureum*, with a high potential for soil shearing (Comino and Druetta, 2010).

Density of earthworms and soil porosity in the profile of agrosystems

The related data is illustrated in Figures 4.

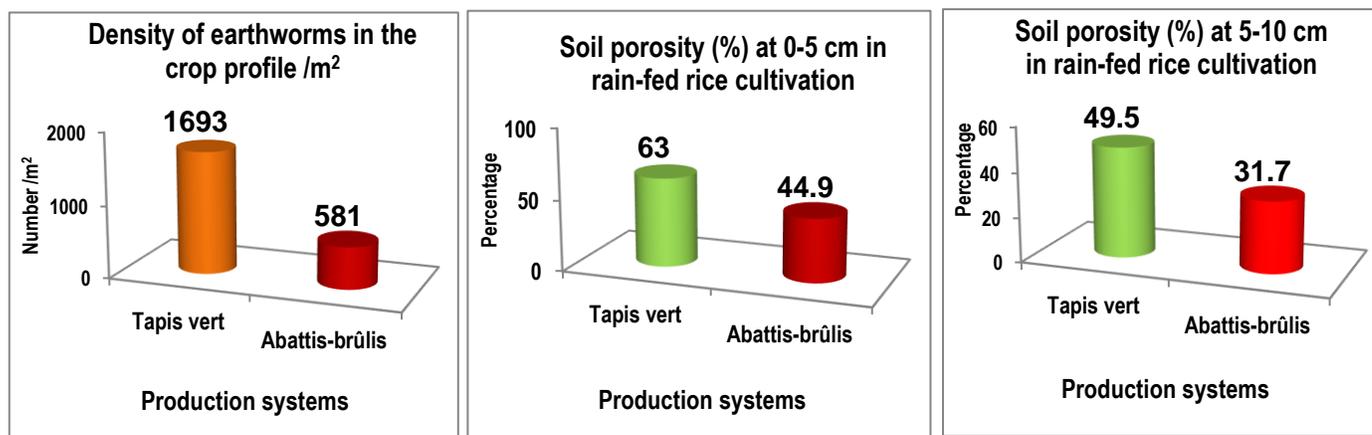


Figure. 4 (A, B, C). Density of earthworms in the crop profile (A) and soil porosity at 0-5 cm (B) and 5-10 cm (C), in rain-fed rice cultivation opposing the systems of cultivation under green cover and slash-and-burn cultivation. The statistical probability : PA = 0.0000; PB = 0.0000; PC = 0.000

It emerges from figures 4B and 4C that the porosity under rice cultivation is improved by 40% and 56% for the 0-5 cm and 5-10 cm strata ($p < 0.0001$) when we pass from "Slash and burn" to "Green Mat". We also notice that this improvement brings the porosity of the subcultural layer back to an average value clearly

exceeding that reported for the surface layer under Slash and burn. The density of earthworms in figure 4A is 581 and 1693, respectively for Slash-and-burn and Green Mat system ; an increase of nearly 200%.

A variable density of earthworms is reported by several authors comparing zero tillage to conventional

tillage: 80 versus 49 (Norgrove *et al*, 2011), 81 versus 52 (Xu *et al*, 2013), 319 versus 61 (Errouissi *et al*, 2011), 572 versus 280 (Schmidt *et al*, 2003). The high densities of earthworms recorded in this experiment are attributed to favorable climatic conditions, to the heavy clay-silt-sandy texture, to methodological care (manual exploration-disintegration of soil monolith) but also and above all to the high production of recyclable inputs and root exudations from perennial roots (Phillips *et al*, 2012) under fallow-grassland with *Mucuna pururiens* and *Pennisetum purpureum*.

Also, the balanced application of organic inputs from grass-legume stands stimulates the activity of earthworms, therefore influencing aggregate dynamics and macroporosity (Erikson *et al*, 2009; Jouquet *et al*,

2012). The porosity in these surface strata is linked to the aggregating activity of roots / edaphic bioagents (soil shear potential) including earthworms (Sileshi and Mafongoya, 2006 ; Li *et al*, 2021).

