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Full length Research paper

Refining the assesment of C pools under eco-managed multi-layered agroforests (cropping in Plates under Green Mat): "the multi-criteria approach by ecological compartments"

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An experiment was carried out in Kisangani (DR Congo) aiming to set up the modalities of a multi-criteria assesment of C applying to peasant fields and toeco-managed multi-layered agroforests. This by comparing "Green Mat"agroforestsystem with the Slash-and-Burn fallows aiming to C stocks and sinks. A device in 5 complete randomized blocks divided into 2 plots each, was chosen to test the “production system” factor (unifactorial ANOVA x Duncan's test). It emerges from this study the following capital points:

✓ **Under complex agro-forest, five new pools, in addition to the tree stratum (18.1%) traditionally admitted in forest C inventories, namely (1) the organomineral soil (46.5%), (2) the litter-mulch (11.5%), (3) the organic soil layer generated under litter (5.4%), (4) the herbaceous layer (12.9%) and (5) the composts produced in situ (5.6%), would be of comparable interest as stock (100%) and sink of C, imposing a multi-criteria assessment approach.**

✓ **The gradual integration of these 5 carbon compartments in the calculation of agroecosystem's C stock / sink will make it possible to avoid current underestimations and improve, depending on the case, up to 90% of the values found, particularly in eco-managed peasant farms and multi-layered agroforests.**

Key words : Green mat, Agrocology, Multi-criteria assesment, multi-layered agroforests, C sink, C stock

INTRODUCTION

In tropical areas, the assessment of carbon stocks or sinks is usually done in forests, due to the primacy of trees dictated by their imposing biomass and their longevity, thus trapping or sequestering organic carbon for several decades or even centuries. This prevents its return to the atmosphere as a so-called "greenhouse" gas. The most common calculation methods use variable allometric equations, as diverse as the structural characteristics of the planet's forests are (Picard *et al,* 2012; COMIFAC, 2013, Loubota et al, 2016, Tsoumou *et al,* 2016). But these are in no way useful when it comes to assessing organic carbon in peasant fields and eco-managed agroforests (Pyame, 2015 ;Gábor *et al,* 2019 ;Nafi *et al,* 2021)!

There are currently nucleo-radioactive methods that make it possible to assess the sequestration of C as well as the gren house gaz (GHG) emissions on a land and to provide the results (Smith *et al,* 2010; Gaspar et al, 2013). In the context of peasant farms, radionuclear techniques, in particular the use of stable isotopic tracers based on 15N, 13C, 2H and 18O are therefore more suitable for MRV processes (IAEA / FAO, 2012), despite the lack of technological mastery and financial inaccessibility reported for rural people.It should also be noted that after a prolonged application of organic

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mulches, the soil can approach its maximum capacity for carbon accumulation and become less efficient at sequestering CO_2, which considerably increases emissions (Lenka and Lal , 2013). But a sequestration-emission balance should be observed within agroecosystems and lead to considerable net sequestration from the care given to management practices (Mi *et al,* 2019 ; Wang *et al,* 2019 ; Li *et al,* 2019).

Also, soluble organic carbon and ammoniacal nitrogen, produced particularly in cropping systems with a high level of organic inputs, among which active legumes, maintain flows of N_2O and CH_4 through an action that both stimulates methanogenesis and inhibit methano-oxidation (Malhi *et al,* 2006; Bayer *et al,* 2012). This calls for local procedural control in carbon assessment.Indeed, the conversion of primary forest to pasture for rearing large livestock is still common in the Amazon basin. The choice of the method of restoring degraded pastures is really crucial for a sustainable balance between the availability of C, N and losses in the gaseous form (Habtegebrial *et al,*2007). It was found that the application of no-till alone in the Amazonian Cerrado only led to a meager stock of carbon and nitrogen given the CO_2 and N_2O emissions incurred (Do Carmo *et al,* 2007).

The introduction of conservation practices must have had a considerable impact on carbon sequestration and GHG emissions. Direct seeding under permanent mulch cropping system (DMC) has a high potential for reducing CH_4 emissions in rice cultivation; this is attributed to the low proportion of dissolved C and a higher AD in conservation agriculture (Li *et al,* 2011; Fiorini *et al,* 2020). Agricultural practices cause variation in physical, chemical and biological properties, which, in turn, affect GHG emissions (Hodge, 2000; Martinez *et al,* 2008 ; Chatterjee and Lal., 2009; Panosso *et al,* 2009; Fu *et al,* 2010 ; Herold *et al,* 2014). The physical protection of mineralizable carbon offered by particulate aggregation constitutes the primary mechanism for stabilizing organic carbon in soils. Thus the dislocation of aggregates during plowing is a key process initiating GHG emissions and carbon losses during the crop establishment phase (Huang, 2004; Pes *et al,* 2011).

The following questions, the 2nd in particular, establish the common thread of the research conducted in this study.

