Physical Characteristics of Soil under Different Cropping and Natural Systems on the Plain of Jars, Xieng Khouang Province, Laos

Florent Tivet[12], Pascal Lienhard[12], André Chabanne[1], Vilasack Saphanthong[2], Thammakham Sosomphou[32], and Lucien Séguy[4]

1. CIRAD-CA, PO Box 2991, Vientiane, Lao PDR, Email: florent.tivet@cirad.fr
2. PRONAE, PO Box 10990, Vientiane, Lao PDR, Email: pronae.pcadr@nafri.org.la
3. NAFRI, PO Box 7170, Vientiane, Lao PDR. Email: contact@nafri.org.la
4. CIRAD-CA, Goiânia, Goias, Brazil, Email: lucien.seguy@cirad.fr

Abstract

Conservation agriculture and direct seeding mulch-based cropping (DMC) systems greatly modify plant and soil interaction. Plants commonly provide energy that fuels biological processes and either directly or indirectly creates structure within soils. Under DMC systems a large biomass is produced both above and below ground, thereby influencing soil parameters. Different methods can be used to measure soil characteristics, but simple and cheap tools for on-site recording are not common. This study attempts to analyse the physical soil parameters (water-stable aggregate, bulk density and soil permeability) of various ecosystems: savannah grassland, pine forest, ploughed upland rice fields, and improved *Brachiaria ruziziensis* and *Stylosanthes guianensis* pasture lands. The results show that these forage species have a clear effect on soil structure: medium soil particles (<0.250mm) are fixed into water-stable aggregates, bulk density decreases, and as a result soil permeability is modified. The continued recording of such data over time will enable evaluation of the iterative and cumulative biological effects (organic content, root density, particle arrangement) of fodder species and cropping systems on soil characteristics.

Keywords: soil physical characteristics, on-site tools, water-stable aggregates, bulk density, permeability, fodder species, savannah grassland, Xieng Khouang province, Laos

1. Introduction

As reported by many authors (Crovetto, 1999; Séguy et al, 2001; Sà et al, 2001; Six et al, 2002), direct seeding mulch-based cropping (DMC) systems generate marked modification of soil characteristics (physical, chemical and biological components). The aim of DMC is to maintain an equilibrium of plant and soil systems, in which the diversity of plants (crops and cover crops), macrofauna and microbial communities stabilises the system during environmental fluctuations. The main principles are that: i) soil is disturbed as little as possible by mechanical action and is always kept covered by crop residues and cover crops; ii) mechanical actions are replaced by biological improvement to soil structure through the strong root systems of cover crops and soil biology; iii) integrated management of pests (equilibrium between populations) and weeds through shade and/or allelopathic effects (Florentin et al, 1991; Séguy et al, 1999; Chiapusio et al, 2002) and water and nutrient competition; and iv) recycling, through deep-rooted cover crops, nutrient-leach deep in the soil below layers used by the roots of cash crops or rice.

Different methods are used to measure soil characteristics; however, simple and cheap tools for on-site recording are not common. The present study attempts to analyse physical parameters under different systems present in savannah grasslands, pine forest, rice after soil ploughing, and fodder species (*Brachiaria ruziziensis*, *Stylosanthes guianensis*). Various parameters were recorded on the same sample to avoid spatial heterogeneity. Measurements were taken of the same sample as water-stable aggregate (Yoder method), bulk density, and soil permeability (coefficient K of Darcy's Law).

2. Material and Methods

2.1. Materials

For on-site sampling three-compartment cylinders were used, allowing extraction without modification of soil structure (Séguy 2004). This tool is presented in Figures 1 and 2.

Water-Stable Aggregate (WSA)

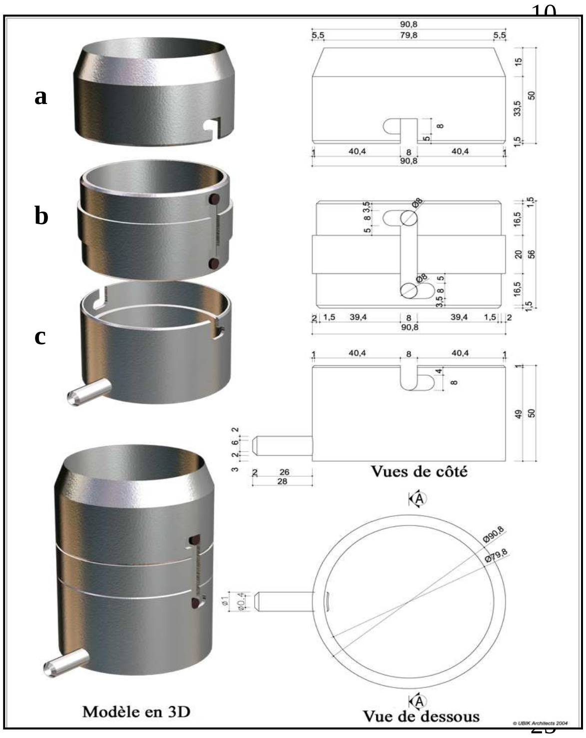
The soil samples contained in the first (a) and third (c) compartments of the cylinders are used to determine the water-stable aggregate. Soil is removed from (a) and (c), and the cylinders replaced on the top and bottom of cylinder b as presented in Fig. 1. A piece of mosquito net is placed between (b) and (c) to avoid soil loss.

The soil removed from (a) and (c) is carefully sieved with a 10 mm sieve. The sample is rewetted for 12 hours, then a part is weighed and placed in a 4 mm sieve. A second part is weighed, then dried for 24 hours at 105°C to determine what the dry weight of the first part would be. The Yoder method is used to give the aggregate mean diameter after sieving in water. The higher the coefficient from this calculation, the higher the stability of the aggregates is deemed to be. Sieving is carried-out using five sieves of 4 mm, 2 mm, 1 mm, 0.25 mm, and 0.125 mm, held firmly together on a steel support and placed in a small water tank. This support is connected to a lever arm which is moved 38 mm up and down 30 times per minute for 30 minutes. When the sieves are raised to the highest level, the upper sieve (4mm) must be a maximum of 1 cm above the water level, ensuring that the samples are always flooded.

