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Yield Gap as Occurring in Lowland Rice Cropping under Guinea Savanna Ecology: Spatial and Temporal Diagnosis for Fixing Research Priority

Konan K. Firmin*
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Koné Brahima
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Nangah K. Yves
Biological Science Training and Research Unit, Department of Geosciences. Péléforo-Gbon-Coulibaly University, Korhogo, Côte d'Ivoire

N'gazoua K. René
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Traoré M. Joachim
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Zadi Florent
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Yao Guy Fernand
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Kouadio K. Hippolyte
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Yao-kouamé Albaert
Earth Science Training and Research Unit, Soil Science Department, Felix Houphouet-Boigny University, Côte d'Ivoire

Abstract: Two lowlands under continuous rice-rice cropping in the centre of Côte d'Ivoire were surveyed in 2013 and 2014 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. Highest yields of 6.09 – 6.16 tha-1 were observed in DS and MS while limited chances of 24% to 30.17% were characterizing the yield over 5 tha-1 (yield class I) in dry season against 18% - 46.31% in wet season. Weeding and irrigation were the most significant agricultural practices for yield improvement during wet and dry seasons respectively meanwhile, soil content of silt and humification rate (K2) were reversibly accounting for 65.85% contributions of the yield class I in addition to Ca and Mg effects. Of course, the recommended NPK fertilizer (150 and 200 kgha-1) should contained Mg in basal application (transplanting) when, 75 and 150 kgha-1 of urea were required at the tillering stage in dry and wet seasons respectively. However, applying NPK fertilizer at heading stage could further increase the yield during the wet season. Definitively, the yield gap was defined as absolute and relative for well understanding and research priority was identified as relevant matters for dry season and hydromorphic zone during further study.

Keywords: Rice yield gap; Topographic section; Cropping season; Lowland; Guinea savanna.

1. Introduction

Rice (*Oryza* spp.) is currently sustaining the livelihoods of about 100 million people in sub-Saharan Africa [1]. It is an important crop in attaining food security and poverty reduction in many low-income, food-deficit African countries [2]. However, the demand for rice far outstrips its production in Africa, which has increased mainly due to land expansion since the 1970s, with only 30% being attributable to an increase in productivity [3].

*Corresponding Author

Because of land shortage due to demographic growth [4], the improvement of the production systems should be the preferred option for meeting the shortfall in rice production of West Africa [5]. This strategy will require intensification including maximizing continuous cropping [6].The current upland rice agro-system based on slash and burning [7] is deemed destructive for the ecology and the lowland is likely the most promising agro-ecology with highest productivity when saving the ecosystem [8]. However, low-land rice yield can range in a threaten low level of about 1.5 tha^{-1} in some ecologies [9, 10] as spatial and temporal variability illustrating the yield gap when compared to the maximum yield expected.

Well, almost the current improved rice varieties are yielding about 6 – 8 tha^{-1} [11] but, soil fertility and agricultural practices combined with seasons' effects on mineral nutrition of plant [12] may contribute to yield variability in a given agro-system. Because of the wide spectrum of soil components and the variability of agricultural practice according to farmers, there is a need to set specific characteristics of yield ranges (low, moderate and high) in a way to control the production. Major components of soil and practices in relation with yield ranges might contribute to this.

The current study was initiated in two lowlands of Centre Côte d'Ivoire for soil and rice yield surveying during the wet and dry seasons of 2013 and 2014. The aim was, i) to characterized yield variability according to season and topographic position in the valley, ii) to identify the yield component according to soil and, iii) to assess the impact of agricultural practice on yield. Overall, the study should fixe research priority towards improvement of rice production in lowland.

2. Materials and Methods

2.1. Studied Sites

Two lowlands of rice production located at M'bé (8˚06N, 6˚00W, 180 m asl) and Lokakpli (7°52'36,05" N, 5°3'6,408" W, 263m asl) respectively in the centre of Côte d'Ivoire were explored in 2013 and 2014. They are distanced about 5 km a part in a Guinea 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 scale. Only grasses are occurring in these valleys (e.g. *Lersia hexandra* and *Frimbristulis* spp) 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 [13].

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 the 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 toposequence on granite bed rock.

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 site. Sampling method was systematic as 50 m along and 20 m across the valley extending the hydromorphic zone (HZ), the fringe valley (FV) and the valley bottom (VB). A longitudinal section of 1550 m was stratified as upper stream (US), median (MS) 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 four cropping cycles from 2013 to 2014. Rice was transplanted randomly with mean density of 430 $plant/m^2$. 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% and yield classes were defined as: Class I: [5 – 10 tha^{-1}]; Class II: [3 – 5 tha^{-1}] and Class III: [0 – 3 tha^{-1}].