"In order to enhance the exceptional agro-climatic potential specific to the Congo Basin:

(1) should we not, on the strength of the "cultivation on plates under Green Mat" system, dare to exploit the degraded peri-urban and savannah lands so immense, establishing substantial C sinks there, in a strategic combination of fallow land, pasture and multiform tree plantations?

(2) Could we, therefore, establish the modalities of a multi-criteria carbon assessment applying to peasant fields and multi-layered agrosystems eco-managed? "

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 undertaken 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 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 *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. of 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 (Pyame, 2015). The textural triangle used is from the Applied Pedology Problems Study Group or GEPPA (Callot *et al,* 1982).

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 (Pyame, op cit.).

EXPERIMENTAL DEVICE

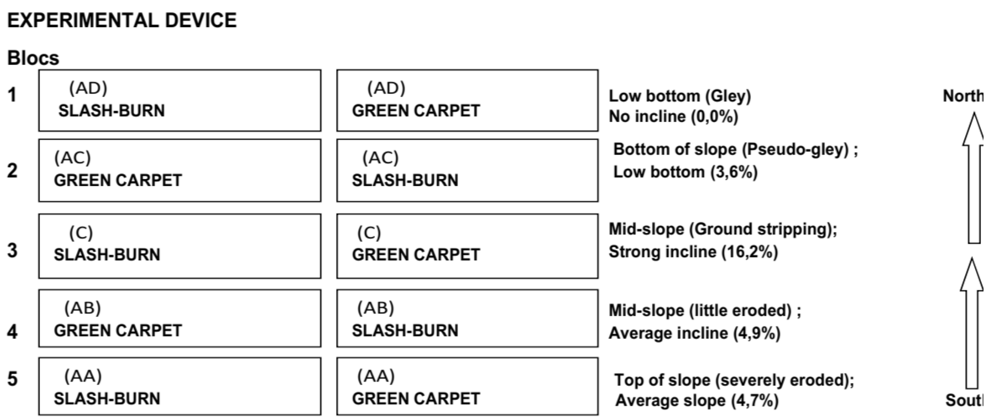


Fig. 1. Experimental device B on the test on the strategic establishment and the refined evaluation of carbon stocks and sinks under agroforests of the agroforestry fallow-grassland type, faced to slash-and-burn cultivation.
Legend: AA, AB, AC, AD and C designate the different experimental blocks. The 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. ⟹ Direction of slope.

BRIEF DESCRIPTION

An agroforestry fallow-pasture with *Pennisetum purpureum, Mucuna pruriens* and *Albizzia chinensis* was established, then managed in alternation, every 6 months, with food crops. *P. purpureum* and *A. chinensis* formed a permanent "green mat", structured in crisscrossing hedges and observing alveolar spaces of about 10m^2 intended to receive crops ("cultivation plates").

These hedges were regularly trimmed during cultivation, providing an abundant and rich biomass intended to cover and permanently amend the soil, thus enriching it with organic matter (carbon).

In order to assess the stock and sink of C thus formed in the agroecosystem, it was imperative to find the method that best responded to this multi-varied ecology.

APPROACH FOLLOWED

A multicriteria approach for ecosystem quantification of C involves evaluating: (1) the C of the organic soil stratum formed under litter, (2) the quadratic diameter characterizing the average tree of the stand, (3) the volume and the wood density for the different fractions of the average tree, (4) various weight indices of this, (5) the biomass of the herbaceous layer, (6) biomass of litter and composts produced in situ, and finally (7) the deduction of C stocks and sinks for each ecological compartment and (8) for the whole agro-forest.

In general, organic C is obtained by volumetric assay, for soil compartments, and deduced from the phytomass (50% DM) for aboveground compartments (Lal, 2010; CIRAD, 2013).

The images presented in the appendix show the characteristics of the agroforests of the agroforestry-fallow-grassland type that are the subject of the study.

Assessment of plant biomass for different compartments of the agroecosystem, in the estimation of carbon sequestration

The operating methods are given **in Table 2** below.

Table N ° 2, Methods for calculating plant biomass other than wood in the agroecosystem

Biomassic compartments	**Calculation methods**
1. Litter	The The litter having been taken from plots of 10cm x 10cm, i.e. 100cm², the tonnage in DM / ha is ded deduced as follows: let m, the mass in gMS collected over 100cm², M (tMS / ha) = m10^{-6} t / 100 x 1 x 10^{-8}ha = **m tMS / ha**
1. 2. The roots	Starting from the recorded root production "m", in kgMS / 9m², the mass in tMS / ha was deduced as follows**: M (tMS/ha) = 10/9 m**
3. Composts	We estimate that **upun 100% of the biomass taken** from the herbaceous shrub green carpet, 50% is applied directly (litter), 25% goes to the farm as fodder and **25% passes through the compost** bin before being exported as fertilizers to cultivated plots.

