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Full length Research paper

Cropping in Plates under Green Mat": impacts, on depleted Ferralsol, regarding generation of fresh organic matter and saturation with exchangeable bases

Pyame MLD[1]*, Mukandama N Jean-Pierre[1] and Baert G[2]

*[1]Faculté de Gestion de Ressources Renouvelables, Université de Kisangani, BP 2012, Kisangani, RD Congo.
[2]University of Gand, Belgium

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An experiment was carried out in Kisangani (DR Congo) on depleted Ferralsol, to examine, faced with the Slash-and-burn system, to what extent and what degree the system of "Cropping in Plates under Green Mat" would favorably affect the regeneration of recyclable organic inputs and saturation with exchangeable bases. A device plan with 12 complete randomized blocks, divided into 6 plots each, was chosen to test the factors "production system" and "microdoses of NPK fertilizer" (two-factor ANOVA x Duncan's test). It emerges from this study the following performance points:

- ✓ **A considerable improvement in total biomass, root biomass and soil saturation with bases under fallow (36.7 vs 4.9 t DM/ha, 12 vs 1.3 t DM/ha and 52.7 vs 12.4%, respectively). That is to say a Green Mat superiority of 7.5, 9.2 and 4.5 times.**
- ✓ **The production of root inputs under "Green Mat" is such that 16 tDM are opposed to each tof DM generated under Slash-and-burn, the synthesis of aerial inputs being limited to a ratio of 4/1. This exceptional root dynamic would explain the enrichment of the soil with humus and its saturation with bases, via mineral recycling.**
- ✓ **An improvement in the efficiency of rainwater recovery by 4 times (62.2 vs 16.2 kgMS /mm rain) and in the efficiency of fertilizer recovery by 18 times (529 vs 29.3 kgMS /kg of fertilizer).**

In the opinion of many authors, crops and meadows managed in zero tillage report very high efficiency in the use of fertilizers, which is conferred by their high rooting density.

Key words: Sustained Land Management, Green Mat, Slash-and-Burn, Depleted Ferralsol, Recyclable inputs

INTRODUCTION

The use of organic inputs and microdoses of mineral fertilizers, across soil and water conservation practices (Mulatie, 2021), has become widespread across the planet since the advent of ecological and sustainable agriculture. But these fertilizers must be produced and renewed on the land for the sustainability of agro-environmental enterprises. Also, herbage and fodder shrub legumes are widely used, with the help of mycorrhizal fungi and other bioagents, in the revegetation and bioremediation of land affected by desertification (Claudio *et al,* 2013; Ebabu *et al,* 2020; Nafi *et al,* 2021) or chemical pollution (Guo *et al,* 2013; Hu *et al,* 2013).

No tillage and minimum tillage are common practices in conservation agriculture (Cooper *et al,* 2020). Although promoting C sequestration and conservation of soil resources, no-till leads, over time, to an increase in resistance to root penetration (Arvidsson *et al,* 2013), thus affecting root development and rain infiltration (Martinez *et al,* 2008, Bayat *et al,* 2013), this being controlled with biochar incorporation (Obia

*Corresponding author's Email:pyamedieudonne2@gmail.com

et al, 2020).

Minimum tillage with residue retention (Modak *et al,* 2020), an exclusive practice in the Green Mat system, makes it possible to relatively circumvent these limitations while safeguarding the essential advantages of no tillage (Głąb *et al,* 2008; López-Fando and Pardo, 2012), more particularly an increased microbial activity (López-Garrido *et al,* 2012; Wang et al, 2020) and the diversity of biological functionalities in the mycorrhizosphere (Nautiyal *et al,* 2010).

It also has significant potential in improving the physical and biological properties of the soil (Hartmann *et al,* 2012) and the suppression of weeds. For a more effective contribution to soil stability and mineral assimilation function, the root systems of trees, shrubs and grasses should be complementary (Badalona*et al,* 2008; Comino *et al,* 2010; Zhang *et al,* 2021).

The intense production of organic inputs and humus, via mycorrhizal activity, therefore greatly reduces the capacity of the soil to block the available phosphorus carried by fertilizers (Mullen, 2005). It also leads to desorption of insoluble P linked to metal sesquioxides, the complexation of $Al^{3+}$from the soil solution and therefore the lifting of the high toxicity of Ferralsols (Huang *et al,* 2008).