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 Pages, *et al.* [14]. Standard procedures for laboratory quality control of measurements, including the use of blanks, replicates and internal reference samples, were followed. The model of Carter, *et al.* [15] was used to estimate the maximum amount of stable SOC (MVC) as bellow:

$$\text{MVC (g C kg}^{-1}\text{ Soil)} = 9.04 + 0.27 \times (\text{\% particles} < 50\ \mu\text{m}) \quad \textbf{(1)}$$

The coefficient of humus mineralization (K_2) was also calculated according to Boure and Samedi [16]:

$$K_2 = (0.3\ t° - 3) / [(1 + 0.05 \times CL\ (\%)) \times (100 + 0.15\ CaCO_3\ (‰))] \quad \textbf{(2)}$$

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.

TSNa (sodium saturation rate = [Na/ (Ca + Mg +K +Na)] × 100 **(3)**

2.5. Statistical analysis

The mean values of rice yield as well as the difference between yield recorded during dry and wet season were determined according to mixed model analysis according to the topographic positions considering the year as random factor. By cross table analysis, the frequency of yield class was determined for topographic positions along and across the valley during wet and dry seasons. Furthermore, yield principal components were identified according to soil parameters (clay, silt, Ca, Mg, K, K_2, MVC, C:N and TSNa) especially for the classes I and III when Pearson correlation analysis was performed for investigating the relationship between yield and agricultural practices in the studied agro-system. Agricultural practices were coded numerically in decreasing order (2 – 0) from well, moderate and bad : Irrigation (well = 2 ; moderate = 1 ; bad = 0) ; weeding (well = 2 ; moderate = 1 ; bad = 0) ; chemical weeding (done = 1 ; not done = 0); Stage of chemical weeding (pre-emergence = 1 ; post-emergence =2) ; Tillage (no tillering = 0 ; manual tillering = 1 ; rototiller = 2) ; weeding during rice growing (sowing or transplanting = 1 ; tillering = 2 ; boosting = 3 ; heading = 4) ; Month of tillering (Marsh = 3 ; April = 4 ; May = 5 ; June = 6 ; July = 7 ; August = 8 ; September = 9 ; October = 10). Fertilizer (NPK or urea) application (applied = 1; not applied = 0). SAS (version 10) was used for statistical analysis and α was fixed at 0.05.

3. Results

3.1. Yield Across Seasons And Topographic Sections

Rice yields are presented across the valley at different seasons with corresponding difference in the table below:

Table-1. Mean value of yield and the corresponding difference according to the seasons and the topographic positions of the valley

Topographic positions	Yield (tha^{-1})			
	Wet Season	Dry season	Difference	Probability
HZ	5.10	4.49	0.61	<0.0001
FV	5.74	5.27	0.47	<0.0001
VB	6.18	5.99	0.19	<0.0001
Upper stream	5.23	5.10	0.13	<0.0001
Median stream	5.76	5.27	0.49	<0.0001
Down stream	6.09	5.39	0.70	<0.0001

Except for the hydromorphic zone of the valley, no difference is observed between the yields of dry and wet seasons although, fairly yield reduction is observed during dry season. Similarly, the differences between yields are significantly low (0.13 – 0.70 tha^{-1}) with lowest values in VB (0.19 tha^{-1}) and the upper stream position (0.13 tha^{-1}). More details of these results are presented in tables 2 and 3 underling different frequencies of yield classes:

Table-2. Yield class frequencies across seasons and according to longitudinal position of the valley

Yield class	Seasons	Frequency (%)		
		Upper stream	Meddle stream	Downstream
Class I	Wet season	30.42	31.67	37.92
	Dry season	34.48	31.53	33.99
Class II	Wet season	51.24	28.10	20.66
	Dry season	40.74	29.01	30.25
Class III	Wet season	27.27	36.36	36.36
	Dry season	28.57	42.86	28.57
χ^2-Probability	0.0059			

Class I: [5 – 10 tha^{-1}]; Class II: [3 – 5 tha^{-1}] and Class III: [0 – 3 tha^{-1}]

There are significantly (P< 0.05) different frequencies of yield classes according to the season variation (Table 2). Nevertheless, lowest difference is observed for the yield classes III at upper stream position of the valley. An increasing trend is observed for yield class I from upper stream to downstream position during the wet season while it is fairly simillar (34% – 31%) in the dry season. The yield class II is more frequent (51% - 40%) at upper stream position whenever the season meanwhile, a reduced values account for the downstream position. Table 3 is showing yield classes frequencies across the transversal section of the valley according the seasons.

Table-3. Yield class frequencies across seasons and the transversal positions of the valley

Yield class	Seasons	Frequency (%)		
		HZ	FV	VB
Class I	Wet season	24.58	36.25	39.17
	Dry season	18.23	35.47	46.31
Class II	Wet season	47.11	28.93	23.97
	Dry season	49.38	32.10	18.52
Class III	Wet season	72.73	18.18	9.09
	Dry season	100.00	0.00	0.00
χ^2-Probability	<0.0001			

Increasing trend of the frequency is observed for the class I across the transversal section of the valley in both dry and wet seasons: highest frequency value of 46.31% is observed in VB in dry season against 39.17% in wet season. In turn, the observed frequencies of yields classes II and III are all decreasing when the class I is characterizing the hydromorphic zone, especially during the dry season underling the low yield spatial occurrence.