The quadratic diameter and the average tree of different stands

The quadratic diameter (dg) represents the diameter at breast height (dbh) of the average tree, deduced from the squares of the dbh values recorded during the general inventory of a stand of trees of known size (N). It therefore makes it possible to assess its total basal area (G) and its average basal area (gm). This index, which gives the characteristic of the average tree of the stand, therefore allows its identification among many others. This allows it to be indexed, thus precisely locating the surveying work affecting the various biomass compartments and the final assessment of the carbon stock of the tree component of the agroecosystem. These dendrological parameters are linked by the formulas below taken from Lokombe (2013):

(1) $\boxed{G = \pi/4 \sum dhp^2}$ (2) $\boxed{gm = G/N}$ (3) $\boxed{dg = 2\sqrt{(gm/\pi)}}$

In situ evaluation of the biomass of the compartments of the average tree

The biomass of the different fractions of the average tree was determined in turn by direct weighing, in the field, after cutting up the felled tree; this using a suspension scale (to the nearest 0.1 kg), and using a tarp, machete, handsaw, pruning shears, calipers and a data transcription kit.

The concrete evaluation went through the in situ weighing of the different compartments of the average tree, the partition of woody sections and bark as well as the determination of the bark weight index and the dry matter coefficient for the different organs of the tree.

Estimating the weight of the woody parts thus requires resorting to the volume and average density of the various fractions, which can only be determined after careful partitioning of wood and bark.

The determination of the dry matter index was therefore carried out separately for bark and wood, the latter also making a clear demarcation between the roots, trunk, branches and twigs from which samples were taken distinctly for the basal, median and summit parts, in order to access a much more reliable average.

The bark weight index (E/B) was therefore determined for the different fractions of the average tree by carefully measuring the weights of wood (B) and bark (E) for each piece sampled. Samples intended for the analysis of the dry matter content (DM%) and the determination of the dry matter index (MSk) were taken in the fresh state, weighed on the field in plastic packaging beforehand tared then sent to the laboratory for further operations.

Evaluation of the density of the wood for the fractions of the average tree

The wood density (D in g/cm^3) was determined and presented, on the one hand for the trunk and roots and, on the other hand, for the branches and twigs. It was deduced from the "dry weight /volume" ratio of the wood segments. Samples were taken, in each case, for the basal, middle and terminal parts, also observing three replicates.

The measurements of the different pieces representing the samples related to the dry weight (Ps), to the average diameter (dm) deduced from d_1 and d_2 taken at the ends and to the volume (V) for pieces measuring 5 cm in height (h). The average of the three repetitions was deduced before being recorded in the calculation tables, and the following formulas were used:

$V = S \times h = 3{,}14\ (dm/2)^2 \times 5 = 3{,}14 \times 5 \times dm^2/4$;

(4) $$\boxed{dm = (d_1+d_2)/2}$$

(5) $$\boxed{V = 3{,}925\ dm^2}$$

We have thus distinguished the root index (Rc / Tr) given by the ratio "weight of the roots (Rc) to weight of the trunk (Tr)", the index of the crown (Hp / Tr) dictated by the ratio "weight of the tree crown (Hp) on trunk weight "and the tree index (Ar / Tr) dictated by the ratio“ total tree weight (Ar) on trunk weight ”.

Evaluation of the weight indices and the carbon sink for the tree stratum

The biomass of the different fractions of the average tree and the total weight of the average tree were determined. The biomass of the tree stand per hectare was deduced through a precise assessment of the land area, a count of trees and multiplying the weight of the average tree by the density of plantation. The C was obtained by dividing the phytomass by 2. This made it possible to extrapolate the level of carbon sequestration per hectare.

The weight indices or coefficients of extension of the biomass at different levels of the system make it possible to evaluate the weight of the tree or its fractions, starting from the weight of the trunk (easily measured by the dbh, the volume and the density). We thus deduce the weight of the roots and of the terminal parts generally forming the crown (all the branches, twigs, leaves, flowers and fruits). Ultimately, the biomass of the entire stand is released, for a more reliable estimate integrating the different compartments of the tree.

Rate of organic C, weight of organomineral soil and mass of sequestered C

The organic carbon content (CO%) was determined by the Walkey and Black method at the soil analysis laboratories of the University of Ghent in Belgium, while the dynamics of the organic matter for the later phase is taken into account, counted and evaluated through the new top soil generated under the litter according to the practice of conservation agriculture.

The evaluation of carbon sequestration was carried out by considering 15 cm of soil thickness for both the topsoil (0-15 cm) and the subsoil (15-30 cm), i.e. a volume of 1500 m^3 / ha . Carbon sequestration in CO_2 equivalents (MCO_2) is obtained by multiplying the last value thus found by the coefficient 3.67 expressing the mass ratio between C and CO_2. However, for new top soil, the soil thickness (h in m) as well as the AD were variable; the mass of sequestered carbon (Mc) was found according to the formulas below

$$\boxed{M_C\ (t/ha) = 10^4 \times h \times D.A. \times}$$

$$\boxed{M_{CO2}\ (t/ha) = 3.67 \times 10^4 \times h \times D.A. \times C.O.\%}$$

The calculation was performed for the 0-15 cm, 15-30 cm strata and the neosol located on the A0 horizon, above the soil surface.

