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RELATIONSHIPS BETWEEN SOIL PHYSICAL PROPERTIES AND CROP YIELDS IN DIFFERENT CROPPING SYSTEMS IN SOUTHERN CAMEROON

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Dedication

To You, Jesus-Christ, with gratitude I dedicate this thesis begging that You may accept it. You are the image of the invisible God, the One in whom the fullness of deity lives in bodily form (Bible, Colossians 1: 15-20), the "Pedo-Agronomist": The One Who First planted a garden and "published His work" (Bible, Genesis, 2:8-9); The First Anesthesist and Transplanting Surgeon (Bible, Genesis, 2:21-22). Thank You for being my Heavenly Mentor.

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Abbreviations

ANOVA	ANalysis Of Variance
AWC	Available Water Capacity
asl	above sea level
BD	bulk density
C	Carbon
^{o}C	Celsius degree
Ca	Calcium
cm	Centimetre
CORR	Correlation
CR	cone resistance to soil penetration
CTA	Technical Centre for Agricultural and Rural Cooperation
Cu	Copper
FAO	Food and Agriculture Organization (of the United Nations)
Fe	Iron
g	Gram
GIC	Groupe d’Initiative Communautaire
GLM	General Linear Model
GMD	Geometric Mean Diameter
H	Hydrogen
h	hour
ha	Hectare
IITA	International Institute of Tropical Agriculture
IRAD	Institute of Agricultural Research for Development
K	Potassium
kg	Kilogram
km	kilometre
LUS	Land Use System
m	Meter
Mg	Magnesium
mm	Millimetre
MPa	mega Pascal
MWD	Mean Weight Diameter
N	Nitrogen fertilizer
n	number of observation
Na	Sodium
ns	not significant
O	Oxygen
P	Phosphorus
P	statistical significance testing

Pl : Plantain
PPMC : Proportion of Plants with Marketable Cobs
PPWC : Proportion of Plants With Cobs
Proc : Procedure
r : correlation coefficient
R : Determination coefficient
REG : Regression
SAS : Statistical Analysis Software
SE : standard error of the mean
* : significant (5%)
** : significant (1%)
*** : significant (0.1%)
SOM : soil organic matter
SSA : sub-Saharan Africa
spp. : species pluralis
WSA : Water Stable Aggregates
yr : Year
§ : Paragraph

Chapter 1

General Introduction

1. General Introduction

1.1 The challenge to meet food demands of a rapidly growing population in traditional agricultural production systems in the humid tropics

The agricultural sector is under enormous pressure, to meet food demand of a projected population of 9.2 billion in 2050 (United Nations, 2009), particularly meeting this demand together with increased challenges from climate change, competition from bioenergy, and land degradation (FAO, 2008). Worldwide, 850 million people suffer from undernourishment (FAO, 2011). Of this, 568 million undernourished people are in the Asia, 217 million in sub-Saharan Africa (SSA), 6 million in northern Africa, 47 million in Latin America and the Caribbean, 1 million in Oceania, and 11 million in the developed countries (FAO, 2011). Yet, there is a great potential for increasing crop yields in most of these regions. For instance for SSA, most farmers have land assets adequate to provide food security and to rise it above subsistence (Conway and Toenniessen, 2003; Balasubramanian et al., 2007); and it is possible to reduce and even erase the gap between the actual yield and the potential yield (Sanchez, 2002; Conway and Toenniessen, 2003; Lal, 2006; Balasubramanian et al., 2007). In spite of this potential and regardless of the increases in food demand, in SSA, the rate of annual increase in crop yields has been more or less stagnant since 1961 (Otsuka and Yamano, 2005).

One of the reasons for this stagnation may be the current agricultural practices. For instance, agricultural practices in the humid tropics of Africa are still largely based on the traditional slash-and-burn system with natural fallow vegetation. A simplified model of this approach is detailed in Figure 1.1. The assumption is that after cropping soil fertility or fertility related parameters increase at high initial rates and asymptotically approach a maximum. At low population densities, even on nutrient-poor soils, full fertility recovery will be attained, but fallow phases may exceed 20 years, followed by a non-essential fallow phase (Type 1 scenario, Figure 1.1). Sustainable land use at maximum land use frequency would require cropping when fertility has just been fully restored (Type 2 scenario, Figure 1.1). Higher land use frequency or shorter fallow periods than in the ‘type 2’ scenario, would hypothetically lead to reductions in crop yields due to incomplete fertility restoration (Type 3 scenario, Figure 1.1) (Hauser et al., 2006).

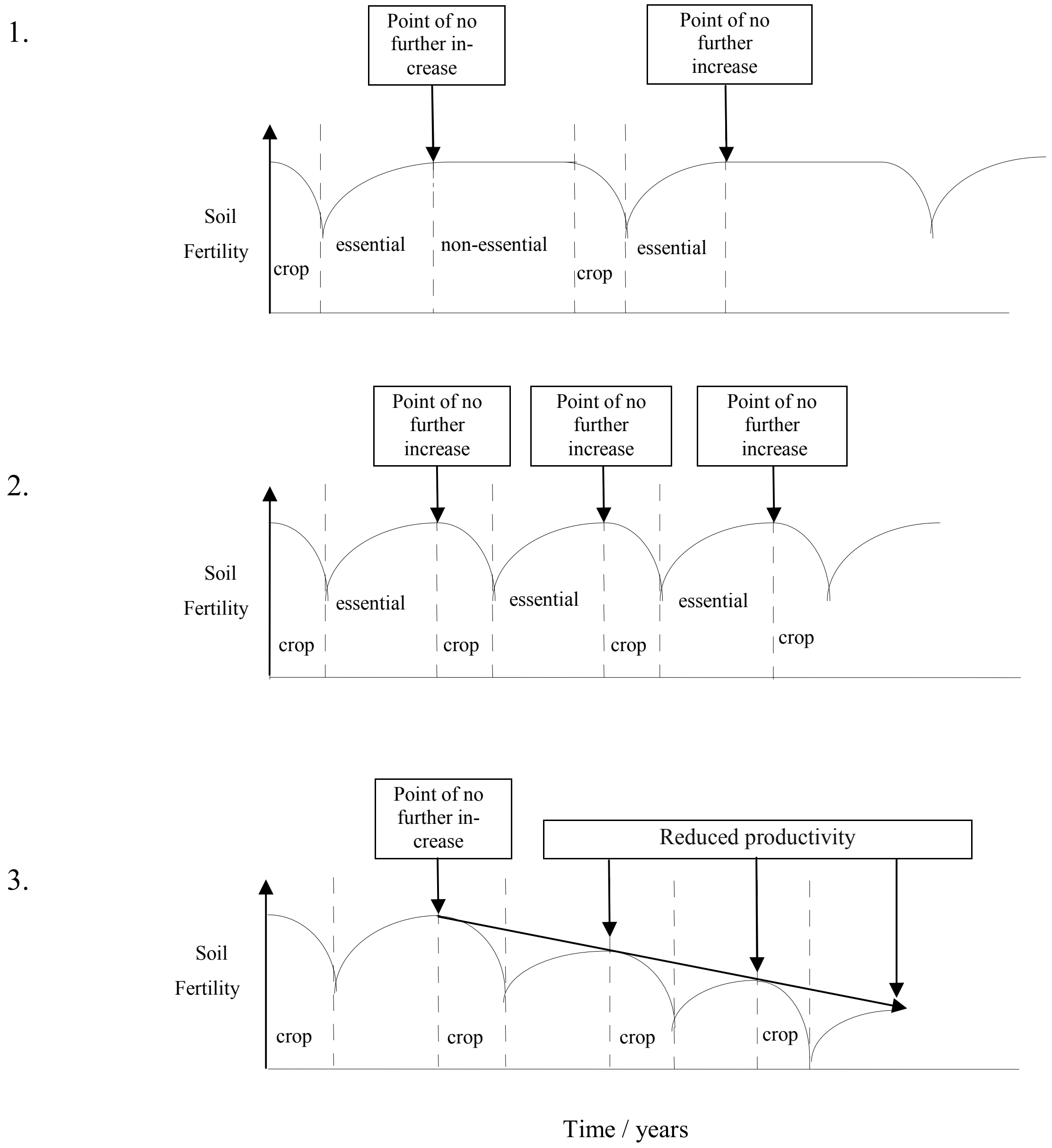

Figure 1.1: Hypothetical relationship between fallow length and soil fertility at different cropping frequencies. (1) cropping frequency low, permitting phases without additional fertility gains; (2) frequency exactly timed to match attainment of maximum fertility; (3) cropping frequency too high to attain maximum fertility (Hauser et al., 2006).

Unfortunately, as populations increase most farmers are forced to cultivate the same fields repeatedly, stripping the land of nutrients and resulting in lower yields and incomes (Fleshman, 2006; Hauser, 2007; Hauser et al., 2008). Their lands are no more in a stable fallow/cropping sequence (scenario 1 or 2 Figure 1.1). Yields decline, and biotic stresses such as weeds pests and diseases increase. The rapidly declining crop yields observed lead to, where still possible, the rapid conversion of forest land into agricultural land to keep pace with the demand for food. This caused that Africa had the second largest net loss of forests (after South America) between 2000 and 2010—about 3.4 million hectares (FAO, 2010).

1.2 Cameroon: Agro-ecological zones and management

The Republic of Cameroon is located between latitudes 1° to 14° N of the equator and longitudes 8° to 16° E of the Greenwich (Figure 1.2). It covers an area of about 475,440 km^2 (total land area being 472,710 km^2 and water being 2,730 km^2), with a population of about 20 million and the population growth rate is about 2.1% per year (CIA, 2012). Among the 20 million habitants, 41 % are between the age 0-14 years, 56 % between 15-64 years and 3 % above 65 years (CIA, 2012). Arable land account for 13 %, land permanently occupied by crops for 3 % while irrigated land covers an area of 0.06% (CIA, 2012). Natural forests cover about 42 % of land area (FAO, 2010a). Cameroon has five major agro-ecological zones:

1.2.1 The Sahelo-Sudanian savannah

The mean annual temperature of the Sahelo-Sudanian savannah is 28 °C, while average rainfall is between 500-1200 mm yr^{-1} (Figure 1.2; IRAD, 2009). "The soils are ferruginous, with little Fe found in the exchange complex so they are grey to brown. They have base saturations around 70 %. They have higher amounts of weatherable minerals and thus more nutrient reserves than their ferralitic counterparts. The dominant clay minerals are phyllosilicate clays composed of smectites, vermiculites, chlorites, micas and kaolinites" (Pamo, 2008). There is also a wide variety of young soils (Vertisols, Leptosols, Regosols, etc.) in this zone (Pamo, 2008). Main food crops are sorghum (*Sorghum bicolor* L.), maize (*Zea mays* L.), rice (*Oryza sativa)* and groundnut (*Arachis hypogeae*), beans *(Phaseolus vulgaris)*, cowpea (*Vigna unguiculata*), onion *(Allium cepa* L.) and sweet potatoes (*Ipomoea batatas* L.) (Cameroun Agri-stat, 2009). Animal production mainly ruminants are the most widespread. They are reared in traditional systems: cattle, goat, sheep horses and donkeys production and management systems vary from free range (scavenging, nomadism and transhumance) in less populated areas, to year-round confinement and cut-and-carry feeding in densely populated areas (Les editions du jaguar, 2000; Pamo, 2008).

1.2.2 The high Guinean savanna

The high Guinean savanna (Figure 1.2) has rainfall between 1200-1600 mm yr^{-1} (IRAD, 2009). They are sparsely populated. The soils are ferruginous as in the sahelo-sudanian savanna zone, although, plinthite which often hardens into an indurated crust, occurs (Pamo, 2008). The main food crops are maize, groundnut, egusi melon (*Cucumeropsis mannii*), yams (*Dioscorea* spp.) and sweet potatoes (Cameroun Agri-stat, 2009). Animal production is still mainly ruminants, but with more horses and donkeys. The rearing systems are similar to that of the previous agro-ecological zone. But the production and management systems vary from free range in less populated areas, to modern livestock farms and ranches (Les editions du jaguar, 2000).