3.2. Yield According to Soil and Agricultural Practices

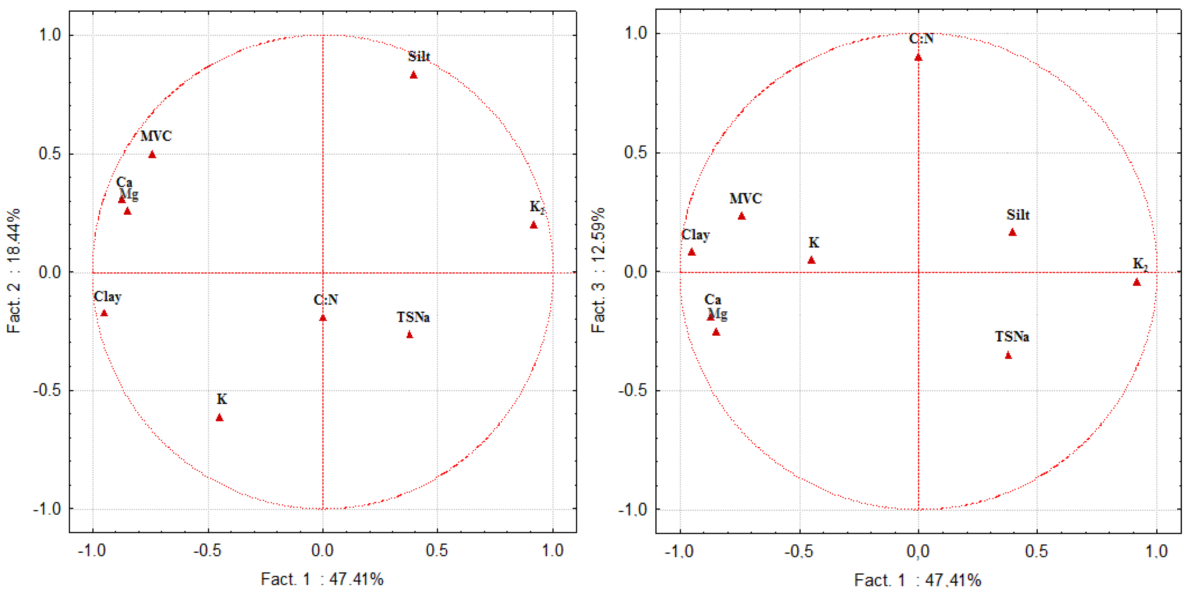
Principal components of the class I of rice yield are presented in table 4 according to studied soil parameters:

Table-4. Matrix of contributions of soil physical and chemical parameters for class I yield

Soil parameters	Components Contribution		
	Factor 1	Factor 2	Factor 3
Clay	-0.94	-0.17	0.08
Silt	0.39	0.83	0.16
MVC	-0.73	0.49	0.23
C:N	0.00	-0.19	0.90
K_2	0.91	0.20	-0.03
Ca	-0.87	0.30	-0.19
Mg	-0.84	0.25	-0.25
K	-0.44	-0.61	0.04
TSNa	0.37	-0.26	-0.35
Cumulative Eigenvalues (%)	47.41	65.85	78.43

There is 78.43% of yield information according to the third factors while, the first factor can realized 47.41% with positive highest contribution of K_2(0.91) against negative contributions of soil contents of clay (-0.95), Ca (-0.87) and Mg (-0.85). Soil content of silt and K_2 value are the most important factors for achieving 65.85% of the yield class I according to Figure 1a while the increase of soil content of K and C:N can improve it up to 78.43% (Figure 1b).

Figure-1. Correlation circles for the yield class I (factor 1 and 2 (a), factor 1 and 3 (b))



(a) **(b)**

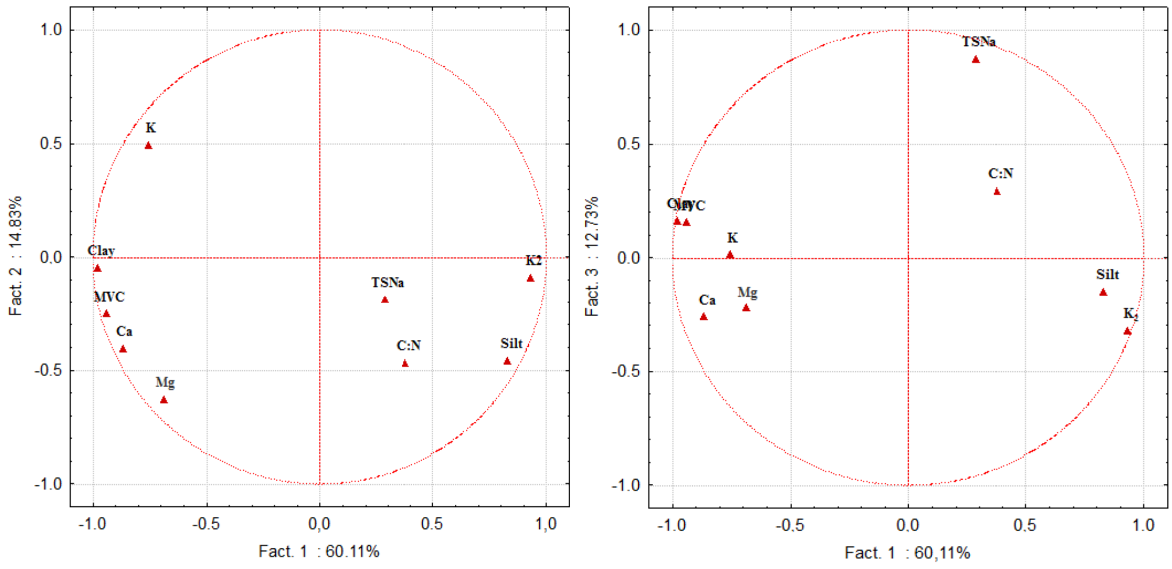
The contributions of soil parameters to the lowest yield (class III) are presented is table 5 according to three factors respectively:

Table-5. Matrix of contributions of soil physical and chemical parameters for class III yield

	Components contribution		
	Factor 1	**Factor 2**	**Factor 3**
Clay	-0.97	-0.04	0.16
Silt	0.82	-0.45	-0.14
MVC	-0.94	-0.25	0.15
C:N	0.37	-0.46	0.29
K_2	0.92	-0.08	-0.32
Ca	-0.86	-0.40	-0.25
Mg	-0.68	-0.62	-0.22
K	-0.75	0.49	0.01
TSNa	0.28	-0.18	0.87
Cumulative Eigenvalues (%)	60.10	74.93	87.65

Up to 87.65% of this yield class can be achieved throughout factor 1 to 3 while, 60.10% can be observed early with the first factor characterized by highest negative contributions of clay (-0.98) , MVC (-0.94) and Ca (-0.87). In turn, soil content of silt (0.83) and K_2 (0.93) value are positively contributing. In fact, K_2 and soil content of silt are highly and positively correlated with yield class III according to figures 2a and 2b while soil contents of Ca and Mg are consistently opposed.

Figure-2. Parameter correlation circle for Class III yields according to factors 1 and 2 (a), 1 and 3 (b)



(a) **(b)**

Though often significant, there are low correlation (<0.30) between agricultural practices and the yield recorded in table 6.

Table-6. Yield coefficient of correlation (R) and the probability (P) with agricultural practices according seasons

Cropping practice		Correlation coefficient of yield	
		Wet season	Dry season
Irrigation	R	0.07	0.16
	P	0.1313	0.0014
Weeding	R	0.28	0.10
	P	<0.0001	0.0499
Period of weeding	R	0.09	0.10
	P	0.0545	0.0499
Post-emergence chemical weeding	R	0.12	-0.03
	P	0.0125	0.5485
Pre-emergence chemical weeding	R	0.09	0.15
	P	0.0604	0.0022
Number of tillering	R	0.11	0.09
	P	0.0274	0.0559
Period between 2 tillering	R	0.12	0.08
	P	0.0146	0.1154
Tillering material	**R**	-0.03	-0.10
	P	0.5219	0.0378
Type of NPK	**R**	-0.12	-0.03
	P	0.0150	0.5633
Applying rate of NPK	**R**	0.21	0.25
	P	<0.0001	<0.0001
Applying rate of urea	**R**	0.21	0.29
	P	<0.0001	<0.0001
Period of urea application	**R**	0.11	0.15
	P	0.0251	0.0029
Nursery duration	**R**	-0.08	-0.11
	P	0.0972	0.0212

Nevertheless, highest significant correlations of 0.25 – 0.15 can be observed during the dry season for the type of NPK fertilizer and the physiological stage of rice during nitrogen supplying.

Table-7. Yield coefficient of correlation with agricultural practices according topographic positions

Cropping practice		Yield coefficient of correlation (R)					
		Longitudinal position			Tranversal position		
		US	MS	DS	HZ	FV	VB
Irrigation	R	0.28	-0.07	0.11	-0.16	0.22	0.04
	P	<0.0001	0.2348	0.0659	0.0090	0.0005	0.4379
Weeding	R	0.09	0.28	0.11	0.08	0.21	0.28
	P	0.1317	<0.0001	0.0755	0.1597	0.0007	<0.0001
Post-emergence chemical weeding	R	0.16	-0.03	0.03	0.12	-0.01	0.05
	P	0.0062	0.6517	0.6051	0.0452	0.8071	0.3771
Pre-emergence chemical weeding	R	0.04	0.13	0.14	0.07	0.19	0.18
	P	0.4132	0.0485	0.0245	0.2541	0.0017	0.0028
Tillage material	R	-0.24	0.19	-0.27	-0.13	-0.11	-0.04
	P	<0.0001	0.0037	<0.0001	0.0298	0.0833	0.4626
Transplanting period (month)	R	-0.03	-0.17	-0.27	-0.23	-0.18	-0.07
	P	0.5976	0.0086	<0.0001	0.0001	0.0035	0.2657
Type of NPK	R	-0.15	-0.003	-0.09	-0.09	-0.15	-0.09
	P	0.0088	0.9546	0.1421	0.1332	0.0118	0.1289
Rate of NPK	R	0.11	0.36	0.29	0.18	0.22	0.34
	P	0.0620	<0.0001	<0.0001	0.0038	0.0003	<0.0001
Rate of urea	R	0.12	0.29	0.26	0.17	0.21	0.34
	P	0.0346	<0.0001	<0.0001	0.0069	0.0008	<0.0001
Period of urea application	R	-0.07	0.31	0.15	0.09	0.15	0.15
	P	0.2110	<0.0001	0.0153	0.1507	0.0149	0.0145