After this shake-up, the soil samples on each sieve are collected and dried for 24 hours at 105°C. Small particles, particularly clay, with a diameter lower than 0.125mm are lost during this process. In order to evaluate the accuracy of this method it is necessary to collect all these soil losses below the last sieve (0.125 mm), to record the total dry weight of all samples, and to compare final the final dry weight with the initial dry weight. The WSA calculation is made using the following formula: $WSA = \sum_{i=1}^{n} \frac{Pi}{Pt}.dmi$ with $dmi = \frac{(di + d(i+1))}{2}$

n = Number of sieves
Pi = Dry weight of soil sample on sieve di
Pt = Sum of all dry soil samples
dmi = Mean diameter of soil aggregates
d(i+1) = Diameter of sieve above di

Fig. 1: Three-compartment cylinder for soil extraction



Permeability, K Coefficient (Darcy)

As previously mentioned, after the soil is removed from (a) and (c) the cylinders are then replaced on the top and bottom of (b). Vaseline and inner tube can be used to avoid water loss between compartments. During the process, certain parameters have to be controlled: i) the water flow has to be constant, and ii) the water must reach the overflow level. Permeability is expressed by the volume flowing through the soil after a defined period. K coefficient is calculated using Darcy's law: $V = K \times \frac{H}{L} \times S$

V: Volume of water flowing trough the soil after time t
L: Height of cylinder (b)
H: Height of cylinder (b) + height until overflow
S: Cylinder section (cm²)

K: Coefficient of permeability ($cm.h^{-1}$)

Bulk density (Da)

Da is measured on the same cylinder as the one used to determine soil permeability. The sample contained in cylinder (b) is removed and dried for 24 hours at 105°C. The dry weight of the sample is measured to express bulk density ($kg.dm^{-3}$).

2.2. Experimental Design and Data Collection

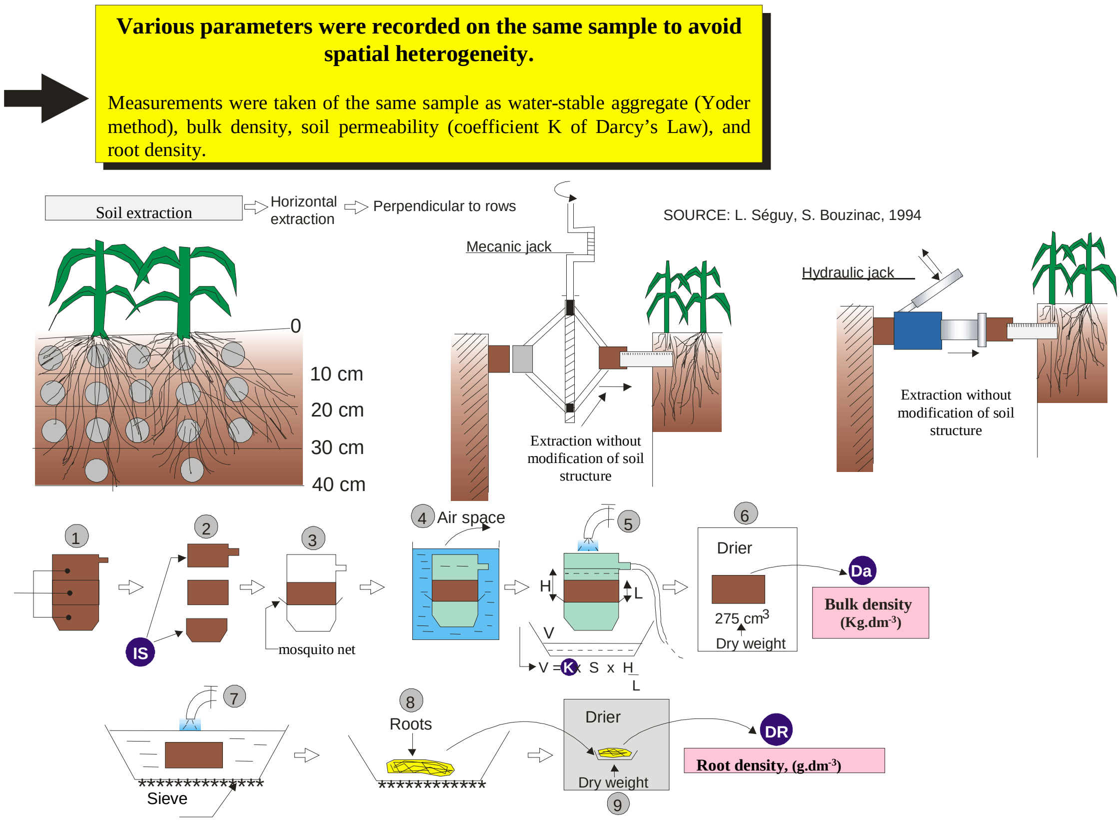
Sampling was carried-out in four main environments on the Plain of Jars, around Phonsavanh, the provincial capital of Xieng Khouang: i) natural savannah grasslands; ii) natural pine forest; iii) rice crop after tillage (first year of cropping); and iv) improved pasture lands with various forage species established by direct sowing (no tillage). Forages were established in June 2004 by direct seeding after control of weeds. The species used were *Brachiaria* - *B. ruziziensis*, *B. decumbens*, *B. mulato* (hybrid), and *B. humidicola* - and the legume *Stylosanthes guianensis* (CIAT 184). These were all cross-linked with two levels of mineral fertilisers to evaluate the indirect impact of different forage growth rates (above-ground and below-ground dry matter production) on soil characteristics. Only the results obtained for *B. ruziziensis* and *S. guianensis* are presented here. Rice was sown in June 2005 after ploughing, and yield was less than 0.2 $t.ha^{-1}$ with no use of fertiliser. Samples were extracted at three depths (0-10 cm, 10-20 cm, and 20-30 cm) with six replicates per depth.