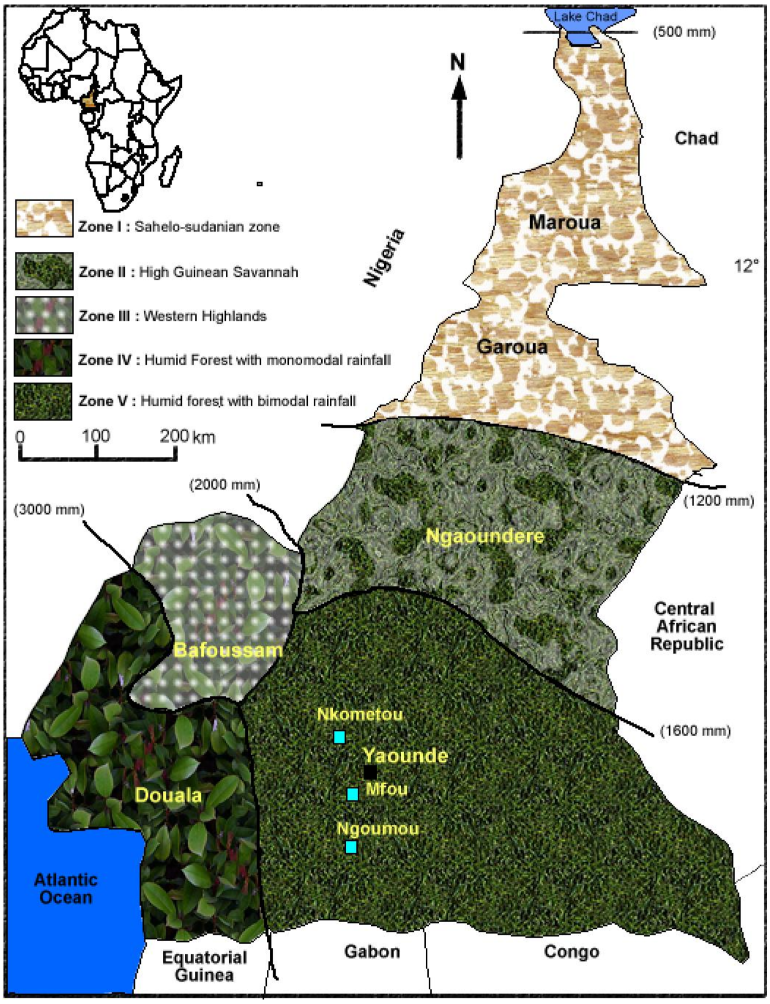

Figure 1.2: Map of Cameroon displaying the 5 agro-ecological zones (IRAD, 2009) and location of the three villages (Nkometou, Mfou and Ngoumou) where experiments of the present study were conducted.

1.2.3 The mountain zone or Western Highlands

The mountain zone (or Western Highlands, Figure 1.2) has a rainfall of 2000-3000 mm yr^{-1} and the annual mean temperature is 21 °C (IRAD, 2009) featuring many high plateaux (1000-1800 m asl), very high altitude mountains (e.g. Mount Oku, 3,011 m above sea level) and very high population density (more than 300 inhabitants/km² in many areas). This region covers only 6% of Cameroon's total surface area but contains 30% of Cameroon's total population. Main food crops are oil palm (*Elaeis guineensis*), maize, cocoyams (*Xanthosoma sagittifolium*), plantains (*Musa* spp.), rice, okra (*Abelmoschus esculentus*), potatoes (*Ipomoea batatas* L. or *Solanum tuberosum* L.), groundnut, beans, tomato (*Solanum lycopersicum* L.) and yams (Cameroun Agri-stat, 2009). Animal production is mainly cattle and pigs reared either in traditional systems or modern livestock farm and ranches (Les editions du jaguar, 2000).

1.2.4 The humid forest with monomodal rainfall

The humid forest with monomodal high rainfall above 3000 and up to 10,000 mm yr^{-1} (Figure 1.2) is localized in the coastal lowlands (IRAD, 2009). The soils are classified as Ferralsols and occur in association with Alisols, Nitisols and Acrisols which have clay accumulation horizons but low base saturation (Ngakanou, 1987). Main food crops are oil palm, plantains, maize, groundnut, egusi melon, cassava (*Manihot esculenta* Crantz), cocoyams, sweet potatoes and yams (Cameroun Agri-stat, 2009). Animal production is mainly small scale livestock farming: goats and sheep for domestic use and with some major poultry-breeding areas (Les editions du jaguar, 2000). Cattle rearing are difficult because of the risk of trypanosomiasis, with the exception of the resistant N'Dama race. However, a vaccine against trypanosomiasis is being used.

1.2.5 The humid forest with bimodal rainfall

The humid forest with bimodal rainfall (figure 1.2), made up of a vast low altitude plain (mean altitude is 650 m asl) is primarily characterised by forest vegetation and abundant precipitations between 1600-2000 mm yr^{-1} mean annual temperature is 25 °C (IRAD, 2009). These soils are Ferralsols as in the previous agro-ecological zone, but they are red soils with a base saturation of 20-40 % (Pamo, 2008). Main food crops are cassava, plantains, groundnut, egusi melon, oil palm, maize, cocoyams, tomato and yams (Cameroun Agri-stat, 2009). Animal production is mainly small scale livestock farming: goats and sheep for domestic use and with some major poultry-breeding areas (Les editions du jaguar, 2000). Cattle's rearing is in a situation similar to the previous agro-ecological zone.

The present study was conducted in this last agro-ecological zone that is in the humid forest with bimodal rainfall. In this southern Cameroon area, slash and burn is used to establish most of the fields. The average farm size of smallholder farmers is around 0.25 ha, the sufficiency of area for slashes and burn is not enough for every family; otherwise says, with demographic growth, some families are already in shortage of land. Moreover, with slash and burn, there is also the heavy financial cost to convert dense rain forest to agricultural lands and the constraint for farmers who always have to go further (by foot or trekking) from their homes. The most common field types are:

- the traditional mixed food crop field, cleared from 2 to 7 years old bush fallow and planted to an intercrop of groundnut, maize and cassava, often with some plantains (*Musa* spp.) and a certain number of minor crops. This system is mostly established and managed by women. The harvest is more for home consumption while the exceeding can be sold.

- the forest field, cleared from mature secondary or primary forest for monocrops of cacao (*Theobroma cacao*), oil palm but dominantly for plantain intercropped with a egusi melon and today often cassava or cocoyam. The forest field are mainly established and managed by men and the harvest is more market oriented.

- Horticultural fields with monocrops of tomatoes, okra, pineapple (*Ananas comosus*), hot pepper (*Capsicum* sp.), watermelon (*Citrullus lanatus*) or maize. (Mutsaers et al., 1981a,b; Büttner, 1996; Wendt, 2002; Wendt and Atemkeng, 2004 and personal observations).

Slash and mulch systems that is clearing (slashing) plots from the forest, planting crops in the resulting mulch before or after the slashing, and, rather than burning, using the decomposing mulch as a source of nutrients (Hauser and Mekoa, 2009), are rare and currently in the experimental or extension phase.

1.3 Attempts to improve crop yields in the humid tropics and associated constraints

In terms of food security in Cameroon, 17 kg of vegetable, and 19 kg of fruits are consumed per capita yr^{-1}, figures far below the standards recommended for a balanced diet (Temple, 2001). Attempts have been undertaken over the last years to find technologies that could improve yields. New technologies were tested, among others: (i) land/rain and runoff waters management, (ii) mechanisation, (iii) soil fertility improvement, and (iv) crop improvement (Matlon and Spencer, 1984).

1.3.1 Improved land/rain and runoff waters management

The objectives of improved land/rain and runoff waters management methods are to protect the soil base over the long-term while at the same time providing an immediate boost to yields (Matlon and Spencer, 1984). For instance, *Pueraria* as a live soil cover legume will reduce the splash effect on soil of rain drops, and also protect the soil from the selective loss of fine particles and nutrients and organic matter through sheet erosion (Roose, 1977), while favouring biological nitrogen fixation, weed and nematodes control and the improvement of soil structure, thus increasing crop yields.

1.3.2 Soil fertility improvement

An estimated 8 million tonnes of nutrients are depleted annually by African agriculture (Fleshman, 2006). Cobo et al. (2010), from a review of approaches on nutrient balances in African land use systems across different spatial scales found data confirming this trend of negative balances in the continent; for nitrogen and potassium for instance, more than 75% of selected studies had mean values below zero. Replenishing nitrogen, potassium, phosphorus and other minerals absorbed by plants and subsequently exported in harvest produce is therefore vital to keep crop yields from declining (Fleshman, 2006). The use of fertilizer to compensate for nutrient export by crops and for low nutrient content of highly weathered and leached soils has been tested in West, East and Southern Africa and yield increases have been reported (Hauser and Nolte, 2002; Bationo et al., 2006; Fleshman, 2006; Chabi-Olaye et al., 2008). However, positive effects of fertilizer do not seem to be the general rule in the humid tropics. In fact, survey data frequently indicate a tremendously variable contribution of fertilizer to food grain yields across farms even within the same village (Nyoro et al., 2004). Kamprath (1972) cited by Baligar and Bennett (1986) working on Ultisols and Oxisols, found that the largest proportion of applied P was fixed by clay fractions dominated by amorphous hydrated oxides of iron and aluminium and in addition, these acid soils have low cations exchange capacity (CEC), rendering added nutrients prone to the risk of leaching. Nonetheless, the cost of mineral fertilizers is somewhat high for farmers, some of who pay the highest fertilizer prices in the world, e.g. \$800 ton^{-1} of urea in Central Cameroon versus \$90 ton^{-1} in Europe. African farmers use fertilizer at only 10 kg ha^{-1}, whereas European farmers use over 200 kg ha^{-1} (Conway and Toenniessen, 2003). Above all, considerable efforts need to be devoted by research to improve nutrients use efficiency by crops. The integration of some leguminous species could also be a potential route for soil fertility improvement in the humid tropics. In fact, the integration of leguminous species can have positive effects on crop yields and soil properties especially in intensive cropping systems (Hulugalle and Kang 1990; Mapa and Gunasena 1995; Kang et al., 1995; Banful et al. 2000).

1.3.3 Mechanical tillage

Manual tillage as commonly practiced in the humid tropics of SSA as compared with no-till systems is highly labour-demanding, and thus has a strong impact on productivity in this labour-constrained environment. Mechanical tillage has the advantage of cultivating larger area with lower labour demand. But within the humid-tropics, tse-tse fly infestation and the abundance of tree and shrub stumps had limited the development of animal based systems, furthermore, mechanization schemes based on the use of tractors have met with limited success because of high capital costs relative to the capital resources and scale of operation of farmers, as well as the lack of know-how in equipment use and maintenance (Matlon and Spencer, 1984; personal observation). Nevertheless, farmers in the humid savanna area are increasingly adopting mechanical tillage, here, entrepreneurs may own a tractor and better-off farmers hire tractors by the day. However, the ownership and use of tractors, in the humid southern Cameroon for instance, is rare. This is because in the southern Cameroon humid areas where field sizes are small, forest regrowth and tree and shrub stumps render their movement difficult. Thus, adoption of mechanical tillage tends to be slower in forested areas. Furthermore, the effects of tillage on crop yield and soil properties seem not to be consistent across crop species and soil types. For example, Couper et al. (1979), working on an Alfisol in the forest-savannah transition zone of south west Nigeria, found that maize grain yields were three times higher on no-till than on tractor-tilled plots for six consecutive years. Wanas (2006), on the contrary, found maize grain yield increased after tillage compared with no-tillage. Furthermore, tillage is likely to lead to soil surface roughness. Depending on its frequency and kind, tillage can destroy soil aggregates and result in degradation of soil structure, with immediate consequences on the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Mamman and Ohu (1997) observed a regular increase in soil bulk density and penetrometer resistance and a reduction in air permeability as tractor usage increased.

1.3.4 Crop improvement

For crop yield increase per unit of cultivated land, it may be crucial to apply more soil nutrients and to till the soil. But improved land /rain and runoff waters management, increased application of fertilizer and tillage alone, may not be sufficient. In fact, it has been demonstrated by Otsuka and Yamano (2005) that in fields where similar land preparation has been applied, improved crop varieties were higher-yielding and more yield responsive to increase fertilizer application than traditional crop varieties. Improved crop varieties could also be more resistant to devastating diseases and tolerant to nutrient-poor soils (Conway and Toenniessen, 2003).

1.4 Soil physical properties: Importance and management

Soil physic seeks to define, measure, and predict the physical properties and behaviour of the soil, both in its natural state and under the influence of human activity (Elsevier, undated). Among soil physical properties, one distinguishes: horizonation, soil colour, texture, bulk density, porosity, soil structure, soil consistence, moisture content, water retention, temperature, infiltration, saturated and unsaturated hydraulic conductivity, penetration resistance.

1.4.1 Soil texture

Soil texture is the relative proportions of sand, silt and clay and also includes particles larger than sand in a soil. These proportions describe the classes of soil texture with a textural triangle. Soil texture can be determined by Robinson pipette method (Aubert et al., 1954) or as in the present study, by hydrometer method (Gee et Bauder, 1986). It has a large influence on water holding capacity (Pidgeon, 1972; Bouma et al., 2003), water conducting ability, soil structure (Tueche et al., 2007), chemical soil properties and the relative stabilisation of soil organic matter (Parton et al., 1987; Six et al., 2002 a and b; Bot and Benites, 2005). Moreover, the proportions of sand, silt and clay can significantly correlate diversely with crop yield (Lal, 1997, Tueche et al., 2013).