On the other hand, the development of perennial grassy root structures usually provides the soil with a closed cover or mulch (Rabary *et al.,* 2008; Kodzwa *et al,* 2020), innumerable root galleries with walls lined with organic cutans for permeability (Chen and Weil, 2011; Kagabo *et al,* 2013) and soil aggregation (Breman and Kessler, 2007; Singh *et al,* 2020).

Finally, what crowns the "Green Mat" system, is its ability in Ecological agriculture intensification through crop-pasture rotations and bio-edaphic agents' proliferation (Lupwayi *et al,* 2012; Santiago *et al,* 2019).

It is therefore necessary to wonder: should the potential of the Green Mat system, regarding primary productivity, recyclable organic inputs and saturation with bases on depleted Ferralsols, not be measured experimentally and its place be specified among the current practices of conservation agriculture?

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 research 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 study undertaken extended 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 made up of evergreen rain forests 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 patches of *Panicum maximum, Pueraria javanica* and *Calopogonium muconoides*. The lowland area along the stream was covered with *Pennisetum purpureum*.

EDAPHO-CLIMATIC CONDITIONS

The soil of Kisangani (Faculty of Science 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 (Pyame *et al,* 2016).

The textural triangle used is from the Applied Pedology Problems Study Group or GEPPA.

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.

EXPERIMENTAL APPARATUS

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

Fallow fields green manure using *Mucuna-Pennisetum* were established on each of the plots of the device reserved for the practice of the Green Mat system. The

The experimental device mounted in this study is given in figure. 2 below

North

Blocs 1	2	3	4	5	6	7	8	9	10	11	12
T03	T2	T01	T1	T03	T2	T01	T1	T03	T3	T02	T2
T01	T3	T02	T2	T01	T3	T02	T2	T01	T2	T03	T1
T02	T1	T03	T02	T02	T1	T03	T3	T02	T1	T01	T3
T3	T01	T2	T01	T3	T03	T2	T01	T1	T02	T2	T02
T2	T03	T3	T03	T1	T01	T3	T02	T2	T03	T3	T01
T1	T02	T1	T3	T2	T02	T1	T03	T3	T01	T1	T03

West -----> -----> -----> -----> -----> -----> -----> -----> -----> -----> -----> ----->-----> -----> -----> -----> -----> -----> East

Fig. 2. Experimental device A on the trial of rain fed rice cultivation under fallow land and ATV-type green manure against slash-and-burn cultivation. The 3m x 4m plots, elongated in the direction of the slope (8.5%), form blocks perpendicular to it.
Legend -----> = Direction of the slope (water flow)

Definition of treatments:

T01 = 20 t of manure + 00 kg of NPK / ha (BURNS)	**T1 = 20 t of manure +00 kg of NPK / ha (GREEN MAT)**
T02 = 20 t of manure + 50 kg of NPK / ha (BURNS)	**T2 = 20 t of manure + 50 kg of NPK / ha (GREEN MAT)**
T03 = 20 t of manure + 100 kg of NPK / ha (BURNS)	**T3 = 20 t of manure + 100 kg of NPK / ha (GREEN MAT)**

SHORT APPROACH

first operation was slashing, carried out by clearing-stumping technic at ground level with a machete.

Each plot was crossed by 8 lines of *Pennisetum purpureum*, the latter being established at spacing of 50 x 50cm, thus observing a holy space of 25 cm on either side. One line of *Mucuna pruriens* was then inserted, established in pockets (2 grains) arranged with a hoe every 100 cm.

Maintenance and fertilizing practices under fallow-green manure

A bimonthly cutting regime was observed for *Pennisetum purpureum*, thus making use of cut-clearing technic with a machete, allowing to recycle all the biomass. *Mucuna pruriens* was in free development until the cut-clearing occurred at 6 months. Also, a stake made of *Pennisetum purpureum* was carried out at 1 month for the training of the young plants of *Mucuna pruriens*. A first spreading of fertilizers at the rate of 10 t DM of manure /ha, i.e. 12 kg /12m^2 plot, associated with 2/3 of the dose of fertilizer aligned per treatment was carried out 1 month after planting: this is the technic of "mineral pre-absorption by fallow-green manure" exploited as the first strategy of mineral capitalization.