Savannah grassland is characterised by acidic soils, deficiencies in nitrogen, phosphorus, potassium, calcium, magnesium, and high aluminium saturation. In addition, local weed species of low palatability produce low amounts of biomass. The main species are *Themeda triandra*, *Hypparhenia newtonii* and *Cymbopogon nardus* (Hacker et al, 1998; Gibson et al, 1999). More than 60,000 ha of savannah grasslands are present in Xieng Khouang province, mainly in the districts of Pek, Phoukhouth and Paxay.

Table 1: Characteristics of treatments

Treatment	Establishment	**2005**	
		Location	Sampling
Pine tree		Pouhoum	October – November 2005
Savannah grassland			
B. ruziziensis direct seeded	May 2004		
S. guianensis direct seeded			
Rice after tillage (upland)	June 2005		

Figure 2: On-site sample extraction and processing for determination of soil parameters.



2.3. *Statistical Analysis*

Graphic representations, calculations of confidence intervals for regressions, and standard deviation (SDEV) were carried out with SigmaPlot 9.0 for Windows (Jandel Scientific). Statistical analysis was carried-out with SPSS 9.0 for Windows.

3. Results

3.1. *Analysis of Water-Stable Aggregate*

Samples from pine forest and savannah grassland are first analysed. The WSA and dry soil weight measured on each sieve showed a low SDEV due to low spatial heterogeneity and good performance of this measure. The accuracy of this method was analysed through collection of the soil particles falling below the last 0.125mm sieve and comparison of initial and final dry weight. The final dry weight represented at least 98% (data not shown) of the total dry soil used at the beginning of the experiment, confirming the good accuracy of this method.

As mentioned before, these morphopedological units on schist and granite are water stable and present a relatively high amount of particles with a mean diameter of around 4mm for 0 cm-10 cm depth (Table 2). This size dropped with lower soil layers, falling to 2.88mm at 20 cm-30 cm under pine forest (Fig. 3). Significant differences ($P<0.05$) were recorded for each depth between these references, with higher particle sizes recorded under savannah grassland.

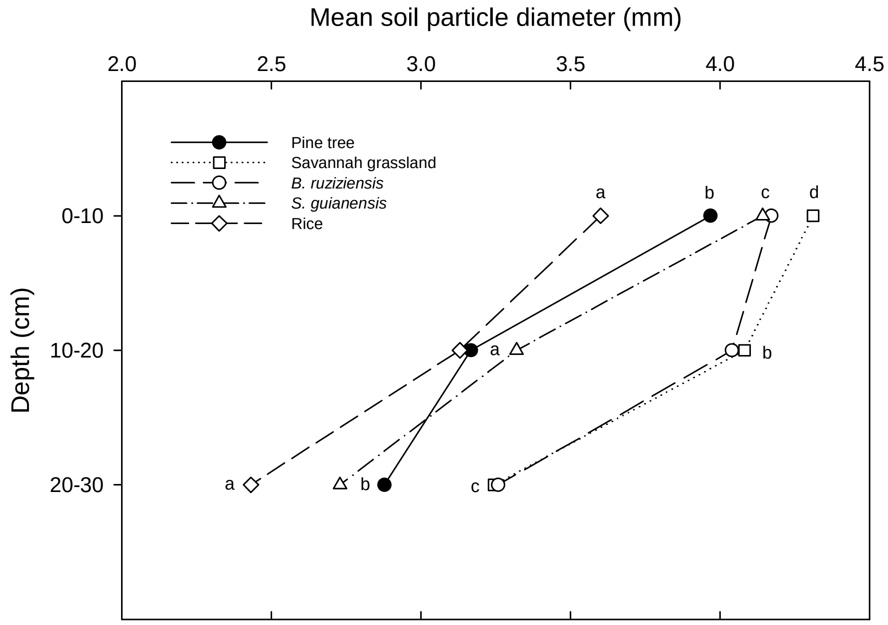
Samples collected on rice crops after ploughing showed a lower WSA, with a mean range of 3.60 and 2.13 for respective depths of 0 cm-10 cm and 20 cm-30 cm. The relative reduction of aggregate size with depth is less pronounced for *B. ruziziensis* and savannah grassland, a fact probably related to a higher level of organic and dry matter and/or microbial activities. The relative reduction for *B. ruziziensis* was 3.2% for 10 cm-20 cm and 21.9% for 20 cm-30 cm. *S. guianensis*, in contrast, showed a relative reduction of 19.9% for 10 cm-20 cm and 34.1% for 20 cm-30 cm.

Table 2: Mean diameter of WSA ± SDEV and mean weight of soil samples ± SDEV from six replications for pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis*, and rice; 2005.