1.4.2 Bulk density and soil cone penetrometer

Bulk density is an indicator of the amount of pore space available within individual soil layers or horizons, as it is inversely proportional to pore space. A high bulk density above 1.5 (Nyobe, 1998; Adekiya and Ojeniyi, 2002; Adekiya et al., 2009) indicates either compaction of the soil or high sand content.

The cone penetrometer is useful in determining soil strength and various level of soil compaction. Measurements can be done *in situ* with the static hand penetrometer Eijkelkamp type. Soil compaction can be induced by natural processes (as rain drops impact) and by field traffic of humans, animals and heavy machinery: Mamman and Ohu (1997) observed a regular increase in soil bulk density and penetrometer resistance and a reduction in air permeability as tractor usage increased. Excessive soil compaction can impede root growth and therefore limits the amount of soil explored by roots thus reducing the plant’s ability to take up nutrients and water (Figure 1.3). Lipiec et al. (1991) found a sharp decreased in crop yield and leaf area index (LAI) when the degree of compactness exceeded values of ~ 91 and 88%, respectively. Note that the degree of compactness or relative compaction is the percent of the ratio between the actual bulk density (ρd) and a reference bulk density (ρdr) or maximum dry bulk density (that is the densest state obtainable by a static pressure of 200 kPa in the uniaxial compression test (Hakansson, 1990) or by the Proctor test (Carter, 1990; Twedorff et al., 1999), and in these two tests are used disturbed samples, for the particular soil: $D=100*\rho d/ \rho dr$)

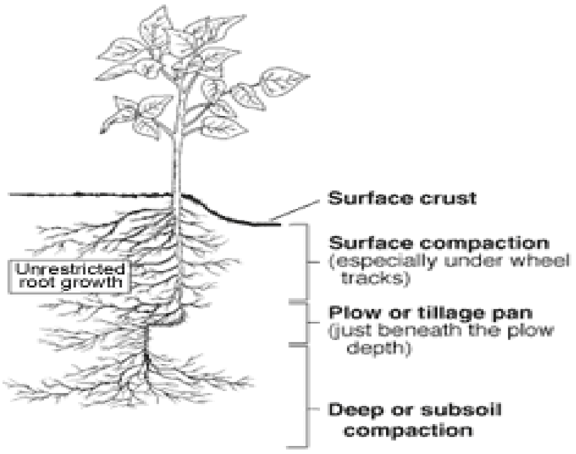

Figure 1.3: Reduced root growth due to soil compaction. (Source: University of Minnesota Extension publication number WW-03115 2001)

1.4.3 Soil structure

Soil structure is the way individual particles of sand, silt, and clay are assembled into larger units called aggregates (FAO, undated). It is caused by the adhesion of those particles by various binding agents which influence soil structure development: amount and type of clay, as well as the exchangeable ions on the clay (Tisdall and Oades 1982; Oades and Water, 1991; Six et al., 2000); amount and type of organic matter, (Tisdall and Oades 1982; Elliott, 1986; Oades and Water, 1991; Six et al., 2000); presence of iron and aluminium oxides (Tisdall and Oades 1982); binding between organic and inorganic compounds (aluminium oxides, cations, clays), e.g. polyvalent cations such as Ca^{2+}, Mg^{2+} and Al^{3+};plants roots, bacteria and fungi exude sticky polysaccharides that bind soil into small aggregates (Tisdall and Oades 1982; Oades and Water, 1991; Tisdall, 1994; Angers and Caron, 1998). The addition of the raw organic matter that bacteria and fungi feed upon favours the formation of desirable soil structure. The destruction of soil structure during land preparation or soil faunal activity decomposing SOM or both, may improve the availability of nutrients to crops. However, aggregation builds intra-aggregate and inter-aggregate pore space which control water, gases, solutes and pollutants movements in the soil. Thus, soil structure can affect aeration, soil compaction, water relations, soil temperature, resistance to erosion and plant root growth.

1.4.4 Temperature

Soil temperature is one of the most important growth factors of plants, along with water, oxygen or plant nutrients. Soil temperature is also a key factor controlling soil biological activity, the decomposition of soil organic matter and soil nutrient availability (Parton et al., 1987; Kirschbaum, 1995; Bot and Benites, 2005). Odjugo (2008) and Ujuanbi (2002) working in Nigeria found that soil temperature was a predictor variable, which determines cassava emergence, growth and yield. Soil temperature can be significantly influenced by cropping practices (Lal, 1974a; 1974b; Ojeniyi, 1986; Nyobe, 1998; Odjugo, 2008); soil water content (McInnes, 2002; Flerchinger, 2002); fallow types: Tueche et al., (unpublished) have found significant soil temperature differences between forest fallow, *Chromolaena odorata* fallow and *Imperata cylindri*ca fallow in a close vicinity.

1.4.5 Soil moisture and water retention

Soil water content or moisture content is the quantity of water contained in a soil material, which can range from 0 (completely dry) to the value of the materials' porosity at saturation. They can be determined in laboratory with soil moisture equipments or in the field with time-domain reflectometry (TDR), hygrometer or a neutron probe. Soil water content is given on a volumetric or mass (gravimetric) basis. Soil moisture content can be improved by 1 to 10 g for every 1 g increase in soil organic matter (SOM) content (Emerson, 1995). The increase may be small, but it may suffice to help maintain crop growth between periods of rainfall of 5 to 10 days (Emerson, 1995). Near or slightly wetter than field capacity moisture conditions are most favourable for both processes. Soil moisture can positively impact LAI and crop yield while it can negatively affected crop emergence (Odjugo, 2008).

1.5 Justification of the choice of plantain, tomato and maize for this study

Information is scarce on the effects of soil physical properties on plantain, maize and tomato yield formation and on their changes during their cropping phase. However, it is known that the behaviour of soil physical properties can be somewhat different during cropping periods or during fallow periods. During cropping periods, clay content and aggregate stability decrease, whereas sand content, bulk density and the resistance to soil penetration increase. During fallow periods, clay content and aggregate stability tend to increase, whereas bulk density declines (Nyobe, 1998; Nounamo et al., 2002; Yemefack et al., 2002, 2004; Chirwan et al., 2004). Nevertheless, increases in clay content during fallow periods usually do not attain the value obtained in virgin forest, even after long fallow (Yemefack et al., 2004).

In West and Central Africa, around 70 million people derive more than 25% of the carbohydrates and 10% of their food energy from plantains (Ortiz and Vuylsteke, 1996; Robinson, 1996). In southern Cameroon, plantain cultivation is carried out after clearing primary or secondary forest, thus drawing heavily on the natural resource base and threatening biodiversity. Many smallholder farmers are already facing a shortage of forest land and would need to produce after short fallow periods. However, this is not an accepted system in Cameroon. There is no information on the reasons for not planting plantain in young fallow but research shows that yields after forest are higher than in short fallow (Hauser et al., 2008). Plantain yields decrease sharply after the harvest of the first plant crop (Hauser, 2007; Hauser et al., 2008). There is a need to develop suitable and profitable plantain production systems that, not only allow plantain to grow efficiently in young fallow, but also sustain yields long after the harvest of the first plant crop, or, at least to find solutions for the usual fallowing of plantain field just after 2 to 3 years cropping, for example by cropping maize immediately after plantain.

Tomato and maize, not as plantain, are commonly grown after natural bush fallow slashed, burned. Tomato and maize are the most important horticultural crop in southern Cameroon (Gockowski and Ndoumbé, 2004). And across Africa the production of high value horticultural crops is being recognized as a possible route out of rural poverty. For example, in Kenya, cultivating kale, tomatoes, and onions increased net profits of smallholders from US$ 91 to US$ 1665 ha^{-1} year^{-1} (Sanchez et al., 2001). In Cameroon, maize production, particularly in the vicinity of cities, is increasingly market-orientated, and is marketed and consumed as fresh cobs rather than dry grain.

1.6 Hypotheses

The main hypotheses addressed in this thesis were:

1. The conversion of fallow lands (forest or bush fallow) to farmland would go together with a change in soil physical properties and the degradation of soil properties,
2. the extend of the changes would be a function of the fallow ages (bush or forest), the cropping systems and the cropping practices (uprooting tree stumps or not; no-tillage, hand or tractor tillage; mineral fertilization or not),
3. the state of the soil physical properties thus will change, and will adversely affect crop yield enabling the identification of improved management strategies,
4. for a given soil physical state and within the same cropping season, diseases incidence and yield will be the same for different varieties,
5. the effect of soil physical properties on crop yield observed for a given crop during the first cropping season will be the same as for a different crop for subsequent seasons.

1.7 Objectives

The general objective of this study was to understand the relationships between soil physical properties and crop yields in different cropping systems in southern Cameroon with the goal to identify improved management strategies.

The specific objectives were to:

a) Understand how different plantain cropping systems affect soil physical properties and plantain bunch yield,

b) evaluate if maize yield and soil physical properties will be affected by previous plantain cropping systems, or by tillage and nitrogen application,

c) assess how land preparation at different levels of intensification and varietal impacts influence tomato production,

d) estimate the residual effects of these previous land preparation methods on maize growth and soil physical properties.

1.8 Outline of the study

This study is based on three published papers (Chapters 2, 3 and 4), and a fourth paper in preparation (Chapter 5). Chapter 1 contextualizes this thesis, introduces the study area and briefly describes the techniques used to adress the objectives of this thesis. Chapter 2 describes the changes of physical properties of soil under plantain cultivation as well as yield plantain fresh bunch yield from different cropping systems, fallow ages in three southern Cameroon villages. Chapter 3 evaluates if cropping maize immediately after plantain is affected by the previous plantain systems and if tillage or N fertilizer would affect maize growth and affect maize growth and grain yield and soil physical properties. Chapter 4 determines how various level of land preparation's intensification affect soil physical properties and at which level of intensification tomato yields were maximized and which tomato cultivar responds best to intensification. Chapter 5 assesses any residual effects of land preparation on maize growth, yield and yield components as well as medium term impacts on soil physical properties. The thesis continues with a general discussion and conclusion in Chapter 6. Summary (in English and German) is found in Chapter 7. All references used in this work are listed in Chapter 8. Appendixes (i.e. abstracts of additional articles published during the doctoral time frame, courses followed), and the C*urriculum Vitae* of the author complete the thesis.

Chapter 2

Influence of different cropping systems on soil physical properties and plantain bunch yield

2. Influence of different cropping systems on soil physical properties and plantain bunch yield[1]

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2.1 Abstract

Information on the effects of soil physical properties on plantain yield is rare. A factorial trial was conducted in three southern Cameroonian villages comparing four cropping systems comprising two planted legumes (1) *Flemingia macrophylla*, (2) *Pueraria phaseoloides,* a crop (3) hot pepper and (4) natural regrowth, all planted to plantain established after conversion of old forest versus young bush fallow. Initially bush fallow had significantly higher sand content, Mean Weight Diameter (MWD), and proportion of macroaggregates, but lower clay content, proportions of mesoaggregates and microaggregates than forest soil. Between 2002 and 2006, clay and silt content, MWD, geometric mean diameter and the proportion of macroaggregates increased, whereas relative sand content, bulk density, the proportions of mesoaggregates and microaggregates decreased in all villages, fallows and cropping systems. Changes of aggregate stability parameters were larger in forest than in bush fallow at Ngoumou and Mfou, and larger in the *F. macrophylla* and natural regrowth systems than in the pepper and pueraria systems. In Ngoumou and Nkometou available water capacity increased. Plantain fresh bunch yield was unaf-

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fected by village, fallow, and cropping systems and was not correlated with soil physical properties or their changes.

Keywords

Flemingia macrophylla, fresh bunch yield, plantain, *Pueraria phaseoloides*, soil physical properties.

2.2 Introduction

Plantains and bananas are a major part of the diet of 100 million people in Africa (Schinzl, 2003). In southern Cameroon, plantain is the most important food cash crop and is a favored staple, with income demand elasticity near one (Temple et al., 1996). Plantain yields are around 5 t/ha in West and Central Africa (CTA, 2001) and decline sharply after the harvest of the first plant crop (Hauser, 2007; Hauser et al., 2008). The low and declining yields are attributed to complete reliance on traditional practices, the lack of plant protection methods and absence of knowledge on improved production methods (CTA, 2001). Consequently, plantain yields have not changed significantly in recent years (1968-1998) (Sharrock and Frison, 1999). The increases in total plantain production in the past were exclusively due to an expansion of the cropped area (Sharrock and Frison, 1999). Plantain cultivation is based on clearing primary or secondary forest in slash and burn systems, thus drawing heavily on the natural resource base and threatening biodiversity. Many smallholder farmers are already facing a shortage of forest land and would need to produce after short fallow periods. However this is not an accepted system in Cameroon. There is no information on the reasons for not planting plantain after young fallows, yet Hauser et al. (2008) have shown a significant yield advantage of planting plantain after forest clearing versus short fallow. Soil nutrient concentrations were not correlated with bunch yields (Hauser, 2007; Hauser et al., 2008), thus chemical properties did not explain yield differences.

