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Research Paper

Soil Organic Carbon as observed in lowlands of Continuous Rice Cropping in Guinea Savanna Ecology towards an Improvement of organic Matter Amendment

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ABSTRACT: *Advocated organic matter (OM) supplying to agriculture soil should be according to the soil properties, resulting different rates requirement instead of applying blank recommendation (12 tha^{-1}). Two lowlands under continuous rice-rice cropping in the centre of Côte d'Ivoire were surveyed in 2013 considering 31 rice fields (farmers) for each location. Soil samples (93) were taken in 0 – 20 cm depth systematically (50 m along × 20 m across) extending the hydromorphic zone (HZ), the fringe valley (FV) and the valley bottom (VB) along the upper stream (US), median (MS) and downstream (DS) positions respectively. Soil organic carbon (SOC) content was differently observed in association with clay or silt particles according the topographic positions. Lowest amounts of SOC, maximum stable C (31.02% – 31.66%) and highest C mineralization (2.72% – 2.97%) rate (K_2) were often accounting for the HZ contrasting with the VB. Unexpected higher rates of 224 tha^{-1}, 269.4 tha^{-1} and 281.03 tha^{-1} as rice and weed residues were required across the transversal section of the valley respectively over the current recommendation of 12 tha^{-1}. Dissolved C and leached nutrients (Na, K, Mg and Ca) may be released from HZ to VB contributing to rice yield gap (4.5 – 6.44 th^{-1}). Soil contents of clay and K were the most relevant yield increasing factors against the contents of sand, silt and K_2 value. More enriched organic-C source was required for improving organic input in the studied agro-systems emphasizing a major constraint for lowland rice production.*

Keywords: *Topographic position, Soil organic carbon, hydromorphy and flooding, rice yield gap*

I. INTRODUCTION

The global soil carbon (C) stock is approximately 2,500 P (1015)g, of which, 70% exists as soil organic C (SOC) in the top 1 m soil depth. Hence, SOC is a major component of the C pool in the terrestrial ecosystems and the global C balance [1, 2]. Inherently, the factors affecting SOC content were identified as dead materials including the type of vegetation and its management regimes, in addition to the biophysical factors, such as climate, hydrology and parental geology material [3]. The dynanamic of SOC is further subjected to soil ability to sink C as a stock in a manner to reduce the greenhouse gas emissions including N2O, CH4 and CO2 productions [4]. This process is contributing to C sequestration [5] while improving soil physical and biological properties contributing to agriculture production [6, 7]. In turn, agriculture is also contributing to 10 – 12% of the total global anthropogenic greenhouse gas emissions as loss of C [8, 9]. These contrasting processes should be positively balanced by organic input in order to prevent agricultural soils impoverishment. Therefore, agricultural soil ability for stocking C needs to be well characterized for the control of the advocated organic amendment [10, 11], especially, in waterlogged soils encountered in inland valley. Actually, these soils are

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acting as C sinks [12, 13] while reducing the expecting mineralization of organic matter (OM) for the recapitalization of the stock of agricultural soil nutrient.

In spite of the high potential of inland valleys for food supplying in Africa [14, 15]), there is lack of sound management strategy of SOM as weakness component of lowland rice agrosystems: indeed, significant increase of rice grain yield could not be observed after straw incorporation into the soil until three cropping seasons duration meanwhile, there was increase of SOM content however [16].

The sinking of C by the soil particles as well as the local temperature influence in SOM mineralization under flooded condition [17] may be of concerns. Therefore, in the line of the advocated strategy developed by [18]), a specific management of organic matter is required for a given pedoclimatic zone referring to soil maximum value of C stability-MVC [19] and the rate (K2) of soil humus mineralization as well as that of soil C (C:N) in some extend. In fact, we assume that OM supplying should be according to the soil properties of which, a part of ecosystem services [20] driving factors may account for different rates requirement instead of applying blanket recommendation (11 – 12 tha^{-1}) for tropical ecology [21, 22].

The current study was volunteer to explore second order lowlands as the most extended inland-valleys in guinea savanna ecology of Côte d'Ivoire for surveying soil and rice grain yield. The relevant parameters (MVC, C/N and K2) of SOM were appreciated in relation with soil particle size in a given topographic position along and across a valley when screening their impact on rice grain yield. The aim was to i) identify organic matter requirement in different topographic positions of the valley and, ii) to point out ecosystem services supplier relative to SOM and nutrients in lowland for rice production. Overall, sustainable lowland management will be recommended for rice production.