Although, many factors can contribute to aggregation (microbial juices, extra radical mycelium of CMAs, root excreta), the action of earthworms remains the most determining, making more effective the multi-faceted contribution of labile substances (BMC, BMN) emanating from metabolism (Norgrove *et al*, 2011; Al-Maliki and Scullion 2013 ; Xie *et al*, 2021).

Average rooting boards and morpho-edaphic beds of agrosystems

The related data is illustrated in Figures 5 and 6.

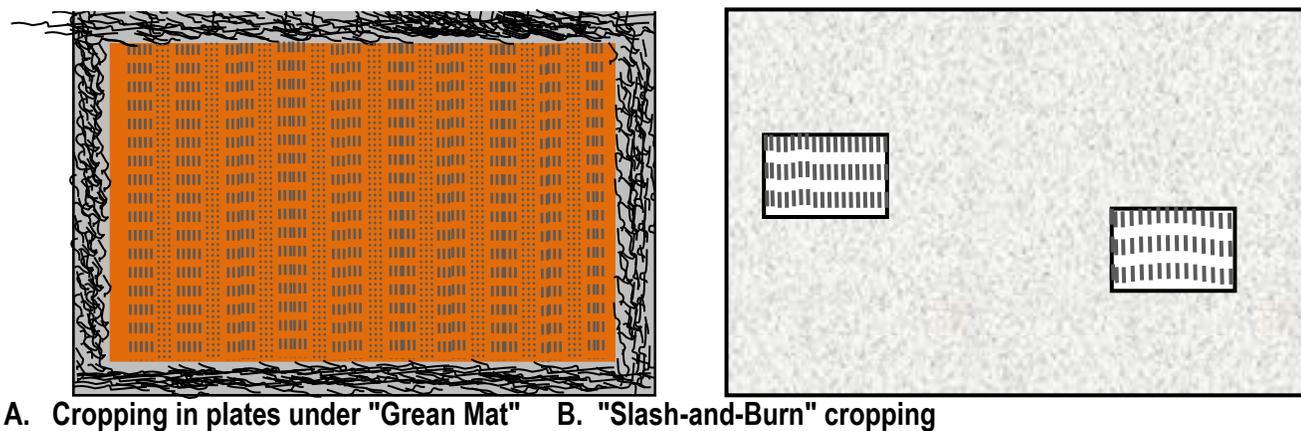


Fig. 5. Average rooting board for the two agroecosystems compared.

Legend

-  10 à 20 kg/m²/10cm (Tapis vert permanent : hautes herbes) : enracinement très dense
-  5 à 10 kg/m²/10cm (Lignes de hautes herbes dans l'assiette culturale et touffes isolées) : dense
-  1 à 5 kg/m²/10cm (Interlignes d'herbe dans l'assiette culturale) : enracinement moyen
-  0 à 1 kg/m²/10cm (Jachère traditionnelle) : enracinement très faible à inexistant