Highest significant and positive correlations (>0.30) are observed at middle stream and valley bottom positions when referring to the rates of NPK, the rate of urea application at physiological stage of rice. In turn, moderate negative significant correlations are observed for transplanting date at downstream of valley and hydromorphic zone. Similar correlations also account for use of type of tillage material along the valley (US and DS).

Table-8. Correlation values of rice grain yield as recorder with water management and cropping practices during wet and dry seasons respectively

Cropping practices		Yield coefficient of correlation	
		Wet season	**Dry season**
Sufficient irrigation	**R**	0.07	0.16
	P	0.1313	0.0014
Low irrigation	**R**	-0.07	-0.16
	P	0.1313	0.0014
Sufficient weeding	**R**	0.29	0.03
	P	<0.0001	0.1783
Low weeding	**R**	- 0.30	-0.03
	P	<0.0001	0.1783
Pre-emergence chemical weeding	**R**	0.12	0.15
	P	0.0125	0.0022
Post-emergence chemical weeding	**R**	0.12	-0.03
	P	0.0125	0.5485

Table 8 shows positive and negative influence of the respective levels of irrigation and weeding on rice yields for wet and dry seasons: insufficient irrigation has negative influence on yield during dry season significantly while, insufficient weeding does so during wet season.

Table-9. Mean value of rice grain yield according to irrigation level, the type and the period of weeding

Cropping practice	**Season**	
	Wet	**Dry**
Sufficient irrigation	5.02a	4.64a
Low irrigation	4.66a	3.98b
P>F	0.1313	0.0014
Weeding plot	5.29a	4.61a
Unweeding plot	4.36b	4.41a
P>F	<0.0001	0.1783
Weeding at tillering	5.06a	4.63a
Weeding at boosting	5.04a	4.62a
P>F	0.0139	0.0234

Table 9 shows the mean values of rice grain yield for different practices of irrigation and weeding (quality and period). Significant effects of irrigation and weeding period are always observed respectively while the quality of weeding does so for wet season with significant difference between the practices: highest yield accounts for weeding plot during wet season when sufficient irrigation is referring to highest yield during dry season.

Table-10. Mean values of rice grain yield according to tillerring practices during wet and dry seasons respectively

Cropping practices	**Season**	
	Wet	**Dry**
No tillering	3.01b	2.96c
Manual tillering	4.86a	4.02b
Rototillering	5.00a	4.94a
P>F	0.052	0.037
One tillage	4.67b	4.40a
Two tillage	5.17a	4.66a
P>F	0.027	0.055
One manual tillage	4.17b	4.40a
Two manual tillage	4.90a	4.66a
P>F	0.027	0.055
One rototillage	4.77b	4.40a
Two rototillage	5.67a	4.66a
P>F	0.0274	0.0559

Table 10 shows significantly highest yield for rototiller whatever the season and yield increasing is observed for repeated tillage even for manual tillage using hue. Nevertheless, significant effect of this practice is limited to wet season. There is slight increase of rice yield for two applications of rototiller with no significant difference however. Table 11 shows the yield observed for the type of NPK fertilizer and suplying rates:

Table-11. Mean values of rice grain yield according basal fertilizer (NPK) practice

Cropping practice	**Season**	
	Wet	**Dry**
Type of NPK		
No supplying	3.82b	3.29c
NPK 12-24- 8+4S+3MgO	5.36a	4.96a
NPK 15-15-15+6S+1B	4.33b	4.37b
P>F	<0.0001	<0.0001
Period of NPK application		
Transplanting	4.95a	4.53b
Tillering	5.45a	4.66b
Boosting	4.95a	5.17a
P>F	<0.0001	<0.0001
Dose of NPK (kgha^{-1})		
50	4.65c	4.72 b
75	4.88b	4.76b
100	5.19b	4.89b
150	5.63a	5.02b
200	6.00a	6.05a
P>F	<0.0001	<0.0001

Highest grain yields are significantly observed for NPK 12-24- 8+4S+3MgO whatever the season. The applying rates ranging of 150 and 200 kgha^{-1} has highest yields during wet and dry seasons respectively. Yields are significantly similar during wet season indifferently to the physiological stage of NPK supplying. In contrast, highest yield is observed during wet season when NPK is supplied at rice boosting stage.