II. MATERIAL AND METHOD

2.1 Studied sites

Two lowlands of rice production located at M'bé (8˚06N, 6˚00W, 180 m) and Lokakpli (7°52'36,05" N, 5°3'6,408" W, 263 m) respectively in the centre of Côte d'Ivoire were explored in 2013 for the study. They are distanced about 5 km a part in Guimea savanna characterized by a bimodal rainfall pattern (1200 mm/year) and 28˚C of annual average temperature. The valley of M'bé is semi-developed contrasting with that of Lokakpli (Lok) where there is improvement of the water control for irrigation and drainage at plot level. Only grasses are occurring in these valleys (e.g. *Lersia hexandra* (Poaceae) and *Frimbristulis* spp (Poaceae)) during the off-season (December – February). Typical shrubs of savanna and trees as *Kaya senegalensis* are characterizing the vegetation of the subsequent upland exposed to annual bush fire [23].

2.2 Land management

The two lowlands were used for rice farming more than 30 years ago. Rice-rice cropping system is observed across both sites along year. After effectiveness of pre-herbicide application (2 – 3 weeks), the lands were flooded (7days), drained and ploughed (15 – 20 cm depth) incorporating weeds and straw before transplanting rice seedlings. Variable rates of fertilizers including N (0 – 87.5 kg ha^{-1}), P (0 – 48 kg ha^{-1}), K (0 – 36 kg ha^{-1}), Mg (0 – 6 kg ha^{-1}) and B (0 – 5 kg ha^{-1}) are usually applied, regardless of the topographic positions.
Plinthic Ferralsol (upland), Arenosol stagnic (fringe valley) and Fluvisol (valley) are developed along a toposequence on granite bed rock. The soils bulk densities were considered as 1.5 g cm^{-3} in HZ and 2 g cm^{-3} for each of the soils in the fringe valley and valley bottom respectively as previously determined by [24].

2.3 Soil sampling and rice yield

Ninety three (93) soil samples were taken in 0 – 20 cm depth in the valley of each of the studied localities. Sampling method was systematic as 50 m along and 20 m across the valley (50 m × 20 m) extending the hydromorphic zone (HZ), the fringe valley (FV) and the valley bottom (VB). A longitudinal section of 1550 m was divided as upper stream (US), median and downstream (DS). Hand augur was used for soil sampling in the beginning of the wet season of 2013.

The rice yield was collected according to farmers (31) in three quadrats of 1m^2 as individual size in each of the locations during two cropping cycles. These quadrats were laid randomly in a field for rice harvest at grain maturity and the field position in the valley was recorded for each of the 372 data. The yield was calculated on the basis of the grain standard moisture content of 14%.

2.4 Soil analysis

The soil samples were dried, ground and sieved (2 mm) before the laboratory analyses were carried out. Soil particle sizes (sand, clay and silt) were determined using Robinson pipette method. Furthermore, soil contents of carbon-C (Wakley and Black), total nitrogen-N (Kjeldahl), exchangeable K, Na, Ca, and Mg (1 N NH_4OAc (pH 7.0)) were also determined as described by [25]. Standard procedures for laboratory quality control of measurements, including the use of blanks, replicates and internal reference samples, were followed.

The model of [19] was used for the maximum amount of stable SOC (MVC) calculation as bellow in (1):
MVC (g C kg^{-1} Soil) = 9.04 + 0.27 × (% particles <50 µm) (1)
The coefficient of humus mineralization (K_2) was also calculated according to Bouvier *et al*. (2016) [18]:
$K_2 = (0.3\ t^{\circ} - 3) / [(1 + 0.05×CL\ (\%)) × (100 + 0.15\ CaCO_3(‰))]$ (2)
Where "t˚" is the annual average temperature (˚C), CL(%) is the proportion of clay in the soil and $CaCO_3$ is the soil content of $CaCO_3$ (%o) knowing that 40.04 % is composed of Ca.