Subsequently, clearing-stumping-chopping at ground level was carried out 6 months after planting, thus sparing the permanent green mat ensuring the honeycombing of the ground. The use of this impressive biomass after cutting was done by compilation with a layer of manure (10 t DM /ha) followed by spreading on the surface of the soil. Care was therefore taken to integrate the remaining third of the dose of fertilizer included in the various treatments: this is "transient microbial immobilization of fertilizers", used as a second mineral capitalization strategy in the Green Mat system.

This ultimately produced "the raw mulch-compost fertilized in situ" which is the backdrop for the "rhizo-bio-organic mat", used as a third strategy of mineral capitalization maintaining a rapid set-up and continual mineral recycling. Root profile samples allowed an evaluation of root production by treatment plot.

Primary productivity: fodder biomass and inputs from fallow

Regular cuts were made at intervals of two months, for the herbaceous layer, and three months, for the wooded layer of the green carpet. Biomass assessed in the field using a suspension balance was also tested for dry matter content in the laboratory and for palatability testing by animals on the pig farm. On average ¾ of the grass and half of the tree pruning were fed to the pigs and consumed with satisfaction.

Chemical analyzes of the soil

The soil samples were taken in December 2010, thus carried for analyzes in Belgium. The current analyzes used are: pH in water and in Kcl, total nitrogen, carbon and organic matter, cation exchange capacity, exchangeable bases, total exchangeable acidity, exchangeable aluminum, organic phosphorus and available phosphorus. These analyzes were carried out in the soil laboratory of the University of Ghent according to Pauwels *et al.* (1992).

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 that followed made use of Statgraphics software. The majority of parameters that have been studied in this device have recourse, in turn, to the two-factor ANOVA, for the significance of the differences between treatments, coupled with the Duncan's test for their discrimination.

RESULTS AND DISCUSSION

Total biomass / fallow root biomass and base saturation

The related data is illustrated in **Figures 1**.

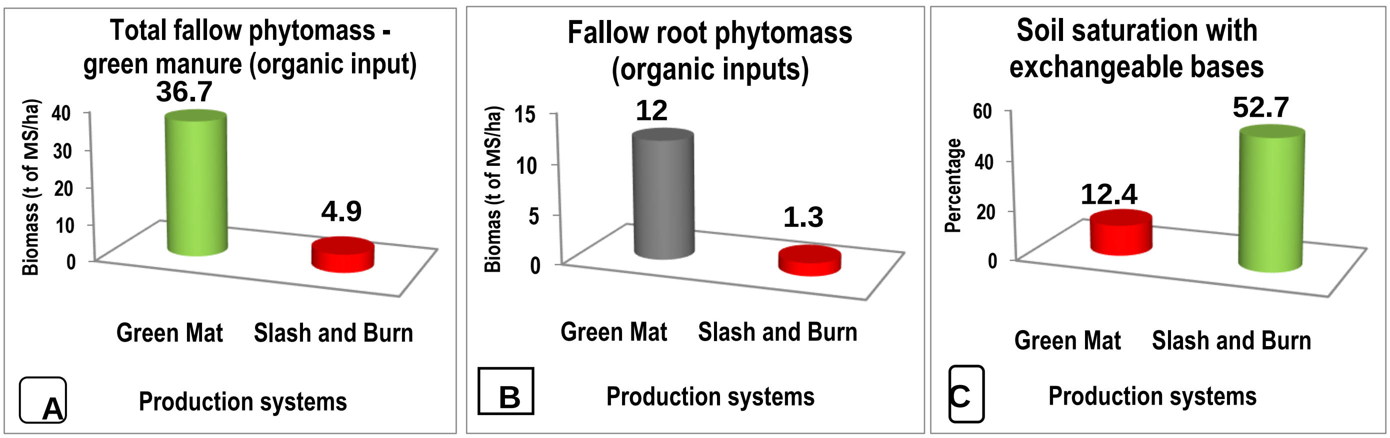

Fig. 1. (A, B, C). Total biomass and root biomass of fallow-green manure (A and B) and saturation of the soil in exchangeable bases (C), opposing the systems of cultivation under green carpet and cultivation on slash and burn. PA = 0.0000; PB = 0.0000; PC = 0.0000.