Information is scarce on the effects of soil physical properties on plantain yield formation and on their changes during the plantain cropping phase. Soil physical properties play a key role in soil sustainability and crop production (Amezketa, 1998). They determine how easily plant roots can grow to access soil nutrients, and how easily water can flow through the soil to deliver these nutrients (Baver et al., 1972; Augustin et al., 1995; Patzek and Pimentel, 2005). When soil physical properties degrade, for instance through compaction due to intensive cropping, they will restrict rooting depth and reduce root elongation and disposition, which in turn, will limit water and nutrient uptake and consequently crop growth and yield (Kooistra et al., 1992; Montagu et al., 2001; Clark et al., 2003). During cropping periods, clay content and aggregate stability decrease, while sand content, bulk density and the resistance to soil penetration increase. During fallow periods, clay content and aggregate stability tend to increase, while bulk density declines (Nyobe 1998; Nounamo et al., 2002; Yemefack et al., 2002, 2004; Chirwan et al., 2004). Nevertheless, increases of clay content during fallow periods usually do not attain the value obtained in virgin forest even after long fallow (Yemefack et al., 2004). Recent research has demonstrated the capacity of some leguminous species, to maintain and improve soil physical properties even in intensive cropping systems. Application of tree prunings improved various soil physical properties (Hulugalle and Kang, 1990; Mapa and Gunasena 1995; Banful et al., 2000). Thus integration of leguminous species may have positive effects on soil physical properties and on plantain yields. Only two references from Africa report on legumes' effects on plantain (Yao, 1998; Banful et al., 2000), yet, none reports soil physical properties in relation to plantain yields.

In an attempt to develop suitable and profitable plantain production systems that may allow to grow plantain in young fallow a factorial trial was set up in three southern Cameroonian villages to determine (1) the effects of fallow age (young bush versus forest), (2) the presence of an intercrop (hot pepper) versus cover crops (*Flemingia macrophylla* or *Pueraria phaseoloides*) or natural regrowth and (3) the sanitation of the plantain planting material on plantain fresh bunch yield (whereby the latter is not subject of this paper).

The objectives of this study were to determine the status of soil physical properties in the different fallow ages, the changes of soil physical properties under plantain cropping in response to the different cropping systems and the impact of soil properties and their changes on plantain fresh bunch yield.

The working hypotheses were: (1) under plantain cropping clay and silt content, aggregate stability and water holding capacity will decrease, (2) sand contend and bulk density will increase, (3) plantain bunch yield is correlated with soil physical properties or with their changes and (4) fallow age and cropping system have no effect on the changes of soil physical properties and their relationship with bunch yields.

2.3 Materials and Methods

2.3.1 Study area

The study was carried out in three villages in Southern Cameroon: Mfou (3° 57'N, 11° 48'E), Nkometou (4° 05'N, 11° 33'E) and Ngoumou (3° 41'N, 11° 25'E). Each village is located in an area representative of a certain range of deforestation and land use intensity (Nolte et al., 2001). The soil at Mfou and Ngoumou are classified as clayey, kaolinitic, Typic Kandiudult (Hulugalle and Ndi, 1993); at Nkometou the soil is an Ultisols, Rhodic Kandiudult (Champetier de Ribes and Aubague, 1956, quoted in Koutika et al., 2008). Annual mean maximum air temperature ranges from 29.6 to 31.9 °C and the mean minimum air temperature from 21.2 to 23.5 °C. All sites have a bimodal rainfall distribution. The major dry season starts in mid-November and lasts through February–March. The total annual rainfall in the three villages over 3 years (2002 to 2004) ranged from 1213 to 1934 mm (Table 2.1).

Table 2.1: Annual rainfall (mm) in three villages in southern Cameroon during the plantain growing phase.

	Annual rainfall (mm)		
	2002	2003	2004
Nkometou	1216	1226	1213
Mfou	1449	1534	1543
Ngoumou	1570	1651	1934

2.3.2 Experimental layout

In each village, experiments were laid out in two land use systems (LUS): 4–5 year-old natural bush fallow dominated by *Chromolaena odorata* (L.) R. M. King & H. Rob., and more than 20 year-old secondary forest. Bush and forest sites were slashed and burned between January and March 2002 depending on local conditions. In each village, the experimental layout was a 2 × 4 factorial complete block design with three replications. The first factor (non-randomized) was the land use system at two levels: forest versus bush fallow. The second factor was the cropping systems at four levels: (1) Plantain + *Flemingia macrophylla* alley cropping, (2) Plantain + *Pueraria phaseoloides* cover cropping, (3) Plantain + cropping in natural regrowth and (4) Plantain + intercropping with hot pepper. In each system, the local plantain (cultivar Essong), used for this trial was treated with boiling water according to Hauser (2007) before planting.

Plots measured 15 × 12 m in the bush fallow and 15 × 6 m in the forest. *Flemingia macrophylla* was seeded in rows to form hedges by drilling grains at a rate of 4 kg ha^{-1} in five rows of 3 m distance between rows in early June, 2002 at Nkometou, mid-June at Mfou and late June at Ngoumou. *Pueraria phaseoloides* was seeded by drilling 12 kg ha^{-1} of grains in four double rows spaced 1 m between two rows and 2 m between adjacent double rows in early June 2002 at Nkometou, mid-June at Mfou and late June at Ngoumou. Seedlings of hot pepper were planted in late June, 2002, early and mid July, 2002 at Mfou, Nkometou and Ngoumou respectively at 1 m × 1 m spacing.

Plantain planting holes of 0.3 × 0.3 × 0.3 m, spaced at 3 × 2 m (1667 plants ha^{-1}), equivalent to 30 plants $plot^{-1}$ in the bush fallow and 15 plants $plot^{-1}$ in the forest were planted at Mfou and Nkometou in the month May 2003 and June 2003 at Ngoumou.

During the plantain cropping phase, *Flemingia* hedges were pruned to about 0.3 m above soil level. The prunings were applied as mulch around the plantains. Plantain + pueraria and Plantain + natural regrowth plots were slashed to soil level during the plantain cropping phase four times a year, the slash remained in the plots. Plantain in the pueraria plots were ring weeded at 0.5 m radius, to prevent the pueraria from climbing. Plantain + pepper plots were hand weeded when deemed necessary.

2.3.3 Determinations of soil physical properties

Before slash and burn, 18 soil samples were collected from each, at that time still undisturbed plot per depth at 0-5 cm and 5-10 cm with a 100 cm^3 cylinder. In February 2006, 16 samples were collected per depth at 0-5 cm and 5-10 cm at the Mfou bush fallow site. All other sites were sampled in the same manner in late December 2006.

Bulk density was determined according to Blake and Hartge (1986). The soil particle-size distribution was determined for each sample using hydrometer method according to Gee and Bauder (1986), from which the soil textural classes were obtained. Aggregate stability was determined according to Angers and Mehuys (1993) using 4.0, 2.0, 1.0, 0.25, and 0.125 mm sieves that were then placed in a wet-sieving apparatus, similar to that described by Kemper and Rosenau (1986). The proportion of water stable aggregates (WSA_i) in each of the size fractions was calculated from the formula:

$$\mathbf{WSA_i} = (w2_i - w3_i)/(w1/(1 + wc) - \sum w3_i) \quad \ldots\ldots\ldots (1)$$

where i = 1, 2, 3, …, n-1, n and corresponds to each fraction in each sample;

wc is the gravimetric water content;

w1 is the weight of the air dried soil that had passed through a 10 mm sieve;

$w2_i$ is the weight of the aggregates on each sieve of the nest, dried at 105°C;

$w3_i$ is the weight of primary particles dried at 105 °C collected from 0.053 mm sieve.

The mean weight diameter (MWD) used to express the size distribution was then determined as:

$$\mathbf{MWD} = \sum_{i=1}^{n} X_i\, WSA_i \quad \ldots\ldots\ldots (2)$$

Where i = 1, 2, 3, …., n and corresponds to each fraction collected, including the one that passes the finest sieve. $\mathbf{X_i}$ is the mean diameter of each size fraction (i.e., mean inter-sieve size); and

WSA_i is as defined in (Eq.1).

The geometric mean diameter (GMD) was calculated after Mazurak (1950) as:

GMD = $\exp [\sum^{n}_{i=1} WSA_i \log X_i / \sum^{n}_{i=1} WSA_i]$……………………………..……….…….(3)

The proportion of soil macroaggregates, mesoaggregates and microaggregates were determined as:

Soil macroaggregates = ∑proportions of water stable aggregates > 2mm…………………..(4)
i.e. all aggregates on the 4 and 2 mm sieves;

Soil mesoaggregates = ∑proportions of water stable aggregates in the <2mm and > 0.25mm (5)
i.e all aggregates on the 1 and 0.25 mm sieves;

Soil microaggregates = ∑proportions of water stable aggregates < 0.25 mm…………….(6)
i.e. all aggregates on the 0.125 mm sieves and below (0-0.125 mm).

Saturated soil samples were subjected to different external gas pressures (-0.01 and –1.50 MPa) on pressure plate and moisture content determined by oven drying. Moisture contents obtained at field capacity (ψ=-0.01 MPa) and at wilting point (ψ=-1.50 MPa) were used to calculate the available water capacity (AWC) (Cassel and Nielsen 1986).

The values for the 0-10 cm soil layer were obtained from the mean of 0-5 cm and 5-10 cm. The absolute changes were computed as the value in 2006 minus the value in 2002 except for Mfou-bush because the sampling was done in February (48 months after the first sampling) instead in December (58 months after the first sampling) as in the other villages. For more consistency, its values were extrapolated until December by calculating as follows:

Extrapolated value = 58 months × (value in February)/ 48 months …..……………..……….(7)

2.3.4 Plantain fresh bunch mass determination

Plantain bunches were harvested when deemed ready by the collaborating farmers. The peduncle was cut between the first and second empty bract above the first hand. Any remaining flower stalk without fruit fingers was removed. Total fresh bunch weight was determined with a balance of +/- 50 g resolution. The fresh bunch yield was calculated as the total bunch weight/plot over the total area of the plot, whereby non-producing plants were considered as not yielding (at value 0). Harvesting was terminated 854 days after planting.

2.3.5 Data analysis

Data were analysed using the General Linear Procedure "Proc GLM" in SAS version 9.1, (SAS, 2001). The Least-square Means/PDIFF option was used to determine levels of significance between pairs of treatment means. Data sets comprised 72 values (2 fallow ages, 4 cropping systems, 3 villages and 3 replicates) and were analysed as three factorial designs to check for interactions. Probabilities are indicated in text and tables up to the conventional level of significance ($P=0.05$). Correlations between bunch yield and soil physical properties were calculated on n=72 across all factors, n=36 when separated by fallow age and n=18 when separated by cropping system.

2.4 Results

2.4.1 Soil physical properties before planting

The soil physical properties before planting pepper legumes and plantains are presented in (Table 2.2). Soils were classified as sandy clay. Sand and silt contents were higher in the bush fallow than the forest. Clay content was accordingly higher in the forest than the bush fallow. Among the villages, Ngoumou had the highest clay content and Nkometou had the highest

(*P=0.002*) silt content. At Mfou sand content was highest (Table 2.2). Bulk density was the lowest at Mfou without a difference between forest and bush fallow. In the other villages BD was lower in the forest (Table 2.2). Aggregate stability, expressed as MWD, GMD and the proportion of soil macroaggregates was significantly ($P \leq 0.008$) higher in bush fallow than in forest fallow of all villages. Aggregate stability was lowest at Ngoumou. The proportion of soil mesoaggregates was highest ($P \leq 0.05$) at Ngoumou. Forest fallow had a greater ($P < 0.0001$) proportion of soil mesoaggregates than bush fallow. Available water capacity (AWC) was significantly higher ($P = 0.004$) in the forest soil at Mfou and Ngoumou than at Nkometou. At Mfou, AWC was significantly higher ($P = 0.0007$) in forest than in the bush fallow (Table 2.2).

2.4.2 Changes in soil physical properties

Between 2002 and 2006 clay and silt content increased in all villages, fallow ages and cropping systems without differences between factors. The village × cropping systems interaction was significant.

At Ngoumou, larger changes of sand ($P=0.04$) and clay ($P=0.03$) content were found in the natural regrowth system than in the pepper intercrop. At Nkometou, the changes in sand and clay content were lower in the plantain + *P. phaseoloides* than in the other cropping systems. No textural changes were found between cropping systems at Mfou (Figure 2.1).

Table 2.2: Initial sand, clay and silt content, bulk density, Mean Weight Diameter (MWD), Geometric Mean diameter (GMD), proportions of macro- meso- and microaggregates and available water capacity (AWC) of the 0-10 cm soil layer in three villages and two fallow ages.