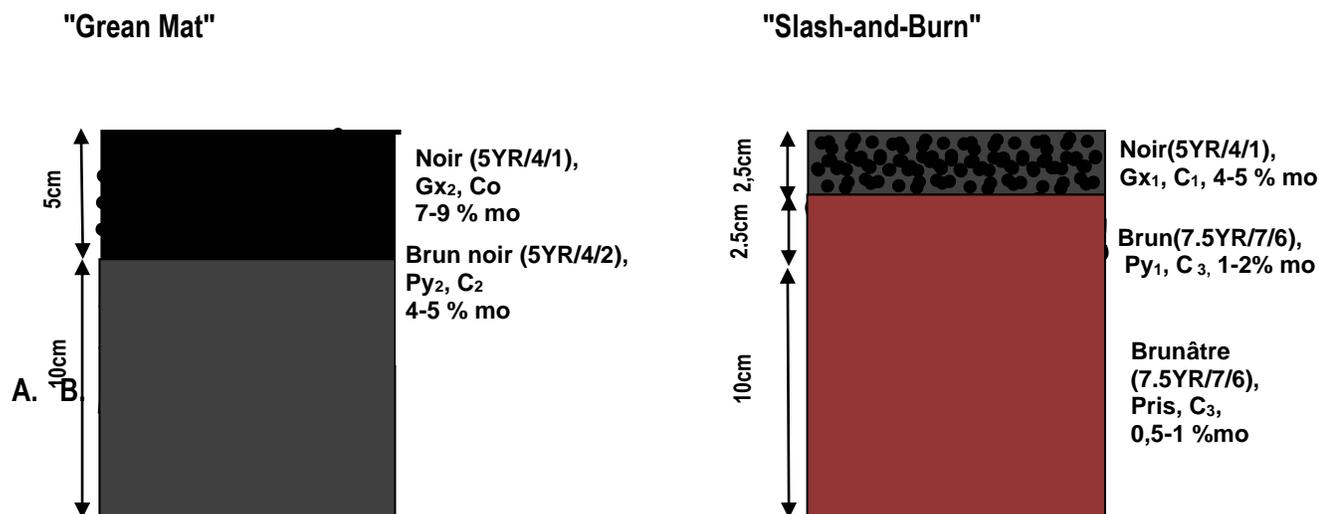


Figure.6. Average morpho-edaphic beds of the two agrosystems compared (depleted soil)

Legend Structure :

Gx₁ : less distinct lumpy structure
 Gx₂ : very lumpy structure
 Py₁ : less distinct blocky structure
 Py₂ : very clear blocky structure
 Pris : prismatic structure

Compactness :

Co : very low compactness. DA : 0,8-1,0 g/cc
 C₁ : average compactness. DA : 1,1-1,2 g/cc
 C₂ : high compactness. DA : 1,3-1,4 g/cc
 C₃ : very high compactness. DA : 1,5-1,9 g/cc

From the analysis of the average rooting boards of agrosystems, presented in figure 5, it appears that the Green Mat system presents a very dense rooting along the greenfull grass-shrub mat surrounding the cultivation areas or micro basins, becoming dense to moderately dense in these, respectively on the lines and interlines of the perennial grassy root structures established there.

The slash-and-burn system has very weak to non-existent rooting, except under the tufts of perennial grasses which establish themselves there sporadically in the inter-campaign. In the Green Mat system, the herb-shrubby green mat, which is graminoleguminous in nature and forms the backbone of the system, thus unfolding in an alveolar spatial configuration. It can thus, thanks to a vigorous, stratified root conformation, claim the high anti-erosion potential, production of biomass and maintenance of soil-root interactions observed in this technology.

From the analysis of the morpho-edaphic beds in figure 6, it appears that the cultivation system under green mat presents, in the most superficial 15 cm section of the soil, a more elaborate crop profile: for the 0- 5 cm stratum, a black soil (5YR / 4/1) with a very lumpy structure, zero to very low compactness (DA = 0.8-1.0 g / cm³) and rich in organic matter (7-9%) ; for the 5-15 cm stratum, a brown-black soil (5YR / 4/2) with

a very clear blocky structure, compact (DA = 1.4 g / cc) and rich in organic matter (4- 5%).

The slash-and-burn system presents a very thin crop profile with a black organomineral layer confined to the most superficial 2.5cm, with a less distinct lumpy structure, of average compactness (DA = 1.1-1.2 g / cm³) and of an average richness in organic matter (4-5%), while the 5-15cm stratum comprises an undisturbed, brownish soil (7.5YR / 7/6), with a prismatic structure, very compact (DA = 1.5-1.9 g / cm³) and very poor in organic matter (0.5-1%).

Below are implications related to the morpho-edaphic transformation potential of Green Mat system.