Table-12. Mean values of rice grain yield according to the rates and period of urea application

Cropping practices	**Season**	
	Wet	**Dry**
Period of urea application		
No fertilizer	3.55b	2.65b
Tillering	4.96a	4.52a
Boosting	5.09a	4.66a
heading	3.59b	4.16a
P>F	0.0001	<0.0001
Dose of urea (kgha^{-1})		
50	5.11b	4.56b
75	5.16b	5.18a
100	5.49a	5.20a
150	6.32a	6.05a
P>F	0.0001	<0.0001

There is significantly highest rice yield when supplying urea during rice tillering stage similarly to that observed boosting stage application whatever the cropping season (Table 12). The optimum rate of urea is identified about 100 kg ha^{-1} during wet season against 75 kg ha^{-1} for dry season cropping.

Table-13. Mean value of rice yield according to water management and weeding practices along and across the valley

Cropping practices	Longitudinal section				Transversale section		
	US	MS	DS		HZ	FV	VB
Irrigation quality							
Sufficient	4.61a	4.79a	5.12a		4.42a	4.87a	5.39a
Insufficient	3.64b	5.25a	4.60a		3.95b	3.46b	4.34a
P>F	<0.0001	0.2348	0.0659		0.0090	0.0005	0.4379
Weeding quality							
Suitable	4.61a	5.25a	5.12a		4.18a	5.00a	5.65a
Moderate	3.64b	4.79a	4.60a		3.92b	4.39b	4.82b
P>F	<0.0001	0.2348	0.0659		0.1597	0.0007	<0.0001
Weeding period							
Tillering stage	4.49a	5.03a	5.17a		4.22a	4.90a	5.48a
Boosting stage	4.42a	4.00b	3.91b		3.44b	4.89a	5.38a
P>F	0.9166	0.0022	0.0023		0.0137	0.0169	0.1302

Except for the yields recorded at the meddle stream (MS) and valley bottom (VB), there is significant effect of irrigation: Highest yields are observed for sufficient irrigation (Table 13). No significant effect of weeding quality is also observed at HZ and downstream positions while highest yield account for suitable weeding elsewhere in the valley. With fewer exceptions (US, FV and VB), higher yields are also observed for the weeding operation during rice tillering stage than that of the boosting stage.

Table-14. Mean values of rice yield according the practices of tillage, duration between two tillage operations and nursery duration according to longitudinal and transversal sections of the valley

	Longitudinal section			Transversale section		
	US	MS	DS	HZ	FV	VB
Type of tillage						
Zero tillage	3.25b	4.41b	3.67b	3.76a	4.50a	5.08a
Manual tillage	3.78b	4.68b	4.36b	3.74a	4.53a	5.27a
Rototiller tillage	4.60a	5.38a	5.32a	4.19b	4.88a	5.42a
P>F	<0.0001	0.0037	<0.0001	0.0298	0.0833	0.4626
Number of tillage						
1	4.25a	4.41b	4.70b	3.75b	4.57b	5.17a
2	4.55a	4.99a	5.36a	4.27a	4.93a	5.50a
P>F	0.0734	0.0081	0.0009	0.0037	0.0398	0.0764
Number of manual tillage using hue						
1	4.24a	4.01a	4.41b	3.21b	4.00a	5.26a
2	4.55a	4.99a	5.36a	4.27a	4.93a	5.50a
P>F	0.0734	0.0081	0.0009	0.0473	0.0398	0.2945
Number of tillage using rototiller						
1	4.55a	4.41b	4.70b	3.75b	4.57b	5.17a
2	4.25a	4.99a	5.36a	4.27a	4.93a	5.50a
P>F	0.0734	0.0081	0.0009	0.0037	0.0398	0.0764

Table 14 is showing the mean values of rice grain yield for the type of tillage, the duration between two tillage operations and the duration of rice nursery. There is significant effect of the type of tillage except for FV and VB : Highest yield accounts for rototiller operation when excluding HZ where zero tillage and manual tillage are inducing highest yields.

Table-15. Mean values of rice grain yield for the duration between two tillage operations and the duration of rice nursery according to longitudinal and transversal sections of the valley

	Longitudinal section				Transversal section		
	US	MS	DS		HZ	FV	VB
Duration between two tillage operations (days)							
15	4.41a	4.41b	4.94a		4.17a	4.50b	5.39a
21	4.44a	5.41a	5.26a		4.38a	4.91a	5.60a
30	5.07a	5.42a	5.95a		4.89a	5.48a	5.96a
***P*>F**	0.0349	0.0029	0.1670		0.0473	0.0074	0.1302
Nursery duration (days)							
13	4.54a	5.56a	6.05a		5.73a	5.80a	6.62a
15	4.26a	5.15a	5.91a		6.59a	6.16a	7.03a
21	4.64a	5.22a	5.08a		5.52a	4.71a	5.46a
25	4.22b	4.07a	4.88a		4.10a	4.45a	5.00a
30	3.19b	4.70a	4.90a		3.67a	3.88a	5.10a
***P*>F**	0.0508	0.0109	0.1598		0.3089	0.3202	0.5509

There is significant effect of the number of tillage is observed except for US and VB while highest yield (4.25 – 5.36 tha^{-1}) accounts for two operations of tillage. Significant effect of the duration between two operations of tillage is observed for US, MS, HZ and FV emphasizing 21 days for the optimum duration. The duration of rice nursery is optimum between 13 and 21 days though only significant for US and MS positions.