Mass of stumps and total phytomass of the herbaceous fraction

The evaluation of the carbon sink having coincided with the last cut of the herbaceous plants, all the aerial parts were reduced to litter, the phytomass of the herbaceous fraction comprising only two terms, namely the mass of the aerial stumps and that of the rootsystem. Distinction was made between fresh and dry stumps during the dry matter assessment, just to make it easier. The C was evaluated at half of the phytomass. The root mass assessment also followed the procedural scheme presented above.

Total C stock of Green Mat and Slash-and-Burn agro-ecosystems

The total carbon stock sequestered under an agrosystem thus comprises two main pools for the slash-and-burn system, namely the herbaceous layer comprising the litter (grass cutting residues) and the organomineral soil of 0-15 cm and from 15-30 cm.

However, agroforestry fallow-grasslands include, in addition to the tree layer traditionally accepted in the biomass accounting of forest ecosystems, five new pools, namely 1) the herbaceous fraction comprising aerial and southern parts, (2) the litter common to these two layers, (3) the new top soil, (4) organomineral soil and (5) the stock of composts obtained from a fraction of the above-ground biomass (residues from grass cutting and tree prunings).

Evaluation of the C stock and sink for the compartments and the entire agrosystem

The assessment of the carbon stock and sink for Green Mat-type agroecosystems went through an estimation of carbon stock and sink by compartment, followed by a carbon balance by terroir.

Statistical analyzes

The data collected on cards, in the various operations 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 two-factor ANOVA, for the significance of the differences between treatments, coupled with the Duncan's test for their discrimination.

RESULTS AND DISCUSSION

This part of study leads us to 2 essential points which are: (1) the application of the "multicriteria approach by ecological compartments" to a typical agroforest (18-month agroforestry fallow-grassland comprising *Albizzia chinensis, Pennisetum purpureum* and *Mucuna pruriens*) and (2) the interest of the approach as well as the advantages provided.

Refining the assessment of C reservoirs in agroforests under eco-agriculture: the ecological compartment approach

Figures. 2 and 3 below show the result of the related analysis.

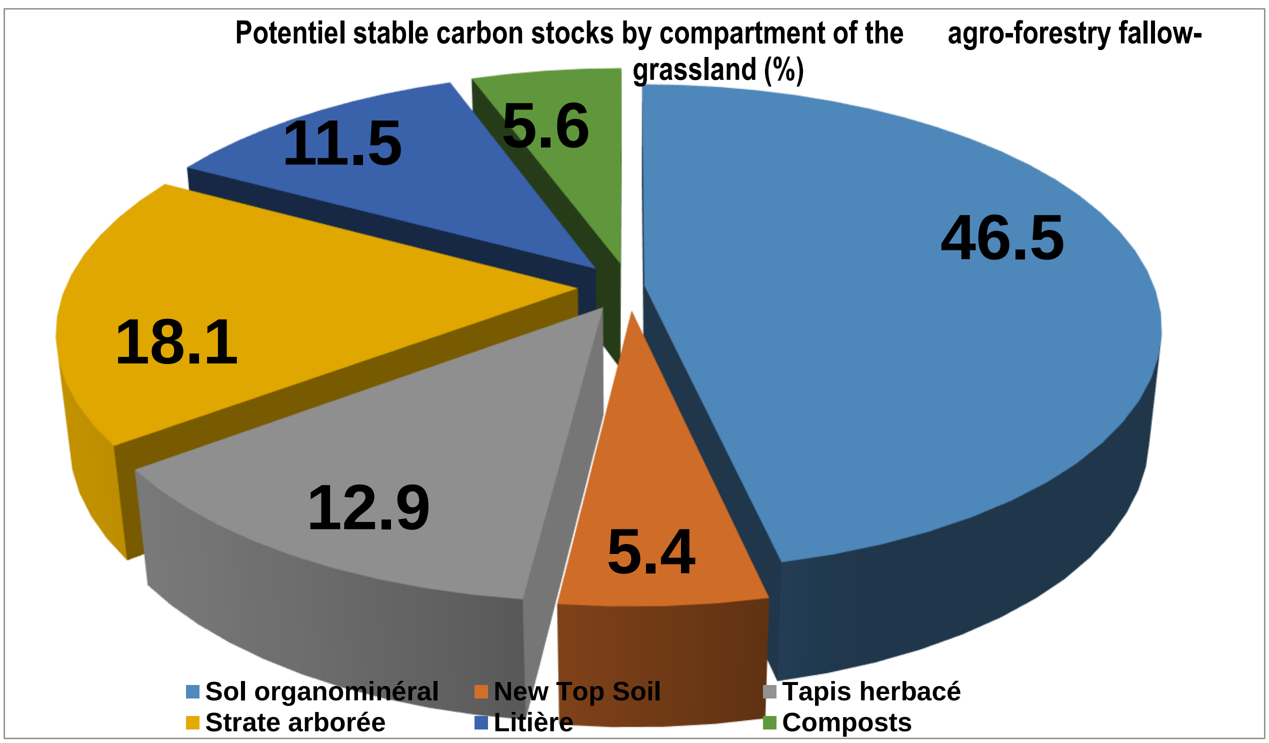


Figure. 2: Potential carbon stocks per compartment of agro-forestry fallow-grassland (cropping under green mat system), converted into stable C. The stable C is obtained by multiplying the organic C freshly incorporated into the soil by 1/3 which is the humified fraction, according to CIRAD (2013), and the C of trees by 2/3 (living wood remaining after sylvicural care).