2.5 Estimation soil organic matter and active C requirements

The SOM was calculated on basis of SOC affected by the standard coefficient of 1.3 for cultivated land before determining soil deficiency in organic matter (SDOM) according the threshold level of 40 g kg^{-1} [26]:
SOM (g kg^{-1}) = SOC × 1.3 (3)
SDOM (g kg^{-1}) = 40 – SOM (4)

Then, soil organic matter requirement (SOMR) was determined for 0 – 20 cm (0.20 m) soil depth across 1 ha (10 000 m2) using soil weight for a specific bulk density (d) at HZ (1.5 g cm-3), FV (2 g cm-3) and VB (2 g cm-3):
SOMR (g kg^{-1}) = SDOM× (d × 0.20 × 10 000) for 1 hectare (5)
Then after, the quantity of organic source (QOS) to be supplied was calculated using the average OC (262.5 kg C) contents of 1 ton of weeds (455 kg C) and 1 ton of rice residues (70 kg C) according to [27] and [28] respectively:QOS (t) = SOMR/ (OC ×1.3) for 1 hectare (6)

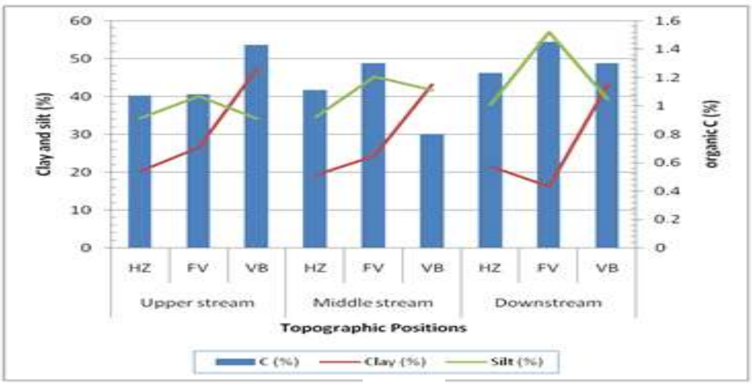
2.6 Statistical analyses

The mean values of soil particle sizes and SOC were determined by descriptive statistic according to the topographic positions along and across the valley for each the studied sites Pearson correlation analysis was also performed between MCV and soil contents of particle sizes (clay, silt and sand), In the same manner, the relation between soil C:N and its contents of particle sizes was explored before that of K_2 with all the studied parameters. The mean values of soil MCV, K_2, K, Na, Ca and Mg were determined by analysis of variance using the Student-Newman and Keuls classification for mean values. By linear model procedure, the rice grain yield was also determined considering the applied rates of fertilizer as error term. Furthermore, studied soil properties were used to explain rice grain yield components running Principal Component Analysis. SAS (version 10) was used for statistical analysis and α was fixed at 0.05.

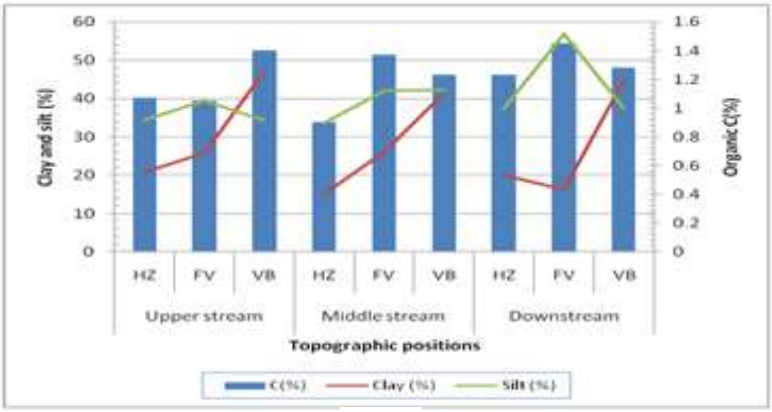
III. RESULTS

3.1. Soil particle sizes and organic carbon variation in the valley

The Fig 1 is showing the mean values of soil contents of clay, silt and carbon along and across the valley at both studied site of M'bé (Fig 1a) and Lokakpli (Fig 1b) respectively. Soil content of organic carbon is roughly increasing along the transversal section of the valley (HZ to the VB) with more consistent trend at the upper stream position and, the soil of FV is likely the richest at middle and downstream positions indifferently to the studied localities. Increasing trend of soil content of clay particle is also observed across the valley contrasting with that of silt outstanding at the FV and coinciding with the highest soil content of carbon at the middle and downstream positions in both valleys. In turn, the highest values of soil organic carbon content (about 1.5%) and that of the clay (50 – 55%) are coinciding at the VB of upper stream however:



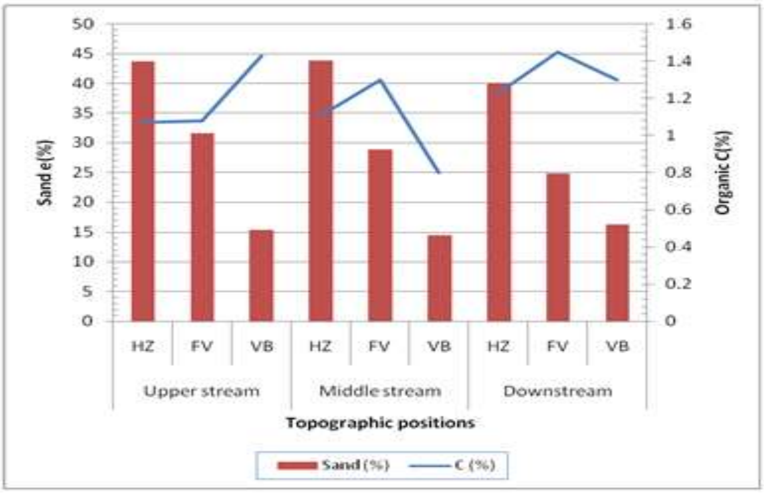
a)



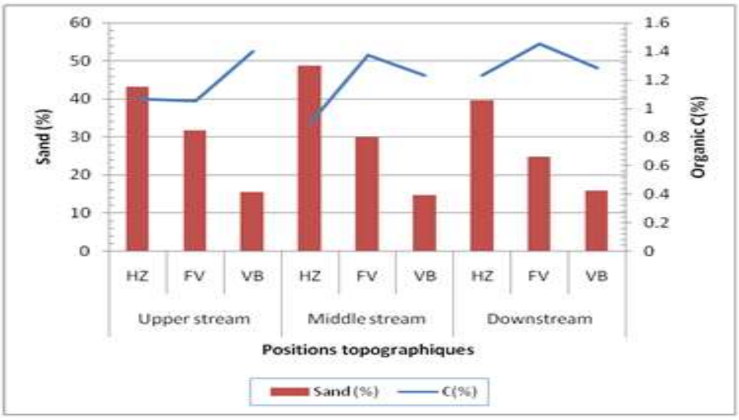
b)

Figure 1: Soil contents of clay ($SE_{M'be}$ = 14.26, ES_{Lok} = 14.22), silt ($SE_{M'be}$ = 10.10, ES_{Lok} = 9.98) and organic carbon ($SE_{M'be}$ = 0.48, ES_{Lok} = 0.50) in different topographic positions across the valley for each of longitudinal position at the localities of **(a)** M'bé (n = 93) and **(b)** Lokakpli (n = 93).

Therefore, SOC content is differently observed according the topographic positions: regular increasing trend along the transversal section of the valley is characterizing the upper stream position while the highest amount is accounting for the FV at middle and downstream positions. Nevertheless, the lowest amount of SOC often accounts for the HZ (Fig 1a and 1b).



a)



b)

Figure 2: Soil contents of sand ($SE_{M'be}$ = 13.31, ES_{Lok} = 13.73) and organic carbon ($SE_{M'be}$ = 0.48, ES_{Lok}= 0.50) in different topographic positions across the valley for each of longitudinal position at the localities of **(a)** M'bé (n = 93) and **(b)** Lokakpli (n = 93)

There is no parallelism between SOC and the content of sand particle (Fig 2a and 2b). In turn, difference in the variation of SOC content is noticeable according to the localities (M'be and Lok) and lowest value of about 0.8% accounts for M'bé in the soil of VB of median position (Fig 2a).

3.2. Soil carbon relevant parameters and particle size

The mean values of SOC stability (MVC) in top soil (0 – 20 cm) are presented in the table 1 for each of the longitudinal sections of the valley and according the transversal position:

Table 1: Maximum values of carbon stability in 0 – 20 cm soil depth according to topographic positions along and across (**HZ**: Hydromorphic zone; **FV**: Fringe valley; **VB**: Valley Bottom) the valley

	Maximum value of C stability (%)		
	Upper stream	**Median**	**Down stream**
HZ	23.86c	22.89c	24.56c
FV	31.02a	31.66a	31.28a
VB	26.24b	27.62b	28.78b
GM	27.24	27.39	28.21
P>F	<0.0001	<0.0001	<0.0001

Letters a, b and c are indicated value with significant difference

The highest values (31.02% – 31.66%) are significantly (*P* <0.0001) observed in the soil of fringe valley (FV) contrasting with the soil of hydromorphic zone (HZ) which is characterized by lowest values (22.89% – 24.56%) indifferently to the longitudinal section of the valley. In turn, the moderate levels account for the soil of the valley bottom (VB).