It emerges from figures 1. (A, B, C), facing Green Mat and Slash-and-burn systems, that the total biomass, the root biomass and the base saturation of the soil under fallow-green manure are 36.7 vs4.9 t DM/ha, 12 vs 1.3 t DM/ha and 52.7 vs 12.4%, respectively. That is, a Green Mat superiority ($p < 0.0001$) of 7.5, 9.2 and 4.5 times.

A variety of factors are mentioned for this performance:

The importance, in the Green Mat system, of a living mulch with vigorous and prospective rooting as a relay for mineral fertilization or a nutrient blotter likely to enhance the value of inputs (Eekeren *et al,* 2010; Dube *et al,* 2012) and to recycle labile and organic phosphorus (Rodrigues *et al,* 2021);

The application of inputs of various qualities, among which biochar, regulating the dynamics of the ions for a high synchronization of mineral supply-demand and a high density of bio-edaphic agents (Singh *et al,* 2007; Bandyopadhyay *et al,* 2010; Martinez, 2010; Li *et al,* 2013; Li *et al,* 2020);

The inclusion, in rotations, of temporary meadows as an alternative to continuous cultivation and to calcium amendments, making it possible to increase the richness in humus and nutrients, biological activity and crop yields (Martínez *et al,* 2013; Ntirenganya, 2010);

The strategy of integrating legumes with perennial grasses, thus forming important pools for enrichment, conservation and propagation of arbuscular mycorrhizae (Pande and Tarafdar, 2004) ;

Incorporation of crop residue which favors biotic and abiotic nitrogen (N) immobilization and stimulate germs proliferation and diversity in the soil (Cao *et al,* 2020 ; Gu *et al,* 2019) ;

The use of direct seeding under permanent plant cover, likely to improve the physical properties including macro porosity, micro structural development, water retention capacity and hydraulic conductivity more increased (He *et al,* 2011;

Thierfelder *et al,* 2013), as well as a high efficiency in the recovery of water and fertilizers (Gonzalez *et al,* 2008; Gosai *et al,* 2009; Govaerts *et al,* 2009).

Production of recyclable residues under fallow including root inputs

It emerges from figures 2 (A, B, C), opposing the

The related data is illustrated in **Figures 2**.

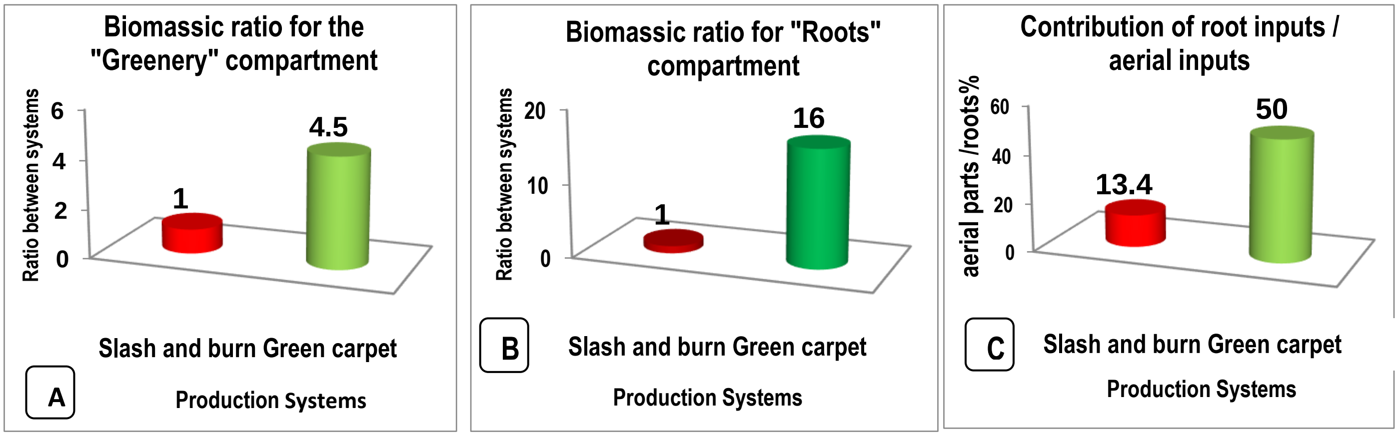

Figure :2 (A, B, C). Biomassic ratio for the "greenery" or aerial parts (A), "roots" compartments (B) and the proportion of root inputs compared to aerial ones (C), opposing the fallows of Green Mat and Slash-and-Burn cultivation systems (50.5 vs. 11.2 and 25.2 vs. 1.5 tMS), exhibiting the highest contribution of root inputs to the Green Mat system productivity.