1) The integration in the rotations of fallow-green manure graminolegume has made it possible, in several regions, to improve the nitrogen and carbon content, as well as the depth of the arable soil (Li *et al*, 2010).

2) Long-term continuous cropping of soybean or constant use of legume cover crops is comparable to crop rotation in mediating microbial abundance / diversity while decrease the relative abundance of pathogenic fungi (Liu *et al*, 2020)

3) The isohypse establishment of permanent and dense herbaceous shrub hedges, to produce mulch in situ, to counter erosion and runoff and to enrich the soil with organic matter, is a practice which has proved its

worth in conservation agriculture (Tesfahuney *et al*, 2013).

4) Zero-tillage practices bypass structural disturbance under cultivation and are more interesting in the tropics where recycling of C and N from microbial biomass is found to be very rapid, thus granting greater efficiency to fertilization practices relying on organic inputs (Pandey *et al*, 2010; Ding *et al*, 2013).

5) It is evoked in conservatory systems, the concept of stabilization of labile organic carbon in micro aggregates, within the conglomerates "clay - iron-aluminum sesquioxides" of Ferralsols, especially when green manures, composts and biochar are used (Conceição *et al*, 2013 ; Glăb *et al*, 2020).

6) Tillage practices with different soil disturbance shape the rhizosphere bacterial community throughout crop growth, with implication on crop yield (Wang *et al*, 2020)

7) According to Séguy *et al*, (2002), the comparison of the forest ecosystem and the most efficient DMCs (direct seeding under mulch/plant cover), from the most reliable agricultural indicators such as organic%C, the annual biomass of the litter and its rate of mineralization, the root biomass and its ability to use rain water, shows that, apart from the biodiversity criterion, the operating modes are comparable.

8) A recent approach is the development-description of a cultural profile of the soil by visual diagnosis, to anticipate the functioning of the soil under different crops and to make projections on yields. (Lal, 2010; Sierra *et al*, 2013; Fuji *et al*, 2013).

CONCLUSION

The following performance points emerge from this study comparing the system of "Cropping in Plates under Green Mat" with the traditional slash-and-burn system:

✓ An improvement in root density and soil-root interface for the 0-5 cm soil stretch (13.4 versus 5.2 g/100 cm³ of soil and 22.2 versus 8.9 cm/cm³), this difference being more marked in the 5-10cm and 15-20cm strata; This justifies the high productivity of the Green Mat system, especially since the 2nd and 4th stratum play a capital role in plant nutrition during dry episodes, for the relative availability of nutrients and water that they display, respectively;

✓ A dense and more compact rooting board, suitable for mineral recycling and for the complete redistribution of edaphic bioagents for fertility improvement, both microbial and faunal;

✓ An improvement in the structure and rate of organic matter of the surface soil (thick layer of very distinct lumpy structure, of zero to very low compactness, at 7-9% organic matter content versus a

very thin layer with a less performed blocky structure, very compact, and 3-4% organic matter content);

✓ An improvement in the density of earthworms (1,693 against 581 / m²), ie an increase of nearly 200%.

This has a very favorable impact on the soil-root interface (root board), porosity, the humus rate and soil macro invertebrates including earthworms. Cultivation in Plates under Green Mat thus displays the essential features of Conservation Agriculture, both ecological and sustainable.