	Village			
	Mfou	**Ngoumou**	**Nkometou**	***P (village)***
Sand content (%)				
Bush fallow	54.3a	49.6b	51.5b	0.03
Forest fallow	49.7	48.0	49.3	ns
P (fallow)	0.0007	ns	ns	
Silt content (%)				
Bush fallow	8.9b	8.6b	11.4a	<0.0001
Forest fallow	8.3b	7.9b	9.4a	0.002
P (fallow)	0.05	0.05	<0.0001	
Clay content (%)				
Bush fallow	36.8b	41.8a	37.1b	0.0002
Forest fallow	42.0ab	44.1a	41.3b	0.03
P (fallow)	<0.0001	ns	0.0009	
Bulk Density (Mg m^{-3})				
Bush fallow	1.04b	1.21a	1.16a	<0.0001
Forest fallow	1.04	1.06	1.08	ns
P (fallow)	ns	<0.0001	0.006	
MWD (mm)				
Bush fallow	4.45a	3.94b	4.66a	0.007
Forest fallow	3.69ab	3.38b	3.82a	0.02
P (fallow)	<0.0001	0.003	<0.0001	
GMD (mm)				
Bush fallow	1.50a	1.38b	1.56a	0.01
Forest fallow	1.32ab	1.26b	1.38a	0.01
P (fallow)	0.0003	0.008	0.0002	
Macroaggregates (%)				
Bush fallow	69.9a	59.8b	71.2a	0.0005
Forest fallow	57.3a	49.9b	56.7a	0.02
P (fallow)	<0.0001	0.0008	<0.0001	
Mesoaggregates (%)				
Bush fallow	18.3b	27.3a	18.2b	<0.0001
Forest fallow	27.9c	36.4a	32.2b	0.05
P (fallow)	<0.0001	<0.0001	<0.0001	
Microaggregates (%)				
Bush fallow	11.8	12.9	10.6	ns
Forest fallow	14.8a	13.7a	11.1b	0.04
P (fallow)	0.02	ns	ns	
AWC (Mg Mg^{-1})				
Bush fallow	0.15	0.16	0.15	ns
Forest fallow	0.17a	0.16a	0.14b	0.004
P (fallow)	0.0007	ns	ns	

ns, not significant; Within lines, values followed by different letters are significantly different at the indicated *P* value.

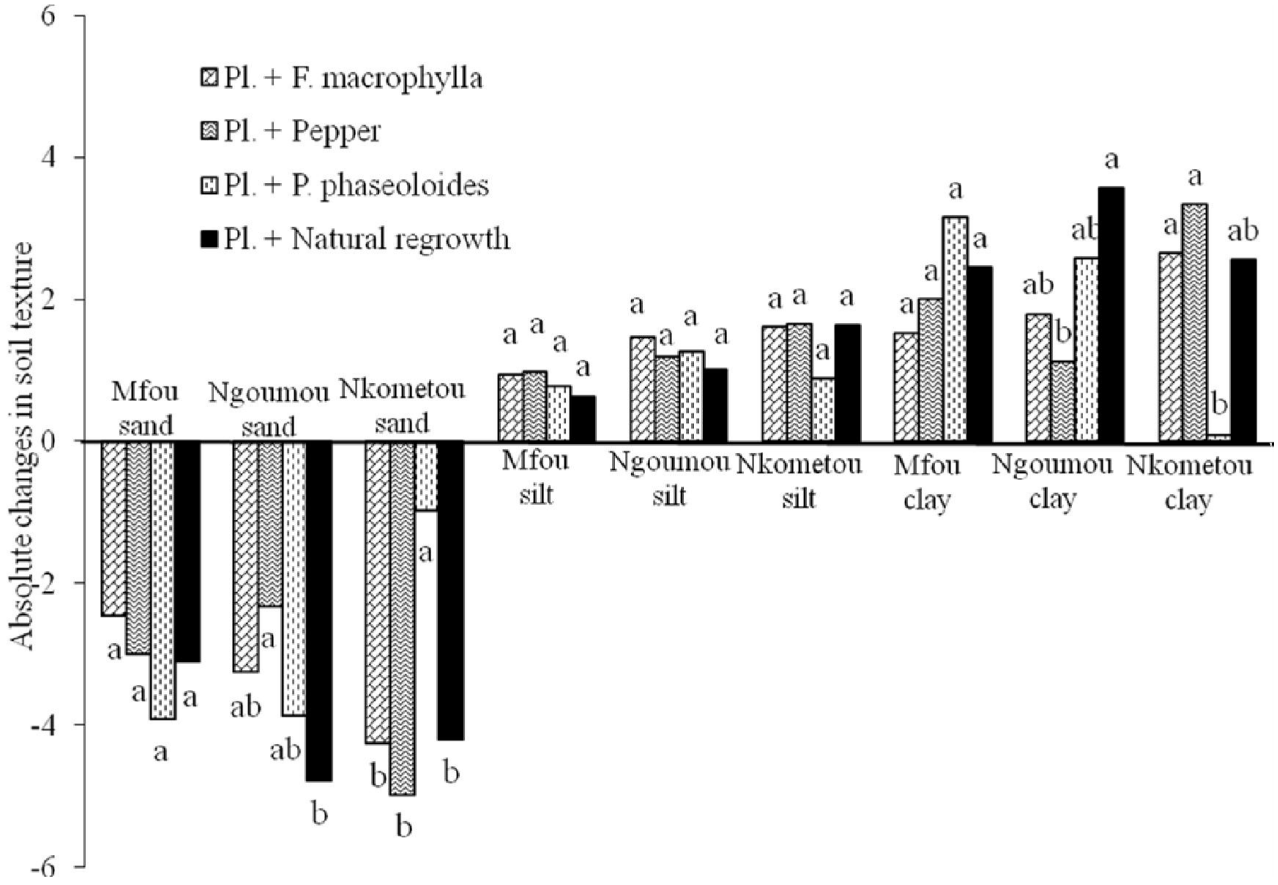

Figure 2.1: Influence of plantain cropping systems (two planted legumes *F. macrophylla*, *P. phaseoloides,* a crop: hot pepper and the natural regrowth, all planted to plantain) on the absolute changes of soil texture parameters (sand, silt and clay contents) in three southern Cameroonian villages (Mfou, Ngoumou and Nkometou), Pl=plantain.

From 2002 to 2006, soil bulk density (BD) decreased highly significantly across villages, fallow ages and cropping systems from 1.04 to 0.97 Mg m^{-3}. Bulk density had a village × fallow interaction (P=0.007) such that in forest fallow changes were the same in all villages yet, in the bush fallow, changes were significantly different between villages (Table 2.3). Decreases in BD were not affected by cropping systems (Table 2.4).

The proportions of mesoaggregates and microaggregates decreased and the proportion of macroaggregates increased highly significantly across villages, fallows with differential effects of the cropping systems (Figure 2.2).

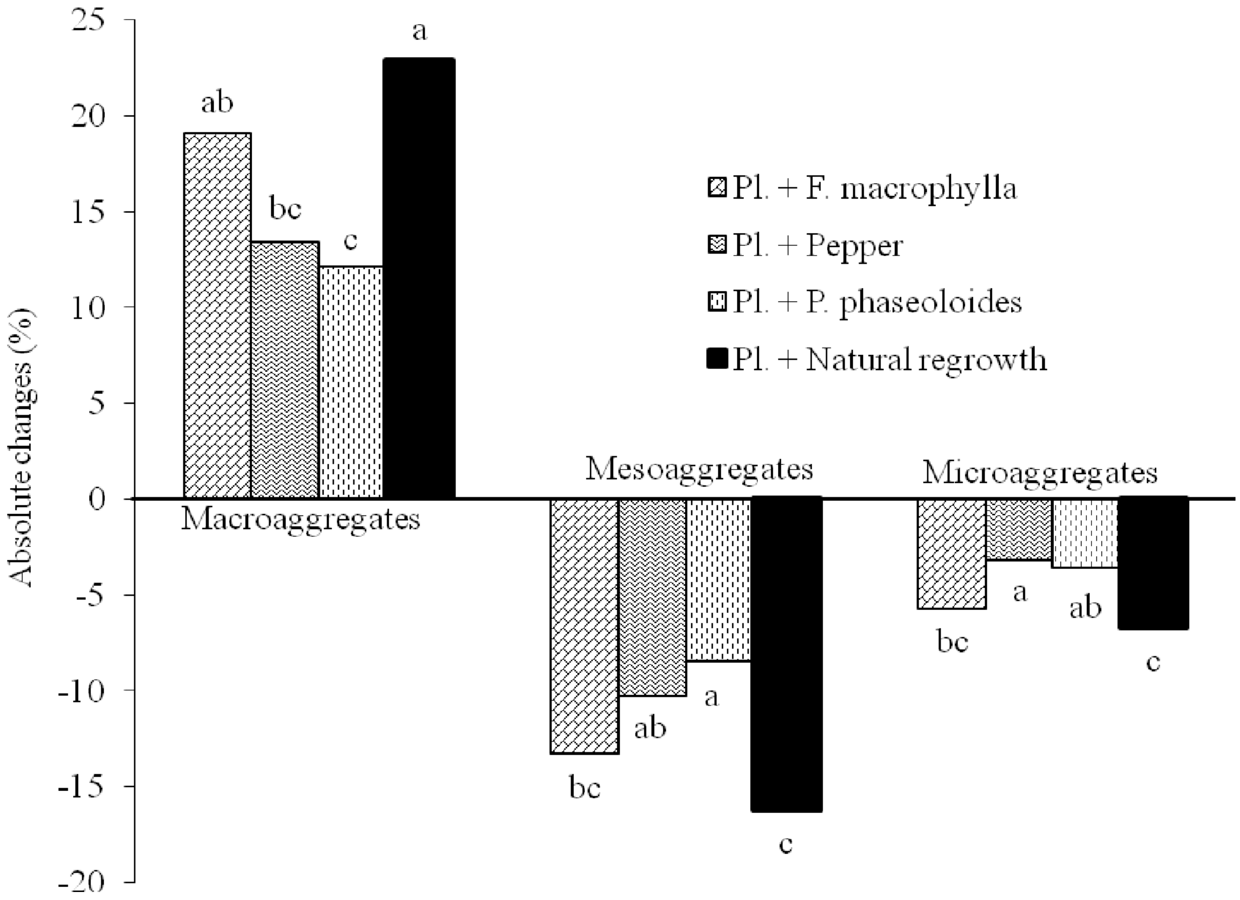

Figure 2.2: Influence of plantain cropping systems (two planted legumes *F. macrophylla*, *P. phaseoloides,* a crop: hot pepper and the natural regrowth, all planted to plantain) on the absolute changes of soil macro-, meso- and microaggregates, averages across villages and fallow ages, in the 0-10 cm soil layer, Pl=plantain.

The absolute changes between 2002 and 2006 of the proportions of macroaggregates, mesoaggregates and the MWD and GMD in forest fallow did not differ between villages. In the bush fallow, the changes of these aggregate stability parameters were significantly higher (P=0.01) at Nkometou than at Ngoumou and Mfou (Table 2.3).

Table 2.3: Absolute changes in soil bulk density, the proportion of soil macroaggregates, mesoaggregates and microaggregates (%), mean weight diameter (MWD) and geometric mean diameter (GMD) in (mm), and soil available water capacity (AWC, Mg Mg^{-1}) in 0-10 cm layer by village and fallow age between 2002 and 2006.

	Village			
	Mfou	**Ngoumou**	**Nkometou**	***P (village)***
Bulk density (Mg m^{-3})				
Bush	-0.02a	-0.10b	-0.09b	0.02
Forest	-0.12	-0.08	-0.08	ns
P (fallow ages)	0.001	ns	ns	
Macroaggregates (%)				
Bush	9.2b	10.7b	21.4a	0.006
Forest	19.8	20.8	18.7	ns
P (fallow ages)	0.006	0.009	ns	
Mesoaggregates (%)				
Bush	-6.5a	-7.3a	-14.6b	0.01
Forest	-12.7	-15.8	-15.1	ns
P (fallow ages)	0.04	0.004	ns	
Microaggregates (%)				
Bush	-2.7a	-3.4a	-6.8b	0.02
Forest	-7.1b	-5.0ab	-3.5a	0.01
P (fallow ages)	0.003	ns	0.03	
MWD (mm)				
Bush	0.86b	0.83b	1.71a	0.004
Forest	1.25	1.44	1.32	ns
P (fallow ages)	ns	0.02	ns	
GMD (mm)				
Bush	0.22b	0.21b	0.50a	0.0002
Forest	0.36	0.36	0.30	ns
P (fallow ages)	0.05	0.03	0.006	
AWC (Mg Mg^{-1})				
Bush	-0.03c	0.03b	0.09a	<0.0001
Forest	-0.04c	0.03b	0.11a	<0.0001
P (fallow ages)	0.04	ns	ns	

ns, not significant. Within lines, values followed by different letters are significantly different at the indicated *P* value.