"Green Mat" to "Slash-and-Burn" systems, that the contribution of root inputs compared to aerial ones is 50 against 13.4%. The production of root inputs under Green Mat is such that 16 t DM are opposed to each t DM generated under Slash-and-Burn, the synthesis of aerial inputs being limited to a ratio of 4/1. That is a consequence of the intensification-stratification of root colonization!

Performance factors are mentioned by many authors:

A high level of microbial activity: the biomass of microbial C, that of microbial N and available P is directly proportional to the amount of inputs accumulated on the surface, stimulating root growth under Conservation Agriculture (Wright, 2009 ; Dos Santos *et al,* 2011; Li *et al,* 2019; Xiao *et al,* 2019);

An assymbiotic sporulation of mycorrhizal fungi is demonstrated after excision of the host plant (death of tufts of grass), in edaphic sectors or microsites enriched with organic matter (Gavito and Olsson, 2008; Lal, 2009b; Quilliam *et al,* 2010; Soares et al, 2019);

The root galleries developped in wet periods by the root system of the fallow-green manure facilitate the penetration of the compact soil by the nourishing roots of the subsequent crop, inducing a much more extensive mycorhization (Chen and Weil, 2011; Stephen *et al,* 2019);

In DMC-type conservation systems, the extent of mineral recycling is such that a notable stratification of fertilizer resources takes place, of which the surface layer of the soil (0-10 cm) is the most filled (Wang *et al,* 2010; Deubel *et al,* 2011; Tiecher *et al,* 2012; Jug *et al,* 2019; Wang *et al,* 2019);

Finally, root growth is accelerated by balanced fertilization carried out at the base of the crop, close to the roots (Roose, 2007) with more nutrients synchronization in soil-plant systems (Nevins et al, 2020).

The synchrony of cover crop decomposition, enzyme activity, AMF colonization and nitrogen availability which enhence the ecosystem productivity (Zhang *et al*, 2019)

Efficiency of mineral-organic fertilization and rain recovery

From the analysis of the data in Figures 4A and 4B, it appears that the efficiency of mineral fertilization, in kg of overall dry production /kg of mineral fertilizer, is 29.3, 451, 641 and 495; that is an efficiency ratio of 1, 15, 17 and 22, respectively for slash-and-burn cultivation and green mat cropping in its three variants.

We note, with the use of the Green Mat system, an improvement in the efficiency of rainwater recovery by 4 times (62.2 vs 16.2 kgMS /mm rain) and in the efficiency of fertilizer recovery by 18 times (529 vs 29.3 kgMS/kg of fertilizer). The crops and meadows managed in zero tillage report very high efficiency in the use of fertilizers, which is conferred by their high rooting density. Grifith in Whyte (1959) reports a root extraction of nitrates 40 times more efficient under *Pennisetum purpureum* than under spontaneous fallow.

Mulching with straw from permanently established local grasses has succeeded, according to the proliferation of soil flora / fauna, in doubling the

The related data is illustrated in Figures 3 and 4.