Treatment	Depth (cm)	Sieve:	Soil weight (g) 4mm	2mm	1mm	0.250mm	0.125mm	WSA (mm)
Forest	0-10	mean	41.33	20.00	12.17	18.17	4.00	3.97
		SDEV	1.21	1.90	0.75	2.04	0.00	0.08
	10-20	mean	27.50	20.17	14.00	24.83	5.00	3.17
		SDEV	4.28	0.98	1.10	1.47	1.10	0.18
	20-30	mean	18.00	21.33	14.00	20.67	4.00	2.88
		SDEV	1.26	0.82	1.41	0.52	0.00	0.05
Savannah	0-10	mean	42.17	18.00	10.33	13.17	3.00	4.31
		SDEV	2.93	1.10	0.52	2.40	0.00	0.05
	10-20	mean	39.33	20.50	10.50	14.67	3.83	4.08
		SDEV	2.25	1.52	0.55	3.08	1.17	0.04
	20-30	mean	23.50	22.00	13.33	17.50	4.50	3.24
		SDEV	2.17	1.90	0.52	1.05	0.55	0.13
B. ruziziensis	0-10	mean	44.17	19.67	12.83	15.67	3.00	4.17
5 550 kg DM.ha^{-1}		SDEV	3.49	2.25	1.47	0.52	0.00	0.16
	10-20	mean	38.50	21.67	11.50	14.67	3.00	4.04
		SDEV	5.24	1.03	1.05	0.52	0.00	0.20
	20-30	mean	28.33	22.67	13.50	24.00	4.00	3.26
		SDEV	4.68	1.51	0.55	1.90	0.00	0.23
B. ruziziensis (F+)	0-10	mean	53.50	15.67	10.67	14.17	3.00	4.61
9 763 kg DM.ha^{-1}		SDEV	2.66	2.16	0.52	0.98	0.00	0.14
	10-20	mean	44.17	21.33	12.00	17.00	3.00	4.13
		SDEV	4.22	1.51	1.90	1.90	0.00	0.24
	20-30	mean	27.67	24.17	14.50	21.67	3.67	3.28
		SDEV	7.87	2.32	1.87	2.80	0.52	0.34
S. guianensis	0-10	mean	42.67	20.33	13.83	14.83	2.50	4.14
		SDEV	2.25	0.82	1.60	0.75	0.55	0.06
	10-20	mean	26.67	23.00	15.50	20.17	3.00	3.32
		SDEV	5.54	2.10	2.26	5.31	0.00	0.44
	20-30	mean	19.33	23.50	21.17	25.17	3.83	2.73
		SDEV	2.66	1.22	0.98	0.75	0.98	0.13
S. guianensis (F+)	0-10	mean	44.17	20.50	13.50	16.00	2.50	4.15
		SDEV	1.72	0.55	1.05	0.63	0.55	0.09
	10-20	mean	27.67	24.50	17.17	21.33	3.17	3.27
		SDEV	6.31	1.87	2.48	3.01	0.41	0.38
	20-30	mean	19.67	27.67	19.83	25.50	3.83	2.76
		SDEV	4.41	0.52	0.41	1.38	0.98	0.25
	0-10	mean	35.17	21.00	12.33	21.67	4.83	3.60
Rice after ploughing		SDEV	1.47	1.67	0.52	1.86	0.98	0.10
	10-20	mean	27.17	19.83	13.33	25.33	5.67	3.13
		SDEV	7.19	2.64	2.25	1.37	0.82	0.35
	20-30	mean	12.67	23.00	16.33	25.67	5.33	2.43
		SDEV	2.25	2.37	4.03	5.24	1.51	0.30

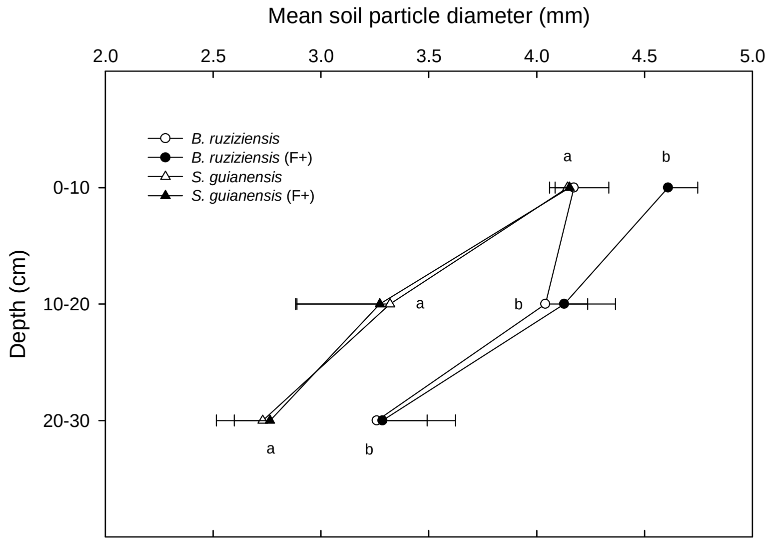
Significant WSA (P<0.05) differences were recorded between savannah grassland and others non-fertilised treatments at each depth (Fig. 3), although *B. ruziziensis* showed similar results for 10 cm-20 cm and 20 cm-30 cm depths. Significant differences were also recorded between rice and all the other treatments for 0 cm -10 cm and 20 cm-30 cm samples. Some treatments showed significant differences only for some depths. For example *B. ruziziensis* and *S. guianensis* differed greatly at depths lower than 10 cm.

Figure 3: Aggregate-mean diameter (six replicates) for pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis* (treatments without fertiliser) and rice for three depths, plus results of Duncan test (0.05).



The effect of higher below-ground (data not shown) and above-ground dry matter (by use of fertiliser) was analysed on soil aggregation for two species (Fig. 4). For *B. ruziziensis*, above-ground dry matter during the rainy season ranged from 5.5 $t.ha^{-1}$ without fertiliser to 9.7 $t.ha^{-1}$ with fertiliser (F+). Dry matter was not recorded for *S. guianensis*. A significantly higher value of WSA (4.61 mm) was noted for *B. ruziziensis* at 0 cm-10 cm. No significant differences were reported for *S. guianensis* at any depth.

Figure 4: Aggregate-mean diameter (six replicates) for *B. ruziziensis* (+F), and *S. guianensis* (+F) for three depths. Results of Duncan test are presented (P>0.05).