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REFERENCES

68. Yang H, Xu M, Li Y, Xu C, Zhai S, Liu, (2020). The impacts of ditch-buried straw layers on the interface soil physicochemical and microbial properties in a rice-wheat rotation system. *Soil & Till. Res. Vol. 202, Aug. 2020*, 104656
- Al-Maliki S, et Scullion J (2013). Interactions between earthworms and residues of differing quality affecting aggregate stability and microbial dynamics. *Applied Soil Ecology*; 64, 2 : 56–622.
- Arai M, Tayasu I, Komatsuzaki M, Uchida M, Shibata Y, Kaneko N (2013). Changes in soil aggregate carbon dynamics under no-tillage with respect to earthworm biomass revealed by radiocarbon analysis. *Soil and Tillage Research*; 126, 1: 42–49
- Arai M, Tayasu I, Komatsuzaki M, Uchida M, Shibata Y, Kaneko N (2013). Changes in soil aggregate carbon dynamics under no-tillage with respect to earthworm biomass revealed by radiocarbon analysis. *Soil and Tillage Research*; 126, 1: 42–49
- Arvidsson J, Westlin A, Sörensson F, (2013). Working depth in non-inversion tillage. Effects on soil physical properties and crop yield in Swedish field experiments. *Soil and Tillage Research*; 126, 1: 259–266
- Ayoubi S, Karchegani P, Mosaddeghi MR, Honarjoo N (2012). Soil aggregation and organic carbon as affected by topography and land use change in western Iran. *Soil and Tillage Research*; 121,
- Baert G, Van Ranst E, (1998). Exchange properties of highly weathered soils of the Low Congo. *Malays Jour of Soil Sc* 2:31-44.
- Bayat H, MR Neyshaburi, Mohammadi K, Nariman-Zadeh N, Irannejad M (2013). Improving water content estimations using penetration resistance and