From the analysis of the data in Figure 2, it should be noted that the carbon stock carried by the tree stratum of the young stand of *Albizzia chinensis* occupies the 2nd place with 18.1%, in the ranking order of the six identified compartments. One compartment come before namely organomineral soil with 46.5%; four compartments are ranked behind, namely the herbaceous layer with 12.8%, the litter with 11.5%, the "New Top Soil" with 5.4% and the composts generated by the agrosystem and kept in reserve (5.6%). In

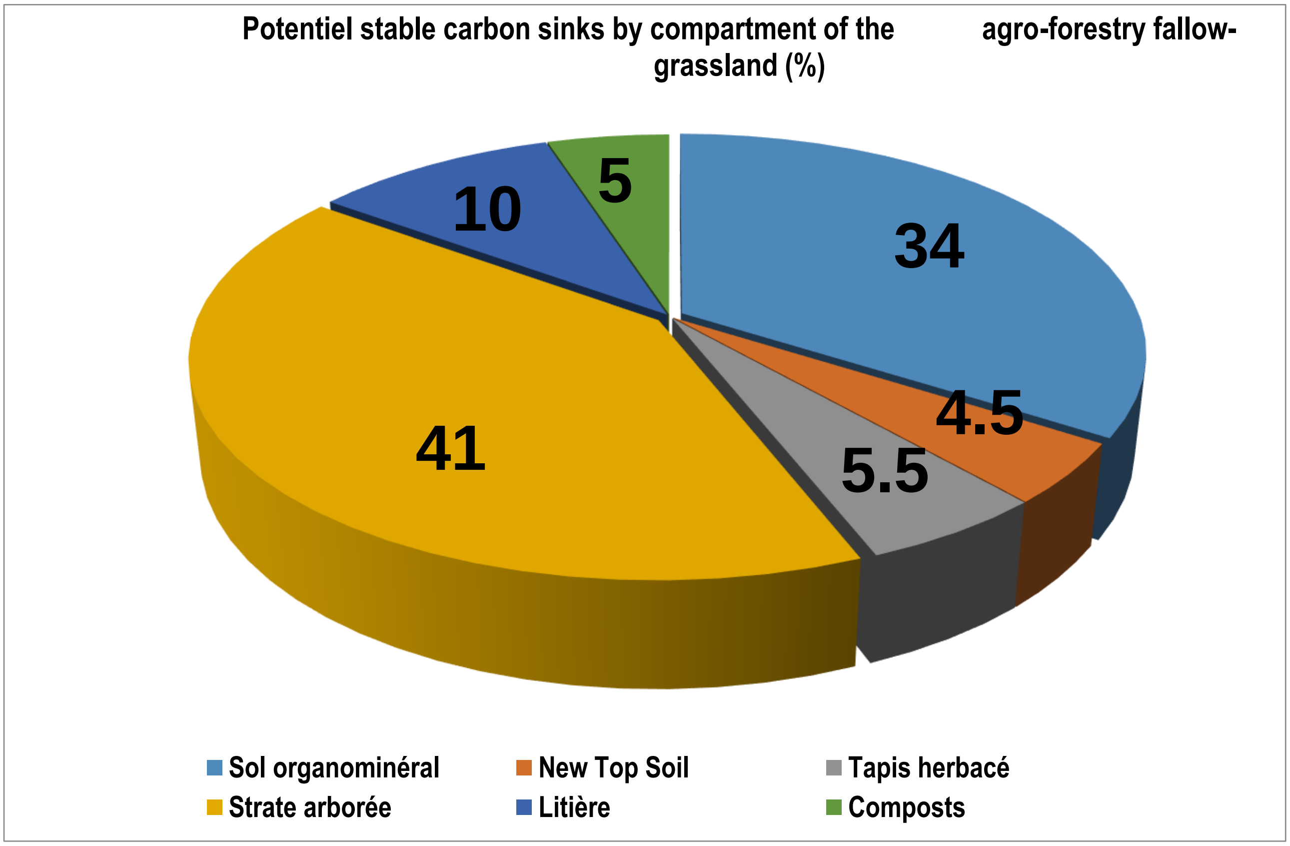


Fig. 3. Potential carbon sinks per compartment of agro-forestry fallow-grassland (cropping under green mat system), converted to stable C. The stable C is obtained by multiplying the organic C freshly incorporated into the soil by 1/3 which is the humified fraction, according to CIRAD (2013), and the C of trees by 2/3 (living wood remaining after silviculturalcare).

addition to the tree stratum traditionally admitted in C inventories, the 5 other ecological compartments, totaling 82% of the C stock, appear to be absolutely essential for the reliability of the assessment.