In the Table 2, soil content of clay (R = 0.42) and the MVC (R = 0.26) are positively and significantly correlated with the rate of C:N especially at upper stream position while, negative correlation values are observed for soil contents of sand (R = -0.24) and silt (R = -0.50) in the VB. Similar relations are significantly observed between C:N and soil content of sand as well as the values of MVC in the valley bottom of downstream position. No significant correlation is observed in the soil of HZ at upper stream position while significant correlations are observed for all the studied parameters in the downstream position, though, different in magnitude with positive values for sand (R = 0.46) and silt (R = 0.96) when negative for clay (R = -0.66) and MVC (R = -0.37). The correlation values observed in the soil of FV are inconsistently positive or negative for the studied parameters depending to the longitudinal section of the valley.

Table 2: Pearson correlation coefficient between C:N and soil particle sizes as well as the maximum value of carbon saturation (MVC) according to the topographic positions

		Upper stream			**Downstream**		
		HZ	**FV**	**VB**	**HZ**	**FV**	**VB**
Clay	**R**	-0.08	-0.71	0.42	-0.66	-0.03	0.17
	P>l rl	0.4088	<0.0001	<0.0001	<0.0001	0.7689	0.1180
Sand	**R**	0.08	0.08	-0.24	0.46	-0.41	-0.28
	P>l rl	0.4030	0.425	0.0180	<0.0001	0.0001	0.0101
Silt	**R**	-0.05	0.70	-0.50	0.97	-0.18	0.12
	P>l rl	0.5776	<0.0001	<0.0001	<0.0001	0.1037	0.2763
MVC	**R**	-0.11	0.02	0.26	-0.37	-0.28	0.50
	P>l rl	0.2582	0.7940	0.0112	0.0006	0.0109	<0.000 1

3.3 Influence of soil nutrients on organic carbon and rice yield implication

Soil content of exchangeable sodium (Na) is at least twice greater than that of the potassium (K) across the valley as presented in table 3: highest content of K is often significantly observed in the soil of the FV while richest soil in Na accounts for the VB though, no significant difference is noticed between the mean values of this nutrient at downstream position.

Table 3: Mean values of exchangeable K, Na, Ca and Mg in 0 – 20 cm of soil depth according to the topographic positions along and across (**HZ**: Hydromorphic zone; **FV**: Fringe valley; **VB**: Valley Bottom) the valley

		Upper stream	Median	Downstream
	HZ	0.09c	0.11a	0.09b
K ($cmolkg^{-1}$)	**FV**	0.17a	0.10ab	0.05c
	VB	0.12b	0.09b	0.16a
	GM ($cmolkg^{-1}$) ***P*>F**	0.13 <0.0001	0.10 0.06	0.10 <0.0001
	HZ	0.21b	0.19c	0.25a
Na ($cmolkg^{-1}$)	**FV**	0.25b	0.28b	0.23a
	VB	0.55a	0.30a	0.23a
	GM ($cmolkg^{-1}$) ***P*>F**	0.34 <0.0001	0.26 <0.0001	0.23 0.1942
	HZ	1.66b	1.45c	1.74c
Ca ($cmolkg^{-1}$)	**FV**	1.76b	1.85b	2.13b
	VB	3.34a	2.58a	2.45a
	GM ($cmolkg^{-1}$) ***P*>F**	2.25 <0.0001	1.96 <0.0001	2.11 <0.0001
	HZ	1.94c	0.67c	0.92c
Mg ($cmolkg^{-1}$)	**FV**	1.00b	1.02b	1.16b
	VB	1.94a	1.49a	1.41a
	MG ($cmolkg^{-1}$) ***P*>F**	1.22 <0.0001	1.06 <0.0001	1.16 <0.0001

Letters a, b and c are indicated value with significant difference

Roughly, soil contents of Na, Ca and Mg are increasing along the transversal section (from HZ to VB) of the valley while, soil content of exchangeable K is more prone to accumulation in the FV position.

Although differences are observed in the relation between the MCV and soil contents of exchangeable cations especially in the VB according to the longitudinal section, lowest value of K_2 is consistently characterizing this transversal section wherever along the valley contrasting with the HZ of upper stream and median positions (Table 4). Highest value of K_2 accounts for the soil of the FV at downstream position of the valley.