- principal component analysis. *Soil and Tillage Research*; 129, 5: 83–92
- Blaise D (2011). Tillage and green manure effects on BT transgenic cotton hybrid grown on rainfed Vertisols of central India. *Soil and Tillage Research*; 114, 2: 86–96
- Bottinelli N, Hallaire V, Menasseri-Aubry S, Guillou C, Cluzeau D (2010). Abundance and stability of below ground earthworm casts influenced by tillage intensity. *Soil and Tillage Research*; 106, 2: 263–267
- Carvalho F, Souza FA, Carrenho R, Morei FM, Jesus EC, Fernandes GW (2012). The mosaic of habitats in the high-altitude Brazilian rupestrian fields is a hotspot for arbuscular mycorrhizal fungi. *Applied Soil Ecology*; 52, 3: 9–19
- Castellany M, Ventrella D, (2012). Impact of conventional and minimum tillage on soil hydraulic conductivity in typical cropping system in Southern Italy. *Soil and Tillage Research*; 124, 2: 47–56
- Comino E, Druetta A (2010.) The effect of Poaceae roots on the shear strength of soils in the Italian alpine environment. *Soil and Tillage Research*; 106, 2: 194–201
- Conceição PC, Dieckow J, Bayer C (2013). Combined role of no-tillage and cropping systems in soil carbon stocks and stabilization. *Soil and Tillage Research*; 129, 4: 40–47
- Cooper RJ, Hama-Aziz ZQ, Hiscock AA Lovett KM, Vrain E, Dugdale SJ, Sünnerberg G, Dockerty T, Hovesen P, Noble L (2020). Conservation till and soil health: Lessons from a 5-year UK farm trial. *Soil&Til. Res.* Vol. 202, Aug. 2020, 104648
- Ding X, Han X, Zhang X, Qiao Y, 2013. Effects of contrasting agricultural management on microbial residues in a Mollisol in China. *Soil and Tillage Research*; 130, 3: 13–17
- Eriksen-H. NS, Speratti AB, Whalen JK, Légère A, Madramootoo CA (2009). Earthworm populations and growth rates related to long-term crop residue and tillage management. *Soil and Tillage Research*; 104, 2: 311–316
- Errouissi F, Moussa-Machraoui S, Ben-Hammoud M, Noura S, (2011). Soil invertebrates in durum wheat cropping system under Mediterranean semi arid conditions: A comparison between conventional and no-tillage management. *Soil and Tillage Research*; 112, 2: 122–132
- Fiorini A, Maris SC, Abalos D, Amaducci S, Tabaglio V (2020). Combining no-till with rye (*Secale cereale* L.) cover crop mitigates nitrous oxide emissions without decreasing yield. *Soil&Til. Res.* Vol. 196, Feb. 2020, 104442.
- Fujii K, Funakawa S, Hayakawa C, Sukartiningih, Kosaki T, 2013. Fluxes of dissolved organic carbon and nitrogen in cropland adjacent forests in a clay-rich Ultisol of Thailand and a sandy Ultisol of Indonesia. *Soil and Till. Res.*; 126, 3: 267–275
- Głąb T, Żabiński A, Sadowska U, Gondek K, Kopeć M, M.-Hersztek M, Tabor S, (2020). Fertilization effects of compost produced from maize, sewage sludge and biochar on soil water retention and chemical properties. *Soil&Til. Res.* Vol. 197, March 2020, 104493
- Gupta V. Roper M, (2010). Protection of free-living nitrogen-fixing bacteria within the soil matrix. *Soil and Till. Res.* 109, 1: 50–54
- Hartmann P, Zink A, Fleige H, Horn R (2012). Effect of compaction, tillage and climate change on soil water balance of Arable Luvisols in North Germany. *Soil and Tillage Research*; 124, 1: 211–218
- Helgason BL, Walley FL, Germid JJ (2011). No-till soil management increases microbial biomass and alters community profiles in soil aggregates. *Applied Soil Ecology*; 46, 3: 390–397
- Herold N, Schöning I, Gutknecht J, Alt F, Boch S, Müller J, Oelmann Y, Socher SA, Wilck W, Wubet T, Schrupp M, (2014). Soil property and management effects on grassland microbial communities across a latitudinal gradient in Germany. *Applied Soil Ecology*; 73, 1: 41–50
- Jiang X, Wright AL, Wang X, Liang F (2011). Tillage-induced changes in fungal and bacterial biomass associated with soil aggregates: A long-term field study in a subtropical rice soil in China. *Applied Soil Ecology*; 48, 2: 168–173
- Johnson MJL., Umiker KJ, S.O. Guy SO (2007). Earthworm dynamics and soil physical properties in the first three years of no-till management. *Soil and Tillage Research*; 94, 2: 338–345
- Jones C (2006). Carbon and catchments. Inspiring real change in natural resource management. In "Managing the carbon cycle". *National Forum 22-23 November 2006. Hanoi, Australie. Http://www.Amazing carbon.com*
- Jouquet P, Plumere T, Thu TD, Rumpel C, Duc TT, Orange D (2010). The rehabilitation of tropical soils using compost and vermicompost is affected by the presence of endogeic earthworms. *Applied Soil Ecology*; 46, 1: 125–133
- Kagabo DM, Stroosnijder L, Visser SM, Moore D (2013). Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. *Soil and Tillage Research*; 128, 4: 23–29
- Kahle P, Möller J, Baum C, Gurgel A ((2013). Tillage-induced changes in the distribution of soil organic matter and the soil aggregate stability under a former short rotation coppice. *Soil and Tillage Research*; 133, 2: 49–53
- Karlen DL, Cambardella CA, Kovar JL, Colvin TS, (2013). Soil quality response to long-term tillage and crop rotation practices. *Soil and Tillage Research*; 133, 3: 54–64.