From analysis of the data in Figure 3, relating to the C sink, the 6 compartments of the C reservoir identified each have its contribution, the contribution of the tree stratum however increasing in importance due to the effect of a use of fast growing tree species.

Valentini (2007), in Costa-Rica, having analyzed cocoa agroforestry systems developed under natural shading against the traditional slash-and-burn system, distinguished, like us, 6 ecological compartments namely the C of shade trees, the C from cocoa trees, C from grasses and undergrowth, C from litter and dead wood, C from roots and organic C from soil.

The carbon stock found in the living above-ground biomass of agroforestry systems thus varies from 10 to 60 t C / ha (Valentini, 2007), from 13 to 42 t C/ha (Schroth *et al,* 2002), from 7 to 43 t C / ha (Albrecht and Kandji, 2003) and around 60 t C / ha (Béer et al, 1990) for age groups ranging from 3 to 10 years. Our results relating to aerial C with trees range from 11 to 20 t of C/ha and are well within this range, for a timing well under 2 years! In addition, the sensitivity of soil organic carbon pools to land management varies depending on former tillage practices (Miller*et al*, 2019)

A variety of strategies set out below, and joining our working methods, are all performance factors underlying our results, in the logic of a multi-criteria evaluation of C sequestration embracing the entire soil-plant system.

Moreover, many authors have pinpointed conservation-type management strategies and practices giving rise to higher biomass production during the year and, therefore, to tighter nitrogen cycles. These, in fact, are more likely to reduce nitrate leaching, pollution of aquifers and N_2O emissions, leading to higher net CO_2 sequestration (Heenan *et al,* 2004; Johnson *et al,* 2005; Oorts *et al,* 2007; Hansen *et al,* 2010; Pelster *et al,* 2011 ; Parihar *et al,* 2020).

Also, Caravaca *et al.* (2002a, b) and, subsequently, Bonfim *et al.* (2013) considered, in landscape restoration aimed at degraded soils, the use of compost mixed with mycorrhizal inoculum, which offers spectacular results in afforestation perimeters (Li *et al,* 2021 ; Qaswar et al, 2020), in the other hand, recommand combined application of manure and inorganic fertilizers in acidic paddy soil which increase sustainability and yield index of rice crop more than chemical fertilization.

Likewise, faced with the severe soil degradation, innovative farmers in the Andes in the Republic of Ecuador have initiated an agroforestry variant of alley cropping, in which the hedges of leguminous trees are reinforced, on steep terrain, by stable grass bands, favoring a gradual formation of terraces (Dercon *et al,* 2003), more increased carbon sequestration (CNRS, 2002; CIRAD, 2013) and spatiotemporal variations of soil C (Xie et al, 2021).

In addition, nitrogenous fertilizers applied at high doses, in the absence of auxiliary nitrate trap plants (nutrient blotters), can lead, in the rainy season, to nitrogen losses by leaching of nitrates and by emission of N_2O largely exceeding the fraction assimilated by the crop plant (Malhi and Lemke, 2007; Carvalho *et al,* 2009; Rochette *et al,* 2009; Ujii *et al,* 2013). Thus, the humidification index is more strongly correlated with CO_2 emissions than with other edaphic parameters (Martins *et al,* 2011; Panosso *et al,* 2011 ; Xu *et al,* 2020).

Traditionally, the C sequestration potential of a soil is assessed according to the distance separating its carbon status from that of the particularly uneroded natural ecosystem.

Thus, the highest C sequestration potential in China has been found in the highlands of the south of the country (subtropical climate), on severely eroded soils (Shi *et al,* 2009). Conservation agriculture, through mulching and no tillage, may help in ecosystem services, including carbon sequestration (Sanaullah *et al,* 2020)

Finally, long-term trials have established that regular mineral intake influences the storage of C in micro aggregates (Hermosín, 2007), thus controlling the dreaded losses through microbial decomposition (Insam, 2007; Ouédraogo *et al,* 2007 ; Majumder *et al,* 2010 ; Rahmati *et al,* 2020 ; Zhao *et al,* 2020).