Table 4: Mean value of humus mineralization rate (K_2) across and along a valley

	K_2 (%)		
	Upper stream	**Median**	**Down stream**
Hydromorphic Zone	2.78a	2.97a	2.72b
Fringe Valley	2.44b	2.47b	2.99a
Valley Bottom	1.62c	1.76c	1.70c
GM (%)	2.28	2.40	2.47
P>F	<0.0001	<0.0001	<0.0001

Significant negative values of correlation between K_2 and MVC are characterizing all the positions of the valley except for the soil of FV at downstream position which is showing positive value. Contrasting correlation values of K_2 are only observed along the valley for the soil at FV position (Table 5):

Table 5: Correlation values and probabilities of K_2 according to soil contents of clay, sand and silt as well as MVC and C/N across and along a valley

		Upper stream			Downstream		
		HZ	**FV**	**VB**	**HZ**	**FV**	**VB**
Clay	**R**	-0.98	-0.98	-0.99	-0.99	-0.99	-0.99
	P>l rl	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sand	**R**	0.96	0.51	0.90	0.98	-0.76	0.84
	P>l rl	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Silt	**R**	0.19	0.64	0.98	0.77	0.91	0.82
	P>l rl	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
MVC	**R**	-0.97	-0.40	-0.92	-0.95	0.80	-0.64
	P>l rl	0.0666	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C/N	**R**	0.15	0.66	-0.48	0.63	0.08	-0.19
	P>l rl	0.1452	<0.0001	<0.0001	<0.0001	<0.0001	0.0796

Whatever the nature of the relations between the studied parameters, the recorded rice grain yield is increasing in the transversal section of the valley showing lowest values in the hydromorphic zone (HZ) against highest in the valley bottom (VB) anywhere of the longitudinal position of the valley (Fig 3).

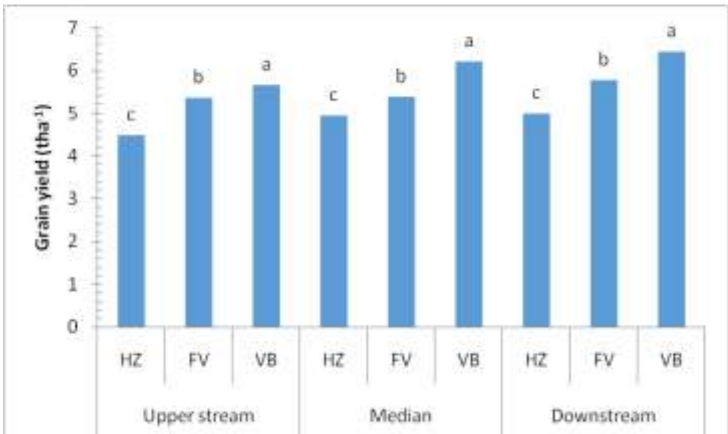


Figure 3: Mean values of rice grain yield along and across the valley (*P*< 0.0001 for each of the longitudinal section)

Average rice grain yield is ranging from 4.5 tha^{-1} to 6.44 tha^{-1} across the studied valleys.

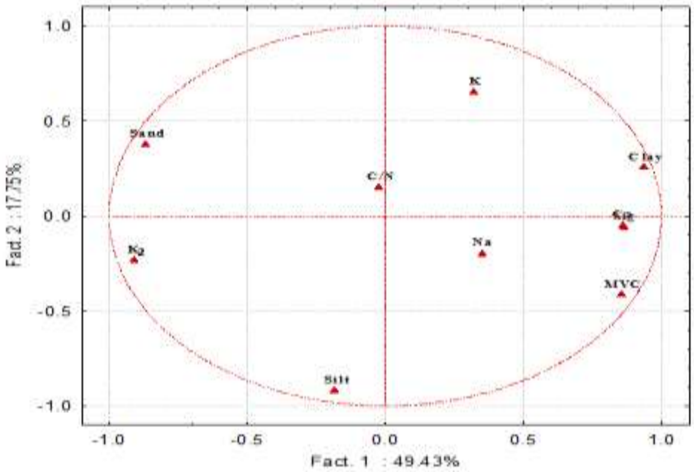


Figure 4: Principal components of rice grain yield according to soil properties for the first and second factors

Soil contents of clay and K are the most yield relevant factors with positive correlations when contrasting with soil content of silt and it's K_2 (Fig 4). In some extend soil contents of Ca, Mg and Na may have also account for main component of rice yield (Fig 5).