- Karlen DL, Veum KS, Sudduth AS, Obrycki JF, Nunes MR (2019). Soil health assessment: Past accomplishments, current activities, and future opportunities. *Soil & Till. Res. Vol. 195, Dec. 2019, 104365*
- Keller T, Sutter A, Nissen K, Rydberg T (2012). Using field measurement of saturated soil hydraulic conductivity to detect low-yielding zone in three Swedish fields. *Soil and Tillage Research; 124, 1: 68–77*
- Lal R (2003). Managing world soils for food security and environmental quality. *Advances in Agronomy 74: 155-192*
- Lal R. (2010). Crop residue and soil C. Carbon management and Sequestration Center. The Ohio State University. USA. 14p
- Lehmann A et, Rillig MC (2013). Are there temporal trends in root architecture and soil aggregation for *Hordeum vulgare* breeding lines? *Applied Soil Ecology; Volum 65, March 2013, Pages 31–34*
- Li S, Wang S, Fan M, Wu Y, Shanguan Z, (2020). Interactions between biochar and nitrogen impact soil carbon mineralization and the microbial community. *Soil & Till. Res. Vol. 196, Feb. 2020, 104437*
- Liu N, Li Y, Cong P, Wanga J, Guo W, Pang H, Zhang H (2021). Depth of straw incorporation significantly alters crop yield, soil organic carbon and total nitrogen in the North China Plain. *Soil & Till. Res. Vol. 205, Jan. 2021, 104772*
- Liu Z, Liu J, Yu Z, Yao Q, Li, Liang A, Zhang W, Mi G, Jin J, Liu X, Wang, G (2020). Long-term continuous cropping of soybean is comparable to crop rotation in mediating microbial abundance, diversity and community composition. *Soil & Till. Res. Vol. 197, March 2020, 104503*
- Li Y, Li Z, Cui S, Liang G, Zhang Q (2021). Microbial-derived carbon components are critical for enhancing soil organic carbon in no-tillage croplands: A global perspective. *Soil & Till. Res. Vol. 205, Jan. 2021, 104758*
- López-Fando C. et Pardo MT (2012). Use of a partial-width tillage system maintains benefits of no-tillage in increasing total soil nitrogen. *Soil and Tillage Research; 118, 1: 32–39*
- López-Garrido RM, Deurer Madejón E, Murillo JM, Moreno F (2012). Tillage influence on biophysical soil properties: a long-term tillage experiment under Mediterranean rainfed conditions in South Spain. *Soil and Tillage Research; 118, 2: 52–60*
- McKenzie DC (2013). Visual soil examination techniques as part of a soil appraisal framework for farm evaluation in Australia. *Soil and Tillage Research; 127, 3: 26–33*
- Modak K, Biswas DR, Ghosh A, Pramanik P, Das TK, Das S, Krishnan P, Bhattacharya, R (2020). Zero tillage and residue retention impact on soil aggregation and carbon stabilization within aggregates in subtropical India 2020. *Soil & Till. Res. Vol. 202, Aug. 2020, 104649*
- Mulatie M, (2021). Impacts of soil and water conservation practices after half of a generation, northwest highlands of Ethiopia. *Soil & Till. Res. Vol. 205, Jan. 2021, 104755*
- Mulotwa M, Paluku I, Dudu A, Niyungeko MB, Josens G, (2003). Données écologiques préliminaires sur le genre *Dichogaster* Beed dans le système de culture sur brûlis de la réserve de Masako à Kisangani. *Ann. Fac. Sc. UNIKIS, 12: 315-325*
- Nautiyal PS, Chauhan C, Bhati R (2010). Changes in soil chemical properties and microbial functional diversity due to 14 years of conversion of grassland to organic agriculture in semi-arid agrosystem. *Soil and Tillage Research; 109, 2: 55–60*
- Norgrove L, Csuzdi C, Hauser S (2011). Effects of cropping and tree density on earthworm community composition and densities in central Cameroon. *Applied Soil Ecology; 49, 1: 268–271*
- Obia A, Cornelissen G, Martinsen V, Smebye AB, Mulder J, (2020). Conservation tillage and biochar improves soil water content and moderates soil temperature in a tropical Acrisol. *Soil & Till. Res. Vol. 197, March 2020, 104521*
- Pandey C, Chaudhuri S, Dagar J, Singh G, Singh R (2010). Soil N mineralization and microbial biomass C affected by tillage level in a hot humid tropic. *Soil and Tillage Research; 110, 1: 33–41*
- Parihar CM, Singh AK, Jat SL, Dey A, Nayak HS, Mandal BN, Saharawat YS, Jat ML, Yadav, OP (2020). Soil quality and carbon sequestration under conservation agriculture with balanced nutrition in intensive cereal-based system *Soil & Till. Res. Vol. 202, Aug. 2020, 104653*
- Peigné J, Vian JF, Cannavacciuolo M, Lefevre V, Gautronneau Y, Boizard H (2013). Assessment of soil structure in the transition layer between topsoil and subsoil using the "profil cultural" method. *Soil and Tillage Research; 127, 3: 13–25*
- Phillips LA, Greer CW, Farrell RE, Germida JJ (2012). Plant root exudates impact the hydrocarbon degradation potential of a weathered-hydrocarbon contaminated soil. *Applied Soil Ecology; 52, Jan.: 56–64*
- Rodenburg J, Stein A, Noordwijk M, Ketterings Q (2003). Spatial variability of soil pH and P in relation to soil run-off following slash-and-burn land clearing in Indonesia. *Soil and Tillage Research; 71, 1: 1–14*
- Rosolem CA, Calonego JC (2013). Phosphorus and potassium budget in the soil-plant system in crop rotations under no-till. *Soil and Tillage Research; 126, 2: 127–133*