Importance of "multi-criteria assessment by ecological compartments" and advantages provided

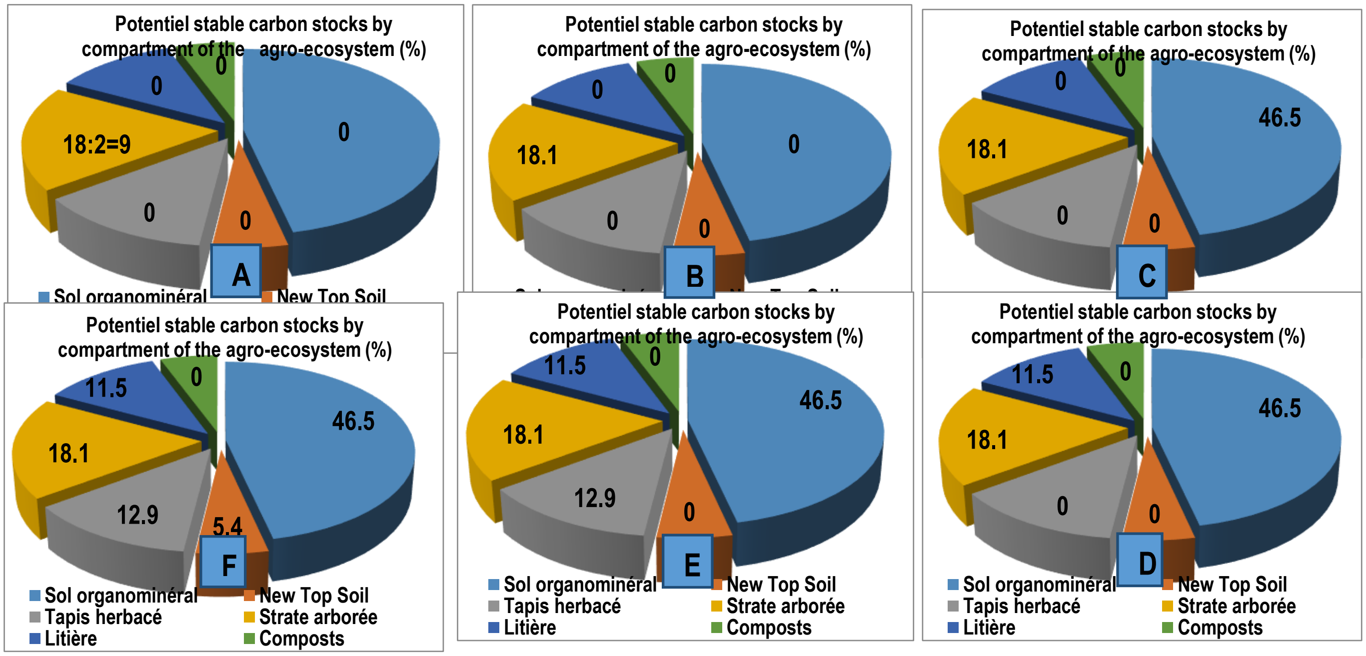
The evaluation of the carbon sink in forest ecosystems is experiencing significant progress but we are not yet at the end of the expected improvement, due to the rough approximations characterizing the estimate of the forest biomass (productivity) of which it is derivative.

In fairly recent times, the organic carbon of a forest was obtained by estimating, through dendrological parameters, half of the exploitable woody biomass, except for crowns, root systems, litter and dead wood(Lokombe, 2013)! Worse still, no mention was made of soil organic carbon, which is the major carbon reservoir, if we consider the different ecological compartments of the forest ecosystem.

The allometric equations developed for different forest ecosystems recently attempted to improve this assessment by significantly reducing the default approximations at the time (Picard *et al,* 2012; COMIFAC, 2013, Loubota *et al,* 2016, Tsoumou *et al,* 2016). However, they are far from being useful if we consider the most varied agroecosystems including eco-managed peasant fields and multi-layered agroforests. A multicriteria assessment approaching the various ecological compartments differently is called for and this is the major contribution of this study!

On analysis, the importance of this multi-criteria assessment could be seen by demonstrating the advantages provided in terms of carbon volume recovered through a refined and more realistic assessment.

Let us see below the different possible scenarios depending on whether this or that other default approximation (Figure.4. A to F, below) occurs during forest carbon assesments if we consider, in the rotation, the fallow phase - agroforestry grassland (temporary meadow) or inter-campaign.



Figures. 4 (A to F). Six cases or scenarios, numbered from A to F, tending towards the most precise estimate and with the highest value in terms of carbon stocks, when taking the option of a multi-criteria assessment by ecological compartments, we recover, one after another, ecosystem sectors traditionally sacrificed (ignored, neglected) to the assessment of C

Six cases or scenarios of erroneous assessment are aligned, numbered from A to F, generally tending towards the most precise estimate and with the highest value in terms of carbon sinks, when taking the option of a multi-criteria assessment by compartment ecological, we recover, one after the other, the ecosystem sectors traditionally sacrificed (ignored, neglected) in the current assessment practices observed!

Case N°1: A very incomplete estimate of forest C based on marketable woody biomass (logs), therefore disregarding the root system and crown (at least 50% of woody biomass).

For the case of this estimate made on young agroforestry fallow-grassland (Figure. 4A), given this loss of 50% on the tree compartment, in addition to not taking into account the C of the various other compartments, we will only have 18.1% / 2 = 9% of the real carbon volume, ie a loss of 91%!

We then go from 9 to 100% when we respect the calculation methods in relation to the various ecological compartments and take therefore a gain of 91% of the C sink which, otherwise, would have been lost by underestimation.