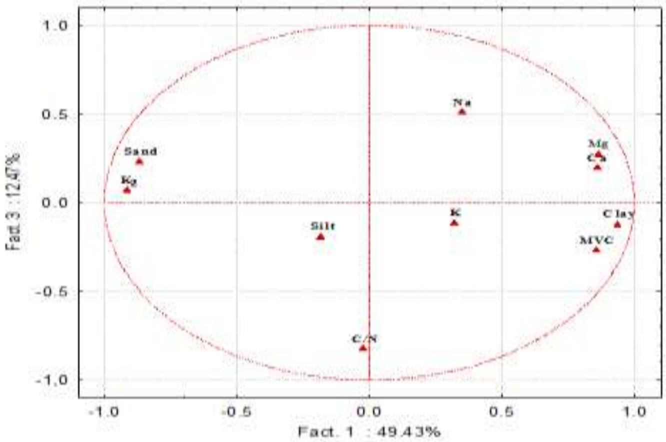


Figure 5: Principal components of rice grain yield according to soil properties for the first and third factors

IV. DISCUSSION

4.1 Soil Organic Carbon anisotropy

There were preferential associations between SOC and its particle sizes according to the topographic sections along and across the valley. Highest content of SOC was likely associated to clay content in the soil of VB at upper stream position while, so was observed for silt particle at FV of median and downstream positions. The poorest soil of the hydromorphic zone (HZ) was also characterized by highest values of sand content (43.88%) and K_2 coupled with lowest MVC in concordance with the lower rice grain yield. Although affected by seasonal waterlogging of perched ground water, HZ is the most aerobic section of inland valley, more prone to SOC turnover especially during the dry season. For 1 ton of crop residue as dry matter potentially releasing up to 70 kgC [28], a minimum amount of 53.36 $gCkg^{-1}$ [70kg - (70 ×(MVC = 23.77)] can account for mineralizations (C:N = 10:1; K_2) and C loss as dissolved C leached towards the lower topographic positions of FV and VB. The slope and the high soil content in sand (53–2000 µm) may have contributed to leaching of C and its mineralization. Therefore, the recorded C-organic amount could not reached 20 $gCkg^{-1}$ (vs. 53.36 $gCkg^{-1}$) beside of lowest contents of K, Ca and Mg in the soil of HZ. Nevertheless, during the wet season, the occurrence of waterlogging may increased the turnover time of raw materials between that of active and passive C-pools [29, 30], resulting a partially decomposed organic matter. These seasonal effects are contributing to the development of a deepest organic horizon of about 0 – 40 cm compared to that of the subsequent soils of the upland (middle and upper slopes, and summit).

The SOC associated with silt (FV at median and downstream positions) and clay (VB at Upper stream position) particles are relatively stable, due to physical protection [31] resulting the highest values of MVC observed. But, C fractions may be different according to the longitudinal section of the valley when referring to the prevalence of silt-OC and clay-OC (Fig 1) as well as the contrasting correlation values observed between the respective particle size and the rate of humus mineralization (K_2). Though not clearly identified in the current study, there is skylight for asserting existence of longitudinal and transversal gradients of SOC in term of quality.

4.2 Soil Organic Carbon requirements

On basis of the average record of SOC, there was low content (< 40 gkg^{-1} soil) of SOM indifferently to the studied valley. SOM deficiency can be estimated about 25.55 gkg^{-1}, 23.40 gkg^{-1} and 24.26 gkg^{-1} for HZ, FV and VB respectively. To fill these gaps for 1 ton of soil within 0 – 20 cm depth, organic matter requirement should be 76.650 tha^{-1}(HZ), 93.600 tha^{-1} (FV) and 97.040 t ha^{-1} (VB) corresponding to 224 tha^{-1}, 269.4 tha^{-1} and 281.03 tha^{-1} of raw material to be applied (rice and weed residues) respectively. In the context of organic material shortage in Africa [32], these practices are unrespectable while emphasizing more suitability of HZ for large adoption of organic farming in some extend. Nevertheless, there is evidence of different rates of organic matter requirement for soil at a given topographic section though; they are twenty times greater than the recurrent recommended rate (12 tha^{-1}). This finding is pointing out difference in organic farming practices when referring to the results observed in upland of semi-arid zone of West Africa [33]. Nevertheless, more investigation involving the kinetic of SOC mineralization [34] is required for underlining the effectiveness of OM amendment in time scale, especially for rice cropping cycle.