Particle sizes were observed for each depth (Fig. 5). Macro water-stable aggregates (>4 mm) dropped greatly under tillage and represented less than 40% of particles at 0 cm-10 cm (Fig. 5d, Fig. 6). In comparison with savannah grassland (control), the relative reduction of macro aggregates for rice was 24.0% for 0 cm-10 cm, 33.2% for 10 cm -20 cm, and 45.8% for 20 cm-30 cm (Fig. 6). Similarly, medium and small water-stable aggregates (0.250 mm and 0.125 mm) increased greatly and represented, in percentage of control, more than 45% for 0 cm-10 cm depth (Fig. 7). These results contrasted with those obtained with *B. ruziziensis*, which showed a very similar distribution of macro water-stable aggregates to savannah grassland (no significant differences for 10 cm-20 cm and 20 cm-30 cm, Fig. 6), and a slight increase in medium-sized particles (2 mm to 0.250 mm) at 0 cm-10 cm and 10 cm-20 cm (Fig. 7ab).

In comparison with savannah grassland, the relative reduction of macro water-stable aggregates (>4 mm) for *S. guianensis* was 6.9% for 0 cm-10 cm, 31.3% for 10 cm-20 cm, and 28.6% for 20 cm-30 cm (Fig. 6). This species showed a surprising drop in macro aggregates, and a relative increase of medium particles (Fig. 7a, b), at respective depths of 0 cm-10 cm and 10 cm-20 cm, of 4% and 12.7% for 2 mm particles, 22.8% and 47.4% for 1 mm particles, and 4.4% and 38.1% for 0.25 mm particles. In contrast, the relative reduction of aggregate of <0.125 mm was 23.9% for 0 cm-10 cm, 21.9% for 10 cm-20 cm and 25.9% for 20 cm-30 cm. Patterns were quite similar for *B. ruziziensis* and *S. guianensis* (Figure 7a, b) across different soil layers (from 0 cm-10 cm and 20 cm-30 cm), with an increase of medium aggregates (from 2 mm to 0.25 mm) and a drops of smaller particles (<0.125 mm). It seems that under *B. ruziziensis* and *S. guianensis*, small aggregates are being glued together to form bigger aggregates. Such results could be linked to higher biological activity (mycorrhizal symbionts), root exudates, and humic compounds under *B. ruziziensis* and *S. guianensis* crops. However, it was difficult to interpret the relative reduction of *S. guianensis* macro aggregates (<4 mm): 6.9% for 0 cm-10 cm, 31.3% for 10 cm-20 cm and 28.6% for 20 cm-30 cm (data not shown).

In contrast, rice and pine forest showed patterns characterised by a decrease of large aggregates and a progressive increase of small water-stable aggregates from 1 to 0.125 mm.

Figure 5: Mean frequency ± SDEV (six replicates) of water-stable aggregates distribution for three depths for pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis*, and rice, 2005

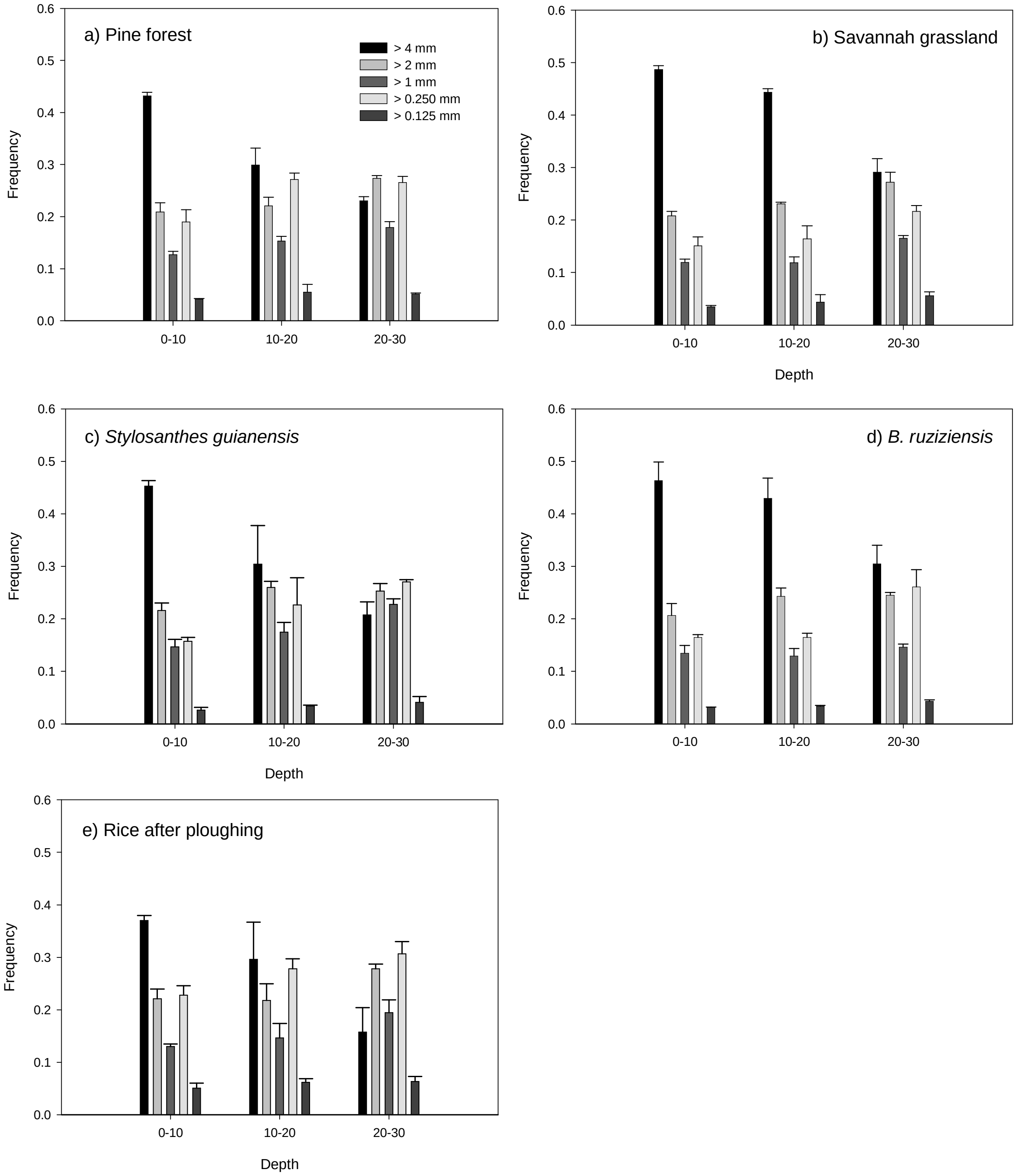


Figure 6: Evolution of water-stable macro aggregates (>4 mm), in percentage of control (savannah grassland), for pine forest, rice, *B. ruziziensis*, rice and *S. guianensis*; 2005. Results of Duncan test are presented (P<0.05).