Case N°2: A very incomplete estimate of forest carbon taking into account not only marketable timber, but all of the woody biomass, including root systems and crowns, without more.

For the case of this estimate made on young agroforestry fallow-grassland (Figure. 4B), given the failure to take into account the C of the various other compartments, we will only have 18.1% of the actual carbon volume, i.e. a loss of about 82%!

We then go from 18 to 100% when we respect the calculation methods in relation to the various ecological compartments and therefore a gain of 82% of the C sink which, otherwise, would have been lost by underestimation.

Case N°3: A less incomplete estimate of forest C taking into account not only the entire woody biomass (18.1%), but also the organic C of the soil in the form of humus (46.5%), nothing more.

For the case of this estimate made on young agroforestry fallow-grassland (Figure. 4C), given the failure to take into account the C of the various other compartments, we will only have 18.1 + 46.5 = 64, 6% of the actual carbon volume, ie a loss of 35.4%!

We then go from 64.6 to 100% when we respect the calculation methods in relation to the various ecological compartments and therefore a gain of 35.4% of the C sink which, otherwise, would have been lost by underestimation.

Case N°4: A fairly exhaustive estimate of forest C taking into account not only the total woody biomass (18.1%) and the organic C of the soil in the form of humus (46.5%) but also the C litter (organic residues on the surface of the soil) and dead wood (11.5%), no more.

For the case of this estimate made on young agroforestry fallow-grassland (Figure. 4D), given the failure to take into account the C of the various other compartments, we will only have 64.6 +11.5 = 76, 1%

of the actual carbon volume, ie a loss of 23.9%!

We then go from 76.1 to 100% when we respect the calculation methods in relation to the various ecological compartments and therefore a gain of 23.9% of the C well which, otherwise, would have been lost by underestimation. .

Case N°5: A more exhaustive estimate of forest C taking into account not only the total woody biomass (18.1%), the organic C of the soil in the form of humus (46.5%), the C litter and dead wood (11.5%), but also the C of the herbaceous stratum found in the undergrowth (12.9%), without more.

For the case of this estimate made on young agroforestry fallow-grassland (Figure. 4E), given the failure to take into account the C of the various other compartments, we will only have 76.1 +12.9 = 89% of the real carbon volume, ie a loss of 11%!

We then go from 89 to 100% when we respect the calculation methods in relation to the various ecological compartments and therefore a gain of 11% of the C sink which, otherwise, would have been lost by underestimation.

Case N°6: An very exhaustive estimate of forest C taking into account not only the total woody biomass (18.1%), the organic C of the soil in the form of humus (46.5%), the C of litter and dead wood (11.5%), the C of the herbaceous carpet found in the undergrowth (12.9%), but also the C of the "New Top Soil" (Jones, 2001, 2002) or organic soil generated on the surface (5.4%), intermixed with rootlets and fine litter (horizon A_{00}), nothing more.

For the case of this estimate made on young agroforestry fallow-grassland (Figure.4F), given the failure to take into account the C of the last compartment identified, namely the "stock of composts resulting from the recycling of agroecosystem products" (tree and grass prunings, locally produced manure), we will only have 89 + 5.4 = 94.4% of the actual carbon volume, i.e. a loss of 5.6%!

We then go from 94.4% to 100% when we respect the calculation methods in relation to the various ecological compartments and therefore a gain of 5.6% of the C well which, otherwise, would have been lost by sub- estimate.

This is why, as a last resort, we propose to integrate into the carbon assessment of agroecosystems, composts taken from fallow (prunings of trees and grasses) and effluents from local livestock integrated into agriculture.

CONCLUSION

Under complex agro-forest, five new pools, in addition to the tree stratum traditionally accepted in forest C inventories, namely (1) organomineral soil, (2) litter-mulch, (3) organic soil stratum generated under litter, (4) the herbaceous layer and (5) the composts produced in situ, would be of comparable interest as stock and sink of C, imposing a multi-criteria assessment approach.

In this logic, the estimation of the biomass for the tree and/or shrub stratum should go through the most precise evaluation of the volume and the density of the trunks, by means of the calculation, for the average tree, of the weight indices relating to the bark (m of bark/wood of the sampled pieces), the root system (m of roots/trunk) and the crown (m of crown/trunk) considered to be key factors for the extension of biomass.

The gradual integration of these 5 carbon compartments in the calculations of the agroecosystem's C stock / sink will make it possible to avoid current underestimations and to improve, depending on the case, up to 90% of the true values, particularly in eco-managed peasant farms and multi-layered agroforests.

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ANNEXE

Cstock and sinkevaluation of Agro-forestry fallow-grassland (Green Mat syst): terroir AA (18 months, upstream)

Cstock and sinkevaluation of Agro-forestry fallow-grassland (Green Mat syst): terroir C (18 monts, downstreem)

C stock and sinkevaluation of Agro-forestry fallow-grassland (Green Mat system): terroir AB (18 monts, lowland)