In fact, the source of SOC was mainly composed of weeds (455 $kgCt^{-1}$) and rice residues (70 $kgCt^{-1}$) including dead roots and root exudations (negligible in the range of micro-molar) in both lowlands [27, 28]. Thus, there was low input of organic carbon in the studied agrosystems. Nevertheless, the lowest soil carbon stability values (22 – 24%) of the soil at HZ were relevant to highest mineralization rate of humus (K_2) hence, increasing its suitability for organic matter management. Well, for about 262.5 kgC (mean for weed and rice) as input of 1 ton of raw materials, only 63 kgC may be bounded as passive C pool (soil structure component) in the soil of HZ against 82.21 kgC and 72.29 kgC at the fringe valley and valley bottom respectively. When referring to labil-pool of 199.7 $kgCt^{-1}$ at HZ and the maximum rate (K_1) of humufication (30%) according to [35], the extreme scenario (24% for MVC) may results about 59.85 kgC (199.5 × 30%) as humus of which, 1.58 kgC [59.85 × K_2] may account for mineralization according to the average value of K_2 (2.82%) at HZ position (Table 4). Hence, the active C-pool within 0 – 20 cm depth of one hectare released by 1 ton of the raw material should be about 0.5267 µgC/g soil, 0.355 µgC/g soil and 14.2 µgC/g soil for HZ, FV and VB respectively in a very low range compared to the reference value of 0.60 mgC/g characterizing agricultural lands elsewhere [36].

In the light of these analyses, low input of OM and poor soil properties relevant to organic matter management are responsible to unsuccessful of OM practice in the studied agro-ecosystems.

4.3 Rice productivity

Although 10:1 was accounting for the average rate of SOC rapid mineralization, highest values could be roughly defined in increasing order (15:1 – 17:1) according to the transversal section of the valleys along with the trend of the average rice grain yield (Fig 3). In fact, the slowness of nutrients releasing by SOC is more pronounced with the increase of C:N [37] thus, saving nutrient from the loss as occurring with water dynamic. Therefore, the HZ was prone to processes of dissolving C and nutrient leaching for gradual enrichment of the FV and the VB, especially with Na, Ca and Mg while highest amount of soil K was accounting for the FV and VB at the upper stream and downstream positions respectively (Table 3). Therefore, accumulative dispersion of soil colloid as occurring with highest amounts of K and Na [38] may occurred in the VB of median and downstream positions hence, reducing the SOC amount in addition to the dissolving effect of flooding [39]. These fractions of C were probably promoting lowest rate of humification (K_2) in the VB in spite of the increase of soil contents of Ca and Mg and agricultural practice [40]. Therefore, the soil contents of Ca and Mg as well as the stable fraction of SOC referring to MVC, may have more contribution to the highest rice yield recorded in VB than the total SOC which was lowest.

In fact, Mg and Ca can extensively and positively affect the mineral nutrition of plants [41] hence, improving the efficiency of the applied mineral fertilizer (NPK) in the studied lowlands. Local geological material characterized by orthose (K) and plagioclase (Ca and Na) minerals may be the main sources of K, Na and Ca with significant contribution of leachates from the HZ.

Overall, the VB is pointed out as the most suitable land for rice production while, the HZ is acting as ecological service supplier beside of the mineralogical nature of local bed rock.

V. CONCLUSION

There were preferential associations between SOC and its particle sizes according to the topographic sections along and across the valley. Quantitative and qualitative differences of SOC may be also accounting to the difference of topographic positions affecting the rate (K_2) of humification. Although, different rates of OM were required according to soil properties, our investigation underlined unsuitability of rice and weed residues as organic sources for awareness. Dissolved C and leached nutrients (Na, K, Mg and Ca) may be released from HZ to VB contributing to rice yield gap (4.5 – 6.44 th^{-1}). Soil contents of clay and K were the most relevant yield increasing factors contrasting with the contents of sand, silt and K_2 value. More enriched organic-C source was required for improving organic input in the studied agro-systems emphasizing a major constraint for lowland rice production. The VB most prone to flooding was deemed most suitable for lowland rice production and HZ was suspected to be ecosystem service supplier to the VB while further investigations are suggested to improve knowledge of SOC kinetic of mineralization and rice grain yield gap comparing with neighboring topographic positions.

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