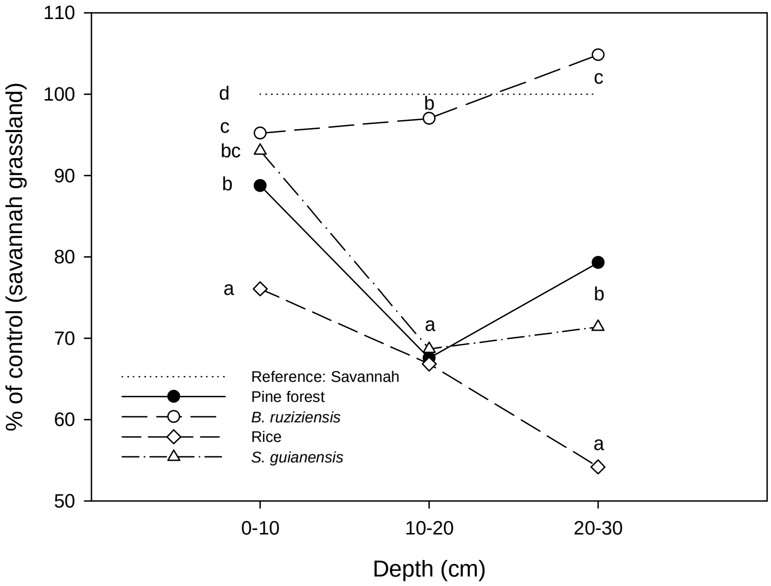
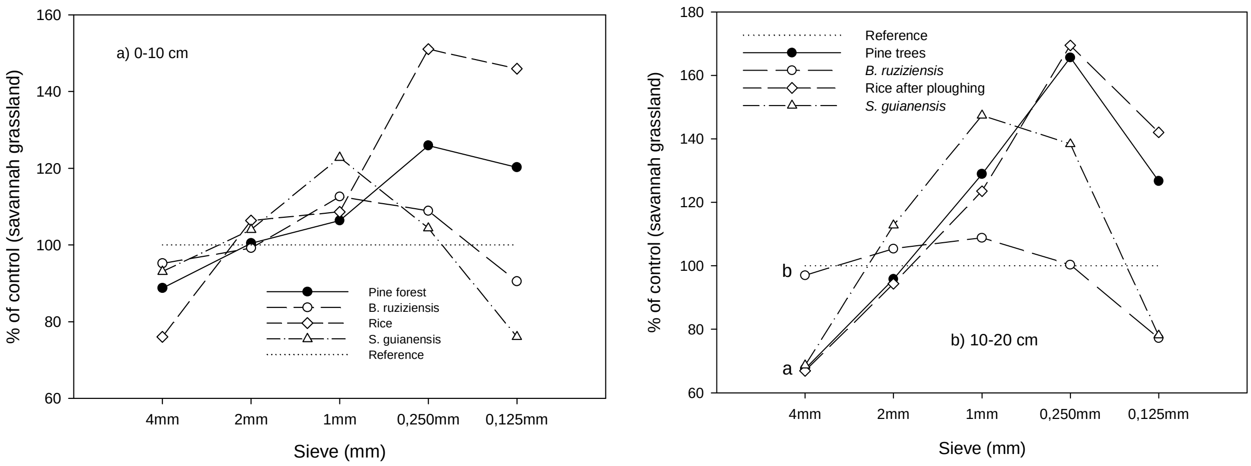


Figure 7: Evolution of WSA, in % of control (savannah grassland), for pine forest, rice, *B. ruziziensis*, rice and *S. guianensis* for depths 0 cm-10 cm (a) and 10 cm-20 cm (b); 2005.



3.2. Bulk density

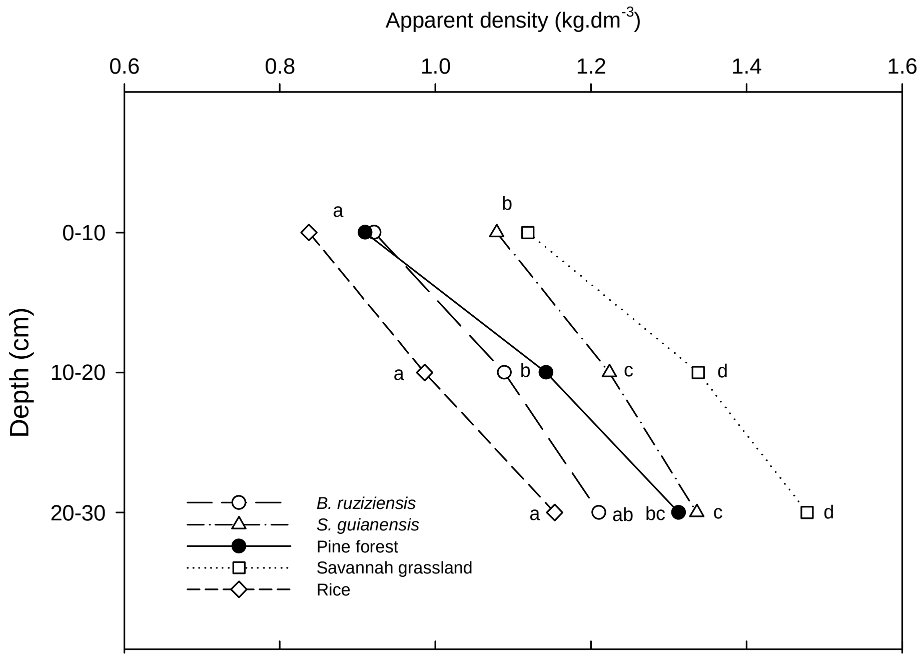
Higher variation coefficients were obtained under rice and pine forest, where spatial heterogeneity was higher than under savannah due to tree placement and ploughing. Da was affected by treatment and soil depths. Da values were higher under savannah grassland and increased with depth, resulting in dense and soil unfavourable for crop root penetration. *Brachiaria ruziziensis*, in contrast, showed low bulk density and we can reasonably conclude that these changes were related to biological soil improvement. Significant bulk density (P<0.05) differences between pine forest and natural savannah and between *B. ruziziensis* and natural savannah, were recorded for each depth; no significant differences were recorded between pine forest and *B. ruziziensis*.