In contrast, there is significant effect of the period of urea supplying to rice except for US position of the valley (Table 16).

Table-16. Mean values of rice yield according to urea fertilizer practices for the transversal and logitudinal section of the valley

Cropping practice	Longitudinal section				Transversal section		
	US	MS	DS		HZ	FV	VB
Period of urea supplying							
No supply	4.63a	2.58b	2.83c		2.40b	3.39b	3.65b
Tillering	4.52a	4.48a	6.38a		4.29a	4.71a	5.24a
Boosting	4.50a	5.06a	5.05b		4.16a	4.91a	5.56a
Heading	4.00a	---	---		3.40a	4.54a	4.05b
***P*>F**	0.3041	<0.0001	<0.0001		0.0004	0.0069	<0.0001
Dose of urea (kgha^{-1})							
50	4.45a	4.98a	4.98b		4.13b	4.87a	5.45a
75	4.32a	---	5.16b		4.13b	5.15a	5.07a
100	4.82a	5.55a	5.95a		4.76b	5.20a	6.24a
150	---	---	6.05a		5.73a	5.38a	6.22a
***P*>F**	0.2284	0.3280	<0.0001		0.0012	0.0129	<0.0001

The recorded yields are similar statistically for urea supplying at rice tillering, boosting and heading stages but, the yield for no urea supplying is different when excluding the result observed at VB. Except for the HZ, highest yields are recorded for the dose of 100 kgha^{-1} and no significant difference of yield is observed with 150 kgha^{-1} as dose of urea. Nor the period neither urea supplying dose has significant effect on rice yield at US position of the valley.

Table-17. Mean values of rice grain yield according to the type and dose of NPK fertilizer for the longitudinal and transversal sections of the valley

Cropping practice	Longitudinal section			Transversal section		
	US	MS	DS	HZ	FV	VB
Type of NPK						
No supplying of de NPK	4.07b	2.55b	3.66c	2.93c	3.84b	3.95c
NPK 12-24- 8+4S+3MgO	4.81a	5.15a	5.58a	4.50a	5.25a	5.85a
NPK 15-15-15+6S+1B	4.20b	4.60a	4.35b	3.74b	4.36b	4.98b
P>F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dose of NPK (kgha^{-1})						
50	4.13a	5.22b	3.52b	4.23ab	4.71a	5.47ab
75	4.36a	6.67a	3.69b	4.30ab	4.99a	5.65ab
100	5.05a	5.30b	4.96c	4.91ab	5.56a	6.0ab
150	4.86a	---	6.06a	---	5.06a	6.39a
200	---	---	5.77a	5.62a	5.21a	6.47a
***P*>F**	0.0956	<0.0001	<0.0001	<0.0001	0.0009	<0.0001

In contrast with the results observed for urea, table 16 shows significant effect of NPK wherever in the valley except for US position when referring to the supplying dose. Yield higher yields (4.5 – 5.85 tha^{-1}) are observed for NPK 12-24- 8+4S+3MgO compared to that of NPK 15-15-15+6S+1B. Lowest yield is observed for no supplying of NPK. Optimum dose is ranging from 75 $kgha^{-1}$ (MS) to 200 $kgha^{-1}$ (HZ) for a yield range of 5.62 – 6.67 tha^{-1}.

4. Discussion

4.1. Spatial and Temporal Variability of Rice Grain Yield

Irrigated lowland rice cropping is important for sustainable rice production because of highest yield potential of rice varieties and water availability. During the current study conducted in developed (Lokapli) and semi-developed (M'be) lowlands with enough water for irrigation, the highest yields were recorded about 6 t ha^{-1} indifferently to rice varieties. This result underlines a minimum yield gap of 2 t ha^{-1} when compared to the yield of homologated and disseminated rice varieties in Côte d'Ivoire [17]. Moreover, an average yield gap of 1 t ha^{-1} was observed between seasons while, 1.5 t ha^{-1} was accounting for the difference between topographic positions for a single cropping cycle. These findings emphasize some limit in the understanding of the concept of yield gap [18] that should be subdivided as absolute and relative when referring to above results respectively. Numberus factors including seed quality [19] and soil variability in lowlands [20-23] are already known to be contributors to this threat while, the effect of season is pointed out durng the current study. In fact, lowest yields were observed at US position with increasing trend along the valley to downstream position. The yield was also increasing across the transversal section of the valley from hydromorphic zone (HZ) to moistest valley bottom (VB). This toposequence differenciation might be induced by qualitative variability of soils from Upper stream to downstream and from HZ to FV as described by Konan [21] and Traore [22].

Moreover, the highest yields were observed during wet season indifferently to the topographic positions along and across the valley. How ether, there is unequal prevailing of yield classes (as defined for the study) according to topographic positions: class I referring to highest yield was prevailing in downstream and valley bottom of the valley while the lowest yields account for upper stream and hydromorphic zone of the valley depending to the seasons: highest yields were observed in valley bottom during dry season probably because of more availability of water acting as irrigation and weed controlling method [16].