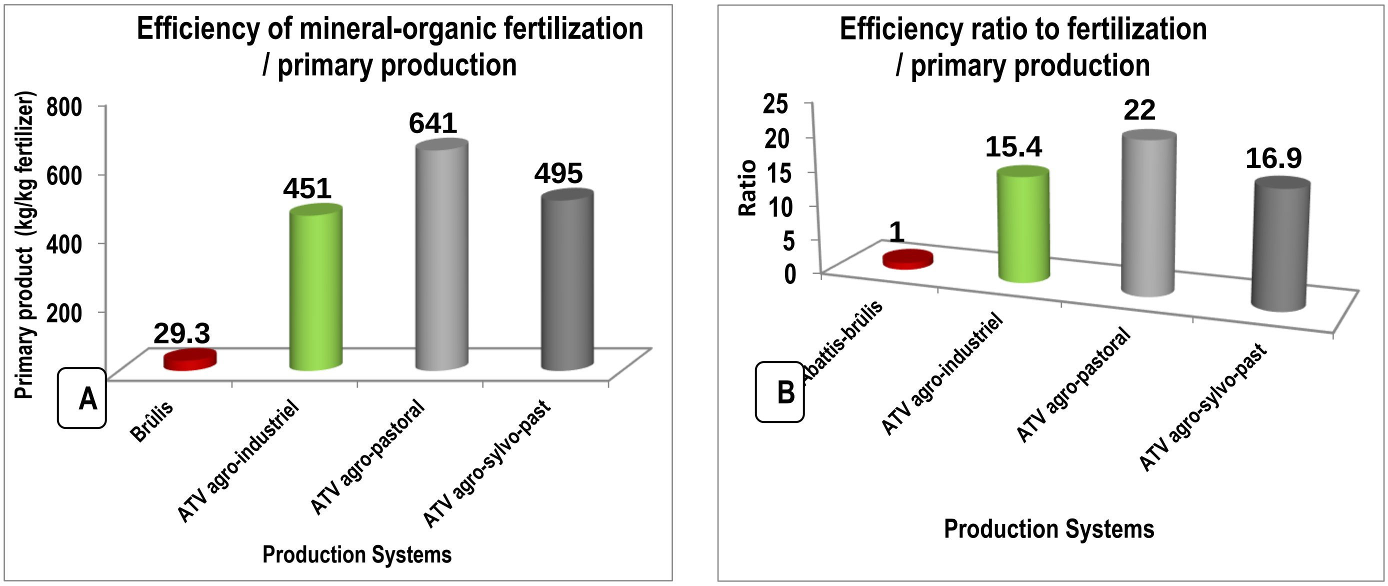

Figure 3 (A, B). Efficiency of mineral fertilization (production generated by 1kg of fertilizer) focused on overall production including crop residues (A) and efficiency ratio between the 2 systems (B). The statistical probability: P_A = 0.0000; P_B = 0.0000.