Da changed drastically under *B. ruziziensis* and *S. guianensis*. Its relative reduction (in percentage of savannah) was, for *B. ruziziensis* and *S. guianensis* respectively, 17.7% and 3.6% for 0 cm-10 cm, 18.6% and 8.5% for 10 cm-20 cm, and 17.6% and 9.6% for 20 cm-30 cm (Table 3). These differences could be explained by the contrasting root systems of the species: *S. guianensis* has a swivelling rooting system while that of *B. ruziziensis* is fasciculate. After one season, *B. ruziziensis* shows a strong ability to decrease bulk density and to create a favourable environment for future root penetration. The Da for rice was very low, probably due to tillage generating a disaggregated structure. To build a clear picture of the negative effects of tillage, parameters have to be set for rice under ploughing and under direct seeding on natural pasture lands. This would clearly record all the effects of each treatment.

Table 3: Mean bulk density ± SDEV (six replicates), and variation coefficient (vc) for pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis* and rice for three depths; data 2005

Treatment	**Depth (cm)**	**Apparent soil density ($g.dm^{-3}$) 2005**		
		Mean	**SE**	**vc**
Forest	0-10	0,91	0,08	8,9%
	10-20	1,14	0,07	6,5%
	20-30	1,31	0,17	13,0%
Savannah	0-10	1,12	0,01	1,2%
	10-20	1,34	0,02	1,4%
	20-30	1,48	0,02	1,4%
B. ruziziensis	0-10	0,92	0,12	13,5%
	10-20	1,09	0,03	3,0%
	20-30	1,22	0,09	7,1%
S. guianensis	0-10	1,08	0,03	2,8%
	10-20	1,22	0,05	4,3%
	20-30	1,34	0,06	4,2%
Rice	0-10	0,84	0,17	20,3%
	10-20	0,99	0,07	7,5%
	20-30	1,15	0,10	8,7%
B. ruziziensis + ferti	0-10	0,98	0,13	13,6%
	10-20	1,10	0,04	3,8%
	20-30	1,22	0,09	7,1%

Figure 8: Mean bulk density (six replicates) for pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis* and rice for three depths; data 2005. Duncan test results are presented (P<0.05).



3.2. Soil Permeability

The variation coefficients recorded were high (Table 4), especially for *S. guianensis*, pine forest and rice. For *S. guianensis* this result may be explained by the spatial distribution of its swivelling rooting systems – a factor which generates contrasting results. In contrast, the *B. ruziziensis* and savannah grassland treatments showed lower SDEV than the other tests. The homogeneity of their rooting system distributions could explain this differentiation.

Soil permeability was higher at the depth of 0 cm-10 cm for rice after tillage, *S. guianensis* and pine forest. Savannah grassland exhibited a globally lower level of K than all the other treatments. *B. ruziziensis* showed lower soil permeability than *S. guianensis*, and also lower bulk density.

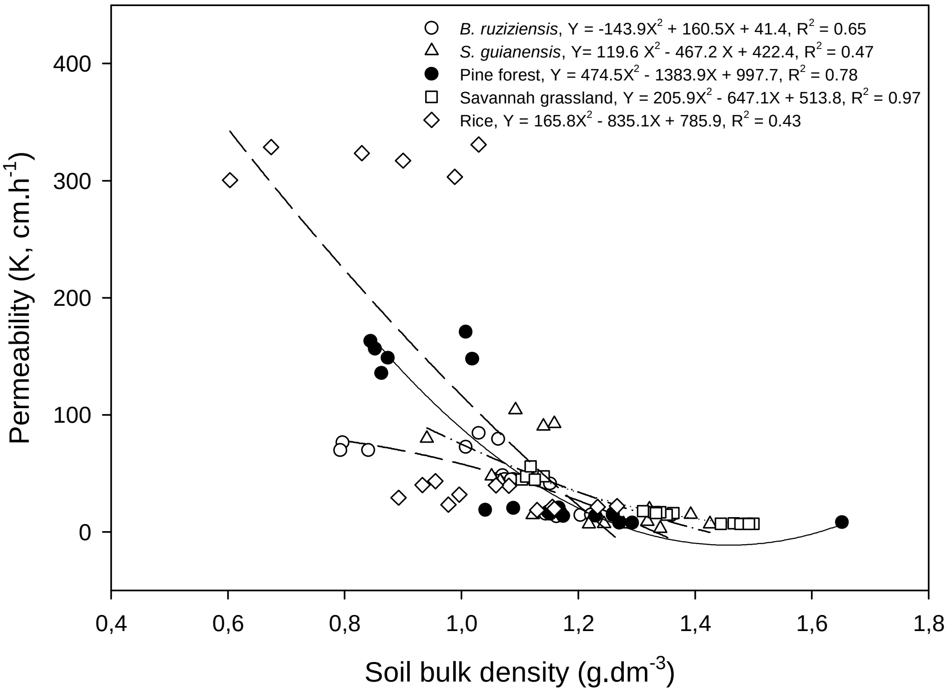
Table 4: Estimates of permeability coefficient (K) ± SDEV (six replicates), and variation coefficient (vc) under pine forest, savannah grassland, *B. ruziziensis*, *S. guianensis* and rice are presented.