Overall, the current study emphasized a trend of yield variability that can be use for the control of yield gap: valley bottom and wet season are recommendable for this goald.

4.2. Edaphic Characteristic of Rice Yield Variability

Raunet [20] has clearly underlined different soils in West african lowlands according to longitudinal and transversal sections resulting differences in their agronomic potential. The results of the current study are deepening knowledge of these differences for rice cropping in guinea savanna: soil texture, the rate of humification (K_2), the amount of carbon for soil stability, the contents of magnesium and calcium were characterizing (> 60% contribution) highest yield which was ranging from 5 to 10 t ha^{-1} (class I). Moderate yields were also characterized by the same parameters thought, the magnetudes are negative. Meanwhile, lowest yields (0 – 3 tha-1) of class III were induced by soil potassium (K) and sodium saturation rate (TSNa). Sandy soils of hydromorphic zone and fringe valley in some extend should be relevant to low yields contrasting with the soil of valley bottom. Concerning the implication of K and TSNa, Konan [21] has indicated K as limiting factor in the same area of current study while UNIFA [24] has demonstrated sodium disturbance effect in the plants mineral nutrition. Thereby, there is insight of K_2 negative impact on rice yield as observed during the current study: NPK supplying at 36 $kgKha^{-1}$ may reinforce the colloid dispersion already induced by TSNa [25-27] while, mineralization rate (K2) is reducing soil organic matter, in away to minimize the complex of clay-humus. In submersible plot, this situation will promote exogenous and endogen minerals leaching. In the light of this analyze, it look likes to be more sustainable when tackling the yield gap in irrigated lowland by organic matter management than chemical fertilizer. This assertion is emphasizing holistic character of yield gap regarding to unexpected high rates of organic matter requirement [28]. Consequently, organic matter management in lowlands should be a research priority in addition to compulsory investigations at hydromorphic zone and upper stream position of the valley likewise during dry season.

4.3. Impact of Cropping Practices on Rice Yield

There is evidence of cropping practices impact on rice growing with significant contribution of biotic and abiotic factors. These factors are involved in many levels of the productivity as extensively exposed by Chaudhary, *et al.* [29]. The results of the current study showed highest contribution of irrigation and weeding to rice productivity as cropping practices when referring to the values of their correlation coefficients respectively. Though, these contributions were more depending to the season than the topographic positions. Overall, there is opportunity of contradiction against zero-tillage recommendation [30] when regarding to the mean values of rice grain yield: During the study, tillage practice has induced highest yield that was further increased by repeated tillages and the type of tillage. Moreover, the duration between repeated tillage has also increasing effect on rice grain yield and 21 days was the optimum duration recommendable. Yield increasing by the duration between repeated tillage may be a consequence of plot submersion by residual flooding water already used for the first tillage. This water can improve soil acidity and weed seed dormancy hence, mitigation some constraints to subsequent rice growing thereby, the yield can be increase by 1 tha^{-1} for 2 – 4 weeks of submersion [31]. The best type of tillage was the use of rototiller and two operations were recommendable. The repeated rototiller tillage could increase the yield by fragmentation and grounding soil and organic matter [32], reinforcing the complex organo-humic [33]. In contrario, zero-tillage, manual tillage using hue, single tillage, transplanting in May, no supplying of basal fertilizer NPK, no supplying of urea and insufficient irrigation during dry season are constraining rice yield while low control of weed did so during wet season.

There was also topographic impact on the effect of cropping practices and significant negative influence was observed for insufficient irrigation at upper stream position and hydromorphic zone of the valley. Irrigation didn't affect significantly the yield during wet season mainly because for rainfall availability but, the low level of land developement may account for this. In fact, there is slow water management practice in this context resulting exessive submersion during transplanting of 15 days old nursery that could not survived. This situation was prevailing for transpling during August, September and October coinciding with the shorter raining season [34]. Nevertheless, depressive effect of dry season could occur for rice transplanted during October especially, at HZ and FV of upper stream position across the valley: dry season can reduce the efficiencies of nitrogen and potassium respectively [12]. This is pointing out contrasting effects of seasons that were relevant to lowland development level for rice cropping in order to improve water control as irrigation and drainage during dry and wet season respectively. Whenever the season, current results of principle component analysis (PCA) and work done by Konan, *et al.* [35] showed the importance of soil content of potassium and its interaction with N in the study agro-system in addition to N-deficiencies as observed across the valley [28].

5. Conclusion

The diagnosis of yield gap on spatial and tempory scales releaved a range of 1 – 2 tha^{-1} as absolute (2 tha-1) or relative (1 – 1.5 tha-1) yield gap. Insuffisant irrigation and weeding were identified as the most significant practices to be improved for yield increasing independly to the seasons. Twice use of rototiller within 21 days period and basal fertilizer as NPK 12-24- 8+4S+3MgO is requirement when applying 75 – 200 kgha-1 during 15 days rice nursery transplanting and 150 – 200 kgha-1 of urea at rice tillering stage. Organic matter management in hydromorphic zone for different seasons was identified as research priority for tackling yield gap in lowland rice cropping.

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