Aggregate stability improved in all cropping systems. The absolute changes between 2002 and 2006 of all aggregate stability parameters (MWD, GMD, proportions of macroaggregates, mesoaggregates and microaggregates) where higher in the natural regrowth and *F. macrophylla* systems and lower in the pepper intercrop and *P. phaseoloides* system (Table 2.3 & 2.4).

The AWC increased in all cropping systems, yet did not differ significantly between systems (Table 2.3). From 2002 to 2006, AWC decreased at Mfou but increased at Nkometou and Ngoumou, irrespectively of fallow age.

Table 2.4: Absolute changes of soil bulk density, Mean Weight Diameter (MWD), Geometric Mean Diameter (GMD) and available water capacity (AWC) of an Ultisol in 0-10 cm depth. Average villages and fallows; n = 18.

	Bulk density (Mg m^{-3})	**MWD**	**GMD**	**AWC** (Mg Mg^{-1})
		------(mm)-----		
Pl + *F. macrophylla*	-0.09	1.37ab	0.37ab	0.034
Pl + Pepper	-0.05	1.07bc	0.28bc	0.031
Pl + *P. phaseoloides*	-0.09	0.85c	0.22c	0.025
Pl + Natural regrowth	-0.10	1.64a	0.43a	0.036
P (cropping systems)	ns	0.02	0.01	ns

ns, not significant. Within columns, values followed by different letters are significantly different at the indicated *P* value. Pl = Plantain

2.4.3 Plantain fresh bunch yield

The average plantain fresh bunch yield was 2.00 Mg ha^{-1}. There were no significant differences between villages, fallow ages and cropping systems (Table 2.5). None of the interactions was significant. However, yields varied strongly within village, fallow ages and cropping system ranging from 0.067 to 4.57 Mg ha^{-1}. Bunch yield at Ngoumou (2.41 Mg ha^{-1}) was 22 % and 49 % higher than at Nkometou and Mfou, respectively. Bunch yield in the forest fallow (2.52 Mg ha^{-1}) was 70 % higher than in the bush fallow. The *P. phaseoloides* system produced 2.55 Mg ha^{-1}; 19, 31 and 86 % more than plantain + the natural regrowth, plantain + the *F. macrophylla* system and the pepper intercrop with plantain, respectively.

Table 2.5: Mean of fresh bunch yield (Mg ha^{-1}) of local plantain

	Mean of fresh bunch yield (Mg ha^{-1})	**S.E.**
Village		
Nkometou	1.97	0.69
Mfou	1.62	0.26
Ngoumou	2.41	0.69
P(village)	ns	
Fallow		
Bush	1.48	0.38
Forest	2.52	0.54
P(fallow)	ns	
Cropping systems		
Pl + *P. phaseoloides*	2.55	0.67
Pl + Natural regrowth	2.14	0.81
Pl + *F. macrophylla*	1.94	0.78
Pl + Pepper	1.37	0.34
P(cropping systems)	ns	

ns, not significant. Pl = plantain; S.E.= standard error

2.4.4 Relationships between bunch yield and soil physical properties

Across villages, fallow ages and cropping systems, no significant correlations were found between fresh bunch yield and soil physical properties. Separating the data by village did not produce significant correlations. Separating the data by fallow age revealed a negative significant correlation of bunch yield with AWC (r^2=0.212, *P=0.005*) in the forest fallow in 2002. Separating the data by cropping system revealed a negative significant correlation of bunch yield with the silt content in 2002 in the pepper intercrop system (r^2=0.287, *P=0.022*).

2.5 Discussion

None of the fallows had generally better soil physical properties at the start of the study. This is contrary to the general perception that forest soils are superior to soils under bush fallow that have been cropped previously.

The initial textural differences between fallow ages have to be regarded as partially site specific properties. The tendency to higher clay contents in the forest soil is likely related to the better soil cover and a higher activity of soil macrofauna such as earthworms depositing casts with higher clay contents than the topsoil at the surface (Hauser, 1993). The higher aggregate stability (MWD, GMD and macroaggregates) in the bush compared to the forest could be associated with the higher sand and silt contents and higher Ca and Mg concentrations and pH (in water) in bush fallow soils (Banful, 2006). Tueche et al. (2007) demonstrated a strong ($P<0.0001$) and positive relationship between these soil properties and MWD, GMD and the proportion of soil macroaggregates. Salako and Hauser (2001) showed the importance of Ca and Mg for the stability of surface (0-10 cm) soil aggregates.

Soil physical properties did not decline under plantain cropping. This is an unexpected result when comparing to reports from other crops (Sanchez et al., 1985; Nyobe, 1998; Nounamo et al., 2002; Yemefack et al., 2002, 2004). The main reason for no decline may be the fundamentally different soil management in plantain crops compared with any other food crop usually grown in southern Cameroon. Plantain fields are not clean weeded and with increasing height of the plantains farmers allow weed growth for rather long periods. In this trial weeding was done with cutlasses four times a year, except for the pepper crop which was clean weeded in the first year. Therefore, while the plantains were growing, the soil was permanently covered as even after weeding the biomass left on the field served as dead mulch. The weed flora, usually dominated by *Chromolaena odorata*, can produce up to 3 Tonnes ha^{-1} biomass within the 3-4 months between weedings (Hauser and Mekoa, 2009).

Most absolute changes of soil physical properties were larger at Nkometou than in the other villages. Weed and planted fallow biomass production was highest at Nkometou (Banful et al., (2008), indicating that life and dead biomass presence are the major factor contributing to positive changes of soil physical properties.

Most absolute changes of soil physical properties were larger after forest fallow than after bush fallow. Old fallows, such as secondary forests, are in general richer in plant debris and soil biota and consequently have higher decomposition rates (Lavelle et al., 2000; Hauser et al., 2005; Ruan et al., 2005). Furthermore, forest clearing changes the microclimate and the soil climate (e.g. increase in soil temperature and soil water content) (Tueche et al., unpublish.). These changes are often followed by higher soil microbial activity (Taylor and Parkinson, 1988; Tian et al., 2000) leading to larger changes in forest fallow than in bush fallow. In the exceptional case of Nkometou, greatest absolute changes of aggregates stability parameters were found after bush fallow. This was most likely the consequence of intensive termite activity in the plots. Termites produce stable aggregates and deposit large quantities of such aggregates on the soil surface. Soil-feeding termites are known to produce faeces that contain organo-mineral complexes that remain stable over long periods (Wood, 1996). Earthworm activity was an unlikely factor in soil physical property changes as earthworm activity was found to be very low at Nkometou (Birang et al., 2003).

The increases of clay and silt content and the decrease of sand content were unexpected and contrary to our hypothesis. Increased clay content can possibly be attributed to a combination of absence of clay migration into deeper layers and sheet erosion that causes the selective loss of fine soil particles, nutrients and organic matter (Roose, 1977; Yemefack et al., 2004) and a higher level of soil macro fauna (earthworms termites and ants) activity contributing to bioturbation of fine materials to the soil surface (Hauser, 1993). In southern Cameroon cropping in a slash and burn system has been shown to drastically reduce earthworm surface casting (Birang et al., 2003; Norgrove et al., 2003a). However, in the current trial simple weed slashing (i.e. not clean weeding) has to be considered a minor disturbance with probably little impact on earthworm activity.

The general decrease in soil bulk density and the increase in soil MWD, GMD and the proportions of soil macroaggregates in all villages, fallow ages and cropping systems is most likely due to the soil cover with biomass and the availability of substrate to the soil flora and fauna. The absolute changes in soil aggregate stability parameters were greatest in the natural regrowth and lowest in the pepper intercrop. The dominant weed species in the natural regrowth, *Chromolaena odorata,* is rich in Ca and Mg. The decomposition of its residues may have released abundant Ca and Mg with positive effects on soil aggregate stability (Salako and Hauser, 2001; Tueche et al., 2007). Such effects may have been amplified through the partial decomposition of the *C. odorata* root network.

The generally low plantain bunch yields remain difficult to explain as the conditions in the growing years were not adverse to plantain. The delayed planting after clearing may be one reason as nutrient leaching may take place and weed infestation could have worsened the conditions at the start of the plantain growing phase. Plantain bunch yields were not affected by any factor thus it is likely that other factors have had more impact on the yields than village, fallow age and cropping system. The absence of significant correlations between soil physical properties and plantain bunch yield across villages, fallow ages and cropping systems indicates that these properties have either little or no effects on plantain bunch yield or were masked by other factors with stronger effects on yield. The weak correlations between AWC and silt content and bunch yield were negative and restricted to certain fallows or cropping systems, thus not suitable to explain yields. In other trials in southern Cameroon soil chemical properties also were found to not explain any yield differences (Hauser et al., 2008). The higher yield in the forest fallow than in bush may be explained by a higher level of nematode infestation in bush fallow (Kanga, 2003) found in the soils of this trial. Forests of 15 to 30 years seem to be a preferred age class as fertility is rebuilt and clearing is still relatively easy. However, there is no reference available where a range of forest ages was cleared for plantain.

The changes in aggregate stability parameters did not follow the ranking of the bunch yields in the different systems thus other characteristics of the cropping system might have been of higher importance in yield formation. The *P. phaseoloides* system produced high amounts of biomass, smothered other weeds and *P. phaseoloides* fixes N. Furthermore, there was a significant reduction in nematode populations in this system before plantains were planted (Banful, 2006). These factors may have contributed to the higher bunch yields. In the *F. macrophylla* system biomass production was low and no reduction of nematodes was found, potentially leading to the lower yields. In the natural regrowth system yields were similar and the system produced similar amounts of biomass. The low yields of the pepper intercrop system may be related to the low weed biomass production after the intensive weeding phase of the pepper crop. The higher fresh bunch yield at Ngoumou than in the other villages could be attributed to the higher rainfall at Ngoumou.

2.6 Conclusion

The changes in soil physical properties under plantain cultivation were similar to those observed during fallow periods in tropical soils. Plantain cultivation did not degrade the determined soil physical properties of the soils investigated. Thus the land may be of immediate use for other crops, thereby decreasing the need of forest clearing. The plantain + *P. phaseoloides* system appears to be the most suitable cropping system for plantain. Recent research (Duindam and Hauser, 2008) and feedback from farmers (Duindam pers. communic., 2008) indicate that *P. phaseoloides* is suitable for a range of other crops as well. It should thus receive more research attention and be promoted to halt soil degradation and deforestation.

Chapter 3

Maize (*Zea mays* L.) yield and soil physical properties as affected by the previous plantain cropping systems, tillage and nitrogen application

3. Maize (*Zea mays* L.) yield and soil physical properties as affected by the previous plantain cropping systems, tillage and nitrogen application[2]

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3.1 Abstract

We evaluated if cropping maize immediately after plantain is affected by the previous plantain systems and if tillage or N fertilizer would affect maize growth and grain yield and soil physical properties. The on-farm experiment was conducted at Mfou in the central Cameroon on a clayey, kaolinitic, Typic Kandiudult. The previous plantain cropping systems that had been established between 2002 and 2006 had 4 systems: two planted legumes (1) *Flemingia macrophylla*, (2) *Pueraria phaseoloides,* (3) an intercrop with hot pepper and (4) natural regrowth. In 2006, all plantain plots were cleared and split into 4, to assess the response of maize to tillage versus no – till and of 60 kg ha^{-1} of N as urea versus nil in a 2 x 2 factorial design. Bush fallow of 8 years of age not cropped during the plantain phase served as control. Maize grain yield was highest in the previously not cropped bush control and lowest in the previous *Flemingia* system. Grain yield in the previous pueraria and natural regrowth systems were not different from control. Maize grain yield was highest when tillage was combined with fertilizer application, significantly higher from individual tillage or fertilizer application. Tilled only and fertilized only produced higher yields than no-till and no fertilizer. Soil physical properties were affected by tillage but did not remain different until the end of the maize growing phase. N fertilizer application had no effect on soil physical properties. Differences in maize grain yield could not be explained by soil physical properties and correlations with maize yield parameters were generally weak.

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Keywords

Cropping history; *Flemingia macrophylla;* nitrogen application; *Pueraria phaseoloides*; soil physical properties; soil tillage.