- Schmidt O, Clements RO, Donaldson RO (2003). Why do cereal–legume intercrops support large earthworm populations? *Applied Soil Ecology*; 22, 2: 181–190
- Séguy L, Bouzinac S et Quillet, JC (2002). Et si l'on avait sous-estimé le potentiel de séquestration pour le semis direct ? Quelles conséquences pour la fertilité des sols et la production ? Dossier séquestration du carbone. <http://agroécologie.cirad.fr>
- Sierra M, Martínez FJ, Verde R, Martín FJ, Macías F (2013). Soil-carbon sequestration and soil-carbon fractions, comparison between poplar plantations and corn crops in south-eastern Spain; *Soil and Tillage Research*; 130, 2: 1–6
- Sileshi G et Mafongoya PL (2006). Variation in macrofaunal communities under contrasting land use systems in eastern Zambia; *Applied Soil Ecology*; 33, 1: 49–60
- Stover HJ, Thorn RG, Bowles JM, Bernards MA, Jacobs CR, (2012). Arbuscular mycorrhizal fungi and vascular plant species abundance and community structure in tallgrass prairies with varying agricultural disturbance histories. *Applied Soil Ecology*; 60 : 61–70
- Tesfahuney WA, Van Rensburg LD, Walker S (2013). In-field runoff as affected by runoff strip length and mulch cover. *Soil and Tillage Research*; 131, 2: 47–54
- Thierfelder C, Mwila M, Rusinamhodzi L (2013). Conservation agriculture in eastern and southern provinces of Zambia: Effects on soil quality and maize productivity. *Soil and Tillage Research*; 126, 1: 246–258
- Uteau D, Pagenkemper SK, Peth S, Horn R (2013). Root and time dependent soil structure formation and its influence on gas transport in the subsoil. *Soil and Tillage Research*; 132, 1: 69–76
- Vakali C, ZallerKöpke JG U (2011). Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. *Soil and Tillage Research*; 111, 2: 133–141
- Wang J, Gao X, Zhou Y, Wu P, Zhao X, (2020). Impact of conservation practices on soil hydrothermal properties and crop water use efficiency in a dry agricultural region of the tibetan plateau. *Soil&Til. Res.Vol. 202, June 2020*, 104619
- Wang Y, Liu L, Tian Y, Wu X, Yang J, Luo Y, Li H, Awasthi MK, Zhao Z , (2020). Temporal and spatial variation of soil microorganisms and nutrient under white clover cover *Soil&Til. Res.Vol. 202, Aug. 2020*, 104666
- Xie E, Zhang Y, Huang B, Zhao Y, Shi X, Hu W, Qu M (2021). Spatiotemporal variations in soil organic carbon and their drivers in southeastern China during 1981–2011 ; *Soil&Til. Res.Vol. 205, Jan. 2021*, 104763
- Xu S, Johnson-Maynard JL, Prather TS (2013). Earthworm density and biomass in relation to plant diversity and soil properties in a Palouse prairie remnant. *Applied Soil Ecology*; 72: 119–127