Treatment	Depth (cm)	K ($cm.h^{-1}$) 2005 Mean	SE	vc
Forest	0-10	153,79	12,46	8,1%
	10-20	17,79	2,64	14,8%
	20-30	11,08	3,51	31,7%
Savannah	0-10	47,70	4,24	8,9%
	10-20	16,37	1,02	6,2%
	20-30	7,05	0,23	3,2%
B. ruziziensis	0-10	75,39	5,80	7,7%
	10-20	44,66	2,30	5,1%
	20-30	14,67	1,05	7,2%
S. guianensis	0-10	147,83	0,35	0,2%
	10-20	45,74	6,93	15,1%
	20-30	34,44	9,42	27,3%
Rice	0-10	317,32	12,85	4,1%
	10-20	37,27	5,49	14,7%
	20-30	21,09	1,67	7,9%

3.3. Soil Permeability against Soil Bulk Density

As shown by Fig. 9, significant quadratic regressions were obtained between soil permeability and bulk density for pine forest (R^2=0.78), savannah grassland (R^2=0.97) and *B. ruziziensis* (R^2=0.65). At comparable values of Da, *B. ruziziensis* showed lower soil permeability than *S. guianensis*, pine forest and savannah. In comparison with the situation on savannah grassland, this regression shows great modification after one year of growth for both *B. ruziziensis* and *S. guianensis*, providing evidence of a strong and multi-factored effect by fodder species on soil permeability against bulk density.

Figure. 9: Quadratic models for soil permeability against bulk density for different treatments.



4. Discussion

The results of the WSA analysis are promising, highlighting the positive features of forage species like *B. ruziziensis* and *S. guianensis*, which seem able to aggregate smaller soil particles. This result suggests these forage species adapt well to acid soils and can produce high amounts of biomass both above and below the ground. Plants provide energy that fuels the biological processes and either directly or indirectly creates structure within soils (Perry et al, 1989). For example, a large amount of photosynthate is allocated to roots and much of that photosynthate is diverted to mycorrhizal symbionts or exuded into the surrounding rhizosphere. Mycorrhizal fungi produce extra-cellular polysaccharides that glue mineral particles together into water-stable aggregates (Lynch and Bragg 1985; Gobat *el al.* 1998).

It is interesting to compare these forages with tested no-tillage systems. Wright and Hons (2005) showed that no-tillage (with no use of cover crop), for a sorghum/wheat/soybean rotation, increased the proportion of macro aggregates (>2 mm) at 0-5 cm, and that the majority of soil organic carbon (SOC) and soil organic nitrogen (SON) was recorded in the largest aggregate-size fractions. Nevertheless, these authors also reported that no increase of macro aggregates was recorded below a depth of 5 cm. *B. ruziziensis* and *S. guianensis* on the other hand have displayed an increased proportion of macro aggregates at a depth of 20 cm-30 cm, and that during a very short process. No-tillage systems have to integrate the use of cover crops to take advantage of the strong and efficient capacity of these species to improve soil parameters. However, no conclusive explanation was found for the decrease of macro aggregates (<4 mm) under *S. guianensis*, possibly due to macro fraction disaggregating. Soil aggregation is a non-equilibrium phenomenon, maintained and increased by periodic influx of fresh extra-cellular polysaccharides. It has been clearly demonstrated that soil aggregation is influenced by the dynamic interaction of the below-ground ecosystem and above-ground species (Perry et al, 1989). Annual records should be made for *B. ruziziensis*, *S. guianensis* and others systems, and linked with analysis of microbial activities to show the beneficial functions of each species or system in soil aggregation.

It is difficult to interpret the positive features of species in regard to bulk density and soil permeability as interaction is complex and various parameters are involved. For example, *B. ruziziensis* shows evidence of positive soil improvement through its strong roots, and at the same time its fasciculate system generates a strong and efficient organic skeleton (higher organic and C content) for water retention (increasing soil micro-porosity), as represented by lower soil permeability (lower Da). At the same value of bulk density, this parameter will be affected by particle size and arrangement, and organic content. In the three different treatments of *B. ruziziensis*, pine tree, and savannah, good quadratic relationships were observed between soil permeability and bulk density. This is due, in the case of *B. ruziziensis*, to a uniform root system, and for pine tree and savannah grassland to a stabilised system where the soil characteristics are not adversely affected by the above-ground species.

In the case of rice and natural pine forest, the lower bulk density is mainly related to macro-porosity (high level of permeability). In contrast, *B. ruziziensis* and *S. guianensis* showed, for lower Da, a lower value of permeability probably related to an increase of micro-porosity. This characteristic has to be analysed during subsequent measurements of Da and soil permeability data as micro-porosity is a main component influencing water retention. It would also be useful to record the coefficient of determination (permeability against. bulk density) over time to evaluate the iterative and cumulative biological effects (organic content, root density, particle arrangement) on soil permeability.

5. Conclusions

Sampling of soils using cylinders, for different land treatments on the Plain of Jars, allowed the measurement of the following soil parameters: water-stable aggregates, bulk density, and soil permeability. While these measurements could be taken using cheap and easy tools, soil profiling is destructive on experimental small plots and cannot be replicated every season through a medium-term process. This study of soil characteristics and evolution will be repeated for different cropping systems with use of cover crops, residue management, and tillage in southern Xayabury. This analysis will be conducted together with biological and chemical analysis to provide an overview of the performances of no-tillage systems.

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