3.2 Introduction

Africa suffered the second largest net loss of forests between 2000 and 2010 – about 3.4 million hectares (FAO, 2010a). Deforestation is mainly caused by the conversion of tropical forest to agricultural land (FAO, 2010a), dominantly used for low input – low output slash and burn agriculture (FAO, 1997). This is associated with the need to meet the food requirements of a growing population and the fact that crop yields decline rapidly, forcing farmers to move on to new land. Plantain is a major food cash crop for most smallholder farmers in the West and Central African humid forest zone. Plantain yields are higher after forest clearing than after short fallow (Hauser et al., 2008), yet, in all systems yields decline sharply after the harvest of the plant crop (Hauser, 2000; Hauser, 2007). Smallholder farmers will soon face a shortage of forest land for agriculture. To address the local food requirements, regional concerns over ecosystem services, integrity and biodiversity conservation and global issues of climate change, there is an urgent need to reduce deforestation and develop agricultural systems that can maintain soil fertility and crop production on already deforested land. Plantain is probably the crop causing most deforestation in southern Cameroon. In an attempt to identify systems that would permit profitable plantain production in short fallow land, Banful (2006) assessed the effects on plantain bunch yields of two leguminous green manure species *Flemingia macrophylla* and *Pueraria phaseoloides* and the natural (weed) regrowth between 2002 and 2006. Soil properties were monitored over the plantain phase. Tueche et al. (2011) found that plantain cultivation did not degrade soil physical properties, suggesting that the land could be of immediate use for other crops. Farmers usually abandon plantain fields to bush fallow for 2 to 7 years before they use the land for other crops (Hauser and Amougou, 2010).

Past studies have shown that tillage and N-fertilizer can significantly affect crop yield and soil physical properties. Tillage can reduce soil aggregation (Zibilske and Bradford, 2007).

Couper et al. (1979), Lal and Dinkins (1979) found higher maize grain yields on no-till than on ploughed plots. Wanas (2006), on the contrary, found maize grain yield increased after tillage compared with no-tillage. When intercropped with cassava, maize grain yield had no consistent positive response to tillage on an Ultisol in southern Cameroon (Hauser et al., 2000). Nitrogen fertilization increased maize yields in southern Cameroon (Hauser and Nolte, 2002). Nitrogen fertilizer can affect soil physical properties: plots not receiving N fertilizer consistently had the largest aggregate mean weighed diameter (MWD) (Limon-Ortega et al., 2009).

The working hypotheses for the treatment combinations and sequences were: (1) *Flemingia macrophylla* and *Pueraria phaseoloides* fix N and may increase soil N that can be used by a maize crop and increase grain yields (2) an intercrop of hot pepper will exploit soil resources and reduce soil fertility leading to lower maize yields after plantain, (3) retaining the natural regrowth during the plantain phase neither reduces nor increases soil fertility and has thus no effect on maize yield, (4) tillage, incorporating the biomass may increase decomposition and mobilize nutrients and increase maize yields, (5) N fertilizer may balance N losses during the plantain phase and increase decomposition of biomass leading to higher N availability and higher maize yields, (6) soil physical properties are unaffected by previous plantain cropping systems but will be negatively affected by both tillage and N application.

The present study was conducted to evaluate if cropping maize immediately after plantain is affected by the previous plantain system and if tillage or N fertilizer would affect maize growth and grain yield and soil physical properties.

3.3 Materials and Methods

3.3.1 Study area

The study was carried out at Mfou (3^{o} 57’N, 11^{o} 48’E), a village in the Centre region of Cameroon. The soil at Mfou is classified as clayey, kaolinitic, Typic Kandiudult (Hulugalle and Ndi, 1993). Annual mean maximum air temperature ranges from 29.6 to 31.9 ^{o} C and the mean minimum air temperature from 21.2 to 23.5 ^{o} C. The relative humidity ranges from 73.8 to 88.0 %.

The site has a bimodal rainfall distribution: the first and second rainy season typically last from mid-March to mid-July and from mid-August to end of November, respectively. The mean total annual rainfall is around 1500 mm.

3.3.2 The previous plantain cropping systems

Conventional suckers of the local plantain cultivar Essong were treated in boiling water (Hauser, 2007) and planted in 2002 in a 4-5 year-old bush dominated by *Chromolaena odorata* ([L.] King and Robinson, 1987). The plantain cropping systems were established in a randomised complete block design with three replications. The cropping systems comprised plantain in the natural regrowth (or plantain sole cropped), plantain intercropped with pepper, with *F. macrophylla* or with *P. phaseoloides*.

3.3.3 Maize seeding, tillage and fertilizer application

The previous plantain cropping systems were manually cleared, the slash remained on the plots and the initial plots of 15 m x 12 m were divided into 4 subplots of 7.5 m x 6.0 m, two of these were not tilled, the other two were either hand hoe tilled or tilled with the small single axle roto-tiller tractor to a depth of around 8-12 cm. Beside the previously cropped plots, additional plots not cropped over the plantain cropping phase and of the same fallow age when the plantains were established, thus 8 years old, served as control. These control plots had the same size and were treated in the same manner as the previously cropped plots. Maize was sown at 0.50 x 0.50 m spacing and thinned to one plant per stand. At 2 and 4 weeks after seeding urea was applied at the rate of 30 kg ha^{-1} N, per application, on one tilled and on one no-till sub-plots per plot.

3.3.4 Observations at maize harvest

At maize harvest one row of maize plants was removed on all sides of each plot. The number of plants, cobs and marketable cobs was counted. All husked cobs were weighed and a sub-sample taken for grain and rachis dry matter determination. After cobs had been removed, 10 randomly selected maize plants were cut at ground level and weighed together with 10 sets of husks and a sub-sample taken for dry matter determination. Subsamples were dried at 65°C to constant mass. Cobs were shelled and grain and rachis mass determined separately. Rachis mass was added to the straw mass. The harvest index was calculated as grain dry matter divided by total above ground dry matter.

3.3.5 Determinations of soil physical properties

Soil samples were collected on a diagonal pattern twice, before tillage in February 2006 and after tillage in early June 2006. Eight soil samples were collected per subplot and per depth at 0.00-0.05 m and 0.05-0.10 m with a 100 cm^3 cylinder. Soil bulk density was determined according to Blake and Hartge (1986). The samples for soil textural determinations were oven dried at 40 °C and passed through a 2 mm sieve to separate gravel from fine earth. 51.0 g of fine earth were used to determine soil texture by hydrometer method according to Gee and Bauder (1986), yet due to high and erratic spatial variation it could not be related to any treatment. Therefore the data are neither shown nor discussed. Available water capacity (AWC) was determined according to Cassel and Nielsen (1986).

Aggregate stability was determined according to Angers and Mehuys (1993). The soil was spread on top of a nest of sieves with opening of 4.0, 2.0, 1.0, 0.25, and 0.125 mm. The sieves were placed in a wet-sieving apparatus, similar to that described by Kemper and Rosenau (1986). The proportion of water stable aggregates (WSA_i) in each of the size fractions was calculated from the formula:

$$\mathbf{WSA_i} = (w2_i - w3_i)/(w1/(1 + wc) - \sum w3_i) \qquad (1)$$

Where i = 1, 2, 3, …, n-1, n and corresponds to each fraction in each sample; wc is the gravimetric water content; w1 is the mass of the air dried soil that had passed through a 10 mm sieve; $w2_i$ is the mass of the aggregates on each sieve of the nest, dried at 105 °C; these $w2_i$ were put in flasks and approximately 50 ml of 0.5% Na-hexametaphosphate was added to each flask and shake for 45 min. Each fraction of dispersed aggregates was returned onto the 0.053 mm sieve and washed with tap water to separate coarse particle from the fine ones (clay and silt). Primary particles thus retained on this sieve were dried at 105 °C and weighed (w3i).

The mean weight diameter (MWD) used to express the size distribution was then determined as:

$$\mathbf{MWD} = \sum_{i=1}^{n} X_i \, WSA_i \qquad (2)$$

Where i = 1, 2, 3, …, n and corresponds to each fraction collected, including the one that passes the finest sieve. $\mathbf{X_i}$ is the mean diameter of each size fraction (i.e., mean inter-sieve size); and $\mathbf{WSA_i}$ is as defined in (Eq.1).

The geometric mean diameter (GMD) was calculated after Mazurak (1950). The proportion of soil macroaggregates, mesoaggregates and microaggregates were determined as:

Soil macroaggregates = ∑proportions of water stable aggregates > 2mm (4)

i.e all aggregates on the 4 and 2 mm sieves;

Soil mesoaggregates = ∑proportions of water stable aggregates in the <2mm and > 0.25mm.(5)

i.e all aggregates on the 1 and 0.25 mm sieves;

Soil microaggregates = ∑proportions of water stable aggregates < 0.25 mm (6)

i.e. all aggregates on the 0.125 mm sieves and below (0-0.125 mm).

Soil strength was measured in situ with the static hand penetrometer Eijkelkamp type. The measurements and the calculations were made according to Bradford (1986) and Nyobe (1998). The appraisal of cone resistances (CR) to soil penetration was made only after tillage in June 2006 in six positions per subplot at 0.05 m increments from 0.0-0.3 m depth.

3.3.6 Data analysis

Data were analysed using the General Linear Procedure "Proc GLM" for split plots in SAS version 9.1, (SAS, 2001). The Least-square Means/PDIFF option was used to determine levels of significance between pairs of treatment means. Data sets comprised 60 values (5 systems, 2 tillage levels, 2 fertilization levels and 3 replicates) and were analysed as three factorial designs to check for interactions. Probabilities are indicated in text and tables up to the level of significance (P=0.10). However, only differences at P<0.05 are labelled "significant". Correlations between maize yield parameters and soil physical properties were calculated using "Proc CORR" on n=60 across all factors and n=30 when separated by tillage or fertilizer application levels.

3.4 Results

3.4.1 Maize yield parameters

Maize plant density at harvest and the harvest index were not affected by any of the factors. The highest proportion of plants producing cobs, number of cobs m^{-2}, marketable cobs m^{-2}, grain, straw and total dry matter yield were attained in the previously not cropped control (Table 3.1). The previous *Flemingia* system produced the lowest maize yields, followed by the previous hot pepper system. The control out-yielded the previous *Pueraria* and natural regrowth systems in cob and marketable cob density, yet, did not attain significantly higher grain, straw and total aboveground biomass yields.

No tillage combined with no fertilizer application produced the lowest cob and marketable cob densities and the lowest proportion of plants with marketable cobs (Table 2). Maize grain and straw biomass were highest when tillage was combined with fertilizer application, significantly different from individual tillage or fertilizer application. The latter produced significantly higher yields than no-till and no fertilizer. Total maize aboveground biomass was highest when tillage and fertilizer application were combined and lowest when neither was applied (Table 3.2).

Table 3.1: Maize yield parameters after 4 plantain cropping systems and a previously not cropped bush control. Data are means across tillage and N- fertilizer treatments. Mfou, southern Cameroon, n=12.

	Cobs	Marketable Cobs	Grain	Straw	Total	PPMC*
Previous system	---------- m^{-2} ----------		------ Mg ha^{-1} dry matter ------			
Flemingia	1.75c	0.98c	1.33c	1.73b	3.06c	0.72bc
Hot pepper	1.95bc	1.31b	1.53bc	2.22a	3.76bc	0.69c
Pueraria	2.12b	1.39b	1.79ab	2.22a	4.01ab	0.78bc
Regrowth	2.08b	1.38b	1.75ab	2.21ab	3.96ab	0.80ab
Control	2.71a	1.75a	2.14a	2.61a	4.74a	0.90a
P (system)	0.0001	0.0013	0.0043	0.0205	0.0039	0.0013

* PPMC = Proportion of plants with cobs

Table 3.2: Maize yield parameters as affected by N fertilizer application and tillage. Data are means across previous plantain cropping systems and a previously not cropped control. Mfou, southern Cameroon, 2006, n=15.

	Cobs	Marketable cobs	Grain	Straw	Total	PPWMC*
	--------- m^{-2} ---------		----- Mg ha^{-1} dry matter -----			
Tillage & fertilizer	2.28a	1.61a	2.20a	2.80a	5.00a	0.581a
No-till & fertilizer	2.20a	1.41a	1.70b	1.96b	3.66bc	0.525a
Tillage & no fertilizer	2.14a	1.42a	1.67b	2.23b	3.90b	0.523a
No-till & no fertilizer	1.87b	1.01b	1.27c	1.79c	3.05c	0.404b

*PPWMC = Proportion of plants with marketable cobs

Across tillage treatments, nitrogen fertilizer increased the cob density (+11.5%) the marketable cob density (+24.4%), grain (+32.8%), straw (+18.4%) and total aboveground biomass (+24.5%) dry matter yield and the proportion of plants producing marketable cobs (+19.2%).

Across fertilizer treatments, tillage increased the marketable cob density (+24.8%), grain (+30.4%), straw (+34.2%) and total aboveground biomass (+32.5%) dry matter yield.

There was a small synergistic effect on the maize grain yield of combined N application and tillage (+0.93 Mg ha^{-1}), with the combined treatments' grain yield exceeding the sum of the individual treatments (N + 0.43 Mg ha^{-1}, tillage +0.41 Mg ha^{-1}) by 0.09 Mg ha^{-1} or 7.3%.