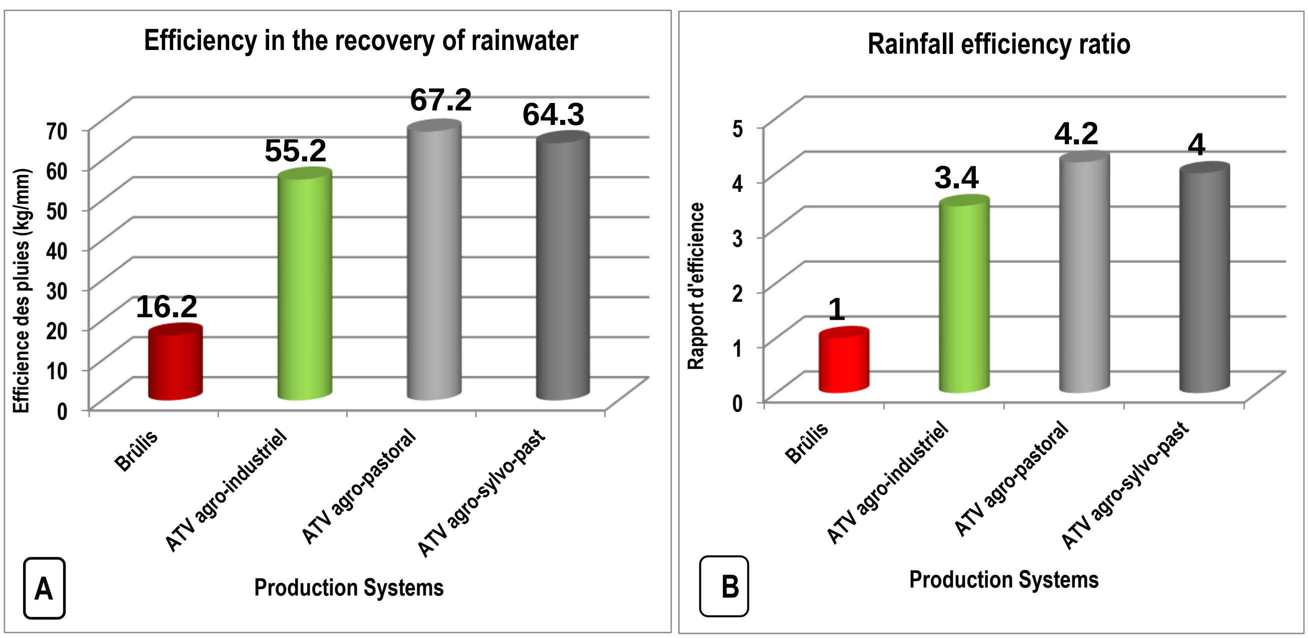

Figure. 4: Efficiencies (A) and efficiency ratio (B) for the recovery of rainwater, for the system of cultivation on plates under green mat versus the system of slash-and-burn cultivation, based on the overall production including crop residues (phytomass).

efficiency of rain recovery in many regions (Strosnijder, 2009 ; Wang *et al,* 2020). Subsoiling coupled to mulching yielded the best maize production and hiest water use efficiency in the Loes Plateau of China (Xie *et al,* 2020). A trial on the previous wheat crop in a semi-arid zone, conducted by Cayci *et al.* (2009) was able to establish a storm water efficiency of around 10 kg/mm. A maximum of 15 kg/mm has been recorded under the same conditions in China (Wang *et al,* 2007). With 62 kg of DM /mm, the efficiency of rain recovery is 4 times greater than in the best agrosystems of the semi-arid environment, however reputed to be economical.

Competitive agriculture can only emerge as a result of the synergistic integration between a whole panoply of ecosystem factors (Reicosky and Wiltz, 2005). This would make it possible to develop a range of economic opportunities that are sorely lacking with the usual export monocultures (Charlton, 2002).

Also, integrated and balanced management strategies from agroecological and socio-economic points of view, capable of sustaining permanent mineral recycling, must be found as an alternative to the massive use of fertilizers, chemical pesticides and calcium amendments in tropical agroecosystems (Calegari *et al,* 2013).

Thus, in a trial carried out in Mexico on a corn farm using fallow land with Mucuna pruriens, Ortiz-Ceballos *et al* (2007) found a clear synergy in the increase in yields between Mucuna pruriens and Balanteodrilus pearsei, a common earthworm in the environment. In particular, it was noted that the system has improved fertility parameters and allows, under manual farming conditions, to dispense somewhat with irrigation, plowing, nitrogen fertilizers and chemical herbicides; which makes it more competitive (Dave Louis, 1989; Dube *et al,* 2012)!

In addition, the use of live mulch increases the intensity of microbiological and biochemical processes allowing to "sustain" production at a lower cost (Rumawas, 1985; Erenstein *et al,* 2008)and occasional tillage can't undo the ecosystem services gained with no-till (Humberto *et al,* 2020)**.**Also, combining no-till with graminae cover crop made it possible to mitigate nitrous oxide emissions without decreasing yield (Fiorini *et al,* 2020). Thus, soil invertebrates are essential and can serve as bioindicators of soil functioning and agrosystem productivity (So *et al,* 2001; Douglas *et al,* 2011; Lou *et al*, 2011; Niemeyer *et al,* 2012).

CONCLUSION

Comparing the Green Carpet and Slash-and-burn systems, it emerges that the total biomass, the root biomass and the saturation of the soil in bases under the fallow-green manure are 36.7 against 4.9 t DM/ha, 12 vs 1.3 t DM/ha and 52.7 vs 12.4%, respectively. That is, a Green Carpet superiority ($p < 0.0001$) of 7.5, 9.2 and 4.5 times.

In this context, the contribution of root inputs compared to aerial ones is 50 (Green mat) against 13.4% (Slash-and-burn). The production of root inputs under Green Carpet is such that 16 t DM are opposed to each t DM generated under Slash-and-burn, the synthesis of aerial inputs is limited to a ratio of 4/1. There is an exceptional root dynamic here which clearly explains the enrichment of the soil with humus and its saturation with bases, via mineral recycling.

Finally, with the use of the ATV system, we note an improvement in the efficiency of rainwater recovery by 4 times (62.2 vs 16.2 kgMS /mm rain) and in the efficiency of fertilizer recovery by 18 times. (529 vs 29.3 kgMS /kg of fertilizer). In the opinion of many authors, crops and meadows managed in zero tillage report very high efficiency in the use of fertilizers, which is conferred by their high rooting density.

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ANNEXE