Within the previous plantain cropping systems, N application and tillage did not significantly interact on any of the maize yield parameters. However, when the previously un-cropped control was included, N application and tillage had significant interaction such that in the un-cropped control N application increased grain yield from 1.57 to 2.71 Mg ha^{-1} (P=0.001) (Figure 3.1), and tillage increased grain yield from 1.73 to 2.54 Mg ha^{-1} (P=0.016) (Figure 3.2), while the increases in all previous plantain systems were insignificant.

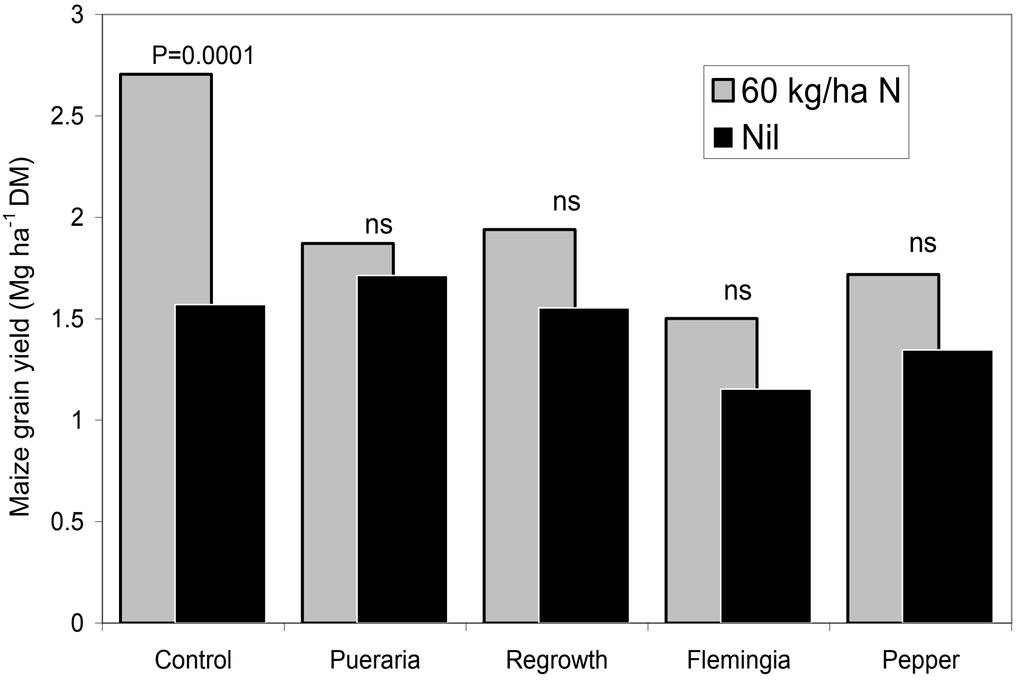

Figure 3.1: Maize grain yield in fertilized and unfertilized previous plantain systems and a previously un-cropped control. Mfou, southern Cameroon, 2006. P values above columns within the same previous system indicate differences between fertilizer treatments.

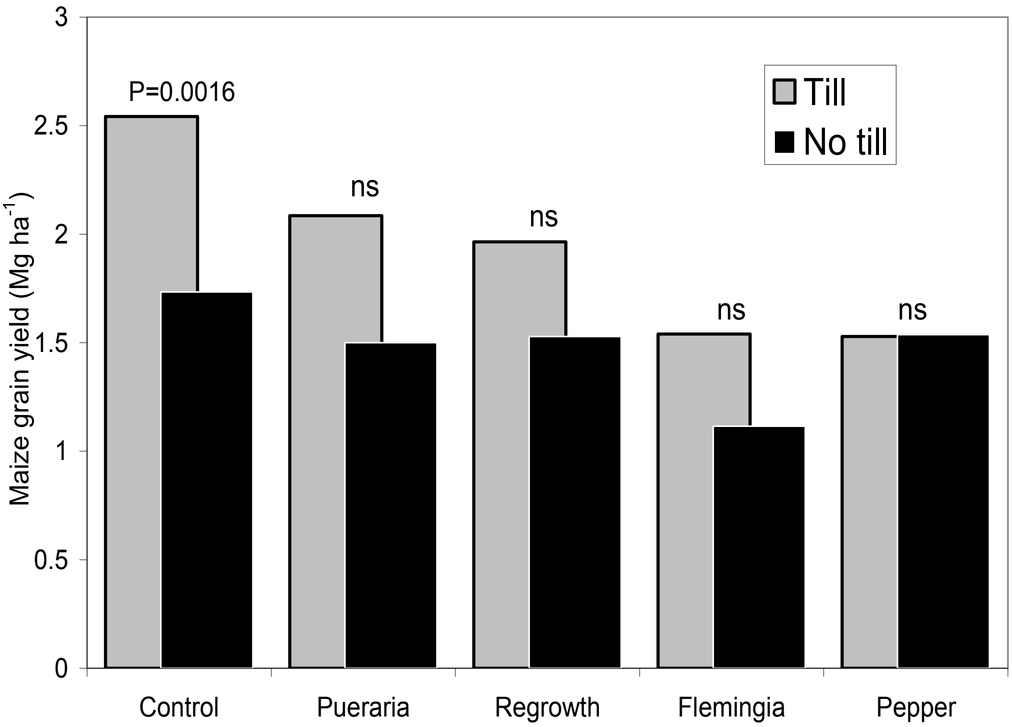

Figure 3.2: Maize grain yield in tilled and no-till previous plantain systems and a previously uncropped control. Mfou, southern Cameroon, 2006. *P* values above columns within the same previous system indicate differences between tillage treatments.

3.4.2 Soil physical properties before and after tillage

Tillage significantly reduced the proportion of soil macroaggregates, the MWD and GMD. The proportions of soil mesoaggregates, microaggregates and the AWC were significantly higher after tillage. Soil bulk density was not significantly affected by tillage (Table 3.3). Soil bulk density was highest in the previous natural regrowth system and lowest in the previously uncropped control, the *Pueraria* and hot pepper system (Table 3.4).

Table 3.3: Effect of tillage on bulk density, the proportions of soil macro.-, meso.-, microaggregates, mean weight diameter (MWD), geometric mean diameter (GMD) and available water capacity (AWC) at 0-10 cm depth on an Ultisol at Mfou, Southern Cameroon. n=48.

Time	Bulk Density ($Mg\ m^{-3}$)	Macro	Meso	Micro	MWD	GMD	AWC ($Mg\ Mg^{-1}$)
		-------------(%)------------			-------(mm)-------		
Before tillage	1.01	77.6	12.8	9.6	5.2	1.7	0.12
After tillage	1.02	62.8	22.0	15.2	4.1	1.4	0.17
P (tillage)	ns	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Cone resistance to soil penetration was higher in the previously un-cropped control, the previous natural regrowth and hot pepper systems than in the previous *Pueraria* and *Flemingia* systems (Table 3.4).

The proportion of soil macroaggregates, the MWD and the GMD were significantly higher in the previously un-cropped control than in the previous *Flemingia* system. The previous *Pueraria,* hot pepper and natural regrowth systems were not different from any another system. The proportion of soil mesoaggregates was highest in the previous *Flemingia* system and lowest in the previously un-cropped control. The previous *Pueraria,* hot pepper and natural regrowth systems were not different from any another system (Table 3.4).

The AWC was significantly higher in the previously un-cropped control than in the previous *Pueraria*, hot pepper and natural regrowth systems, yet not different from that in the previous *Flemingia* system (Table 3.4).

Neither tillage nor N fertilizer application had significant effects on the soil physical properties. No significant interactions between tillage and N fertilizer application or previous cropping systems were found.

3.4.3 Relationships between maize yield parameters and soil physical properties

Across previous cropping systems, tillage and nitrogen fertilization, weak, yet significant positive correlations were found between maize grain yield and the proportion of microaggregates ($r=+0.402$, $P<0.002$) and bulk density ($r=+0.290$, $P<0.025$). Weak, yet significant negative correlations were found between maize grain yield and the proportion of macroaggregates ($r=-0.289$, $P=0.025$), the MWD ($r=-0.27$, $P=0.04$) and the GMD ($r=-0.325$, $P=0.011$).

Within no-till plots no correlation was found between grain yield and soil physical properties. In tilled plots significant negative correlations were found between maize grain yield and the proportion of macroaggregates ($r=-0.36$, $P<0.05$) and the GMD ($r=-0.375$, $P=0.041$). Significant positive correlations were found between maize grain yield and bulk density ($r=+0.520$, $P=0.003$) and the proportion of microaggregates ($r=+0.38$, $P=0.04$).

Table 3.4: Soil bulk density, cone resistance to soil penetration (CR), the proportions of soil macro.-, meso.- and microaggregates, Mean Weight Diameter (MWD), Geometric Mean Diameter (GMD) and available water capacity (AWC) after land preparation of an Ultisol at 0-10 cm depth. n = 12 at the level of the systems, n=30 at the level of tillage or fertilization.

	Bulk density	CR	Macro	Meso	Micro	MWD	GMD	AWC
	(Mg m^{-3})	(MPa)	----------------(%)---------------			--------(mm)-------		(Mg Mg^{-1})
Previous plantain system								
Control	0.99 b	0.70 a	68.3 a	17.5 b	14.2	4.5 a	1.5 a	0.184 a
Pueraria	1.00 b	0.54 b	63.0 ab	22.0 ab	15.0	4.1 ab	1.4 ab	0.165 b
Natural regrowth	1.05 a	0.69 a	64.9 ab	19.9 ab	15.2	4.2 ab	1.4 ab	0.158 b
Hot pepper	1.00 b	0.77 a	63.6 ab	22.3 ab	14.1	4.1 ab	1.4 ab	0.164 b
Fleminigia	1.02 ab	0.47 b	59.8 b	23.7 a	16.5	3.9 b	1.3 b	0.171 ab
P (systems)	0.07	0.006	0.07	0. 09	ns	0.047	0.048	0.026
Tillage effect								
No-till	1.01	0.61	64.3	21.7	14.0	4.2	1.4	0.165
Tilled	1.01	0.66	63.6	20.5	15.9	4.2	1.4	0.172
P (tillage)	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen effect								
No fertilizer	1.01	0.65	64.8	20.9	14.3	4.3	1.4	0.170
Fertilizer	1.02	0.62	63.1	21.2	15.7	4.1	1.4	0.166
P (N fertilizer)	ns	ns	ns	ns	ns	ns	ns	ns

ns, not significant. Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

3.5 Discussion

An average maize grain yield of 1.7 Mg ha^{-1} can be considered high compared to maize yields usually obtained by smallholders in Central Africa being around 0.9 Mg ha^{-1} (FAOSTAT, 2010b). This relatively high yield may be explained by the absence of other crops and a relatively high plant density compared to usual intercrops. However, yields are low compared with those from sole maize crops in Southern Cameroon which can be up to 4 Mg ha^{-1} when grown in green legume – maize rotations (Hauser and Nolte, 2002; Hauser et al., 2008).

The higher grain yield attained in the previously un-cropped control was somewhat predictable because soil fertility probably had been restored during the 8 years of fallow to levels higher than in the different plantain systems. The significant grain yield increase in the control after tillage indicates that soil nutrient stocks were present and apparently required mobilization or increased decomposition to become available to the maize. However, the significant grain yield increase through N application may indicate a relative lack of N, whereby N application may as well have contributed to higher decomposition rates of soil organic matter. Fallow may accumulate SOM forms that decompose faster if the soil is tilled or the N supply increased. The low or absent grain yield response to N application and tillage in the previously cropped plantain systems may indicate that these SOM forms were not present by the end of the plantain cropping phase. This assumption is supported by the fact that in the hot pepper system, which had lowest biomass accumulation during the plantain phase (Banful, 2006) the effect of tillage was nil. In the *Pueraria* and natural regrowth systems which had produced considerable biomass (Banful, 2006), yields increased by about one third, albeit insignificantly. The grain yield increases due to N fertilizer were similar yet the lowest in the previous *Pueraria* system, in which N was probably accumulated through N – fixation. The *Flemingia* system’s poor performance may be due to a large portion of the nutrients being stored in wood and a woody root system and thus neither mobilized by tillage nor through N fertilizer within the short duration of a maize crop.

Significantly higher yields in tilled plots than no-till plots were also found by Osuji (1984), Scopel et al. (2001) and Wanas (2006). In our study however, grain yield differences could not be explained by differences in soil physical properties between tilled and no-till plots. Better root growth may be an explanation (Prihar et al., 2000; Hasan, 2000; Ahadiyat and Ranamukhaarachchi, 2008), yet from this study no root data can be provided.

The significant differences of MWD, GMD, the proportions of soil macroaggregates and mesoaggregates between the control and the previous *Flemingia* system could possibly be related to the systems creating different types of organic matter and thus aggregate-binding agents (Tisdall and Oades, 1982; Christensen, 2001) and types and proportions of aggregating nutrient elements (Tueche et al., 2007; Qiang et al., 2007). The values of these soil aggregate stability parameters followed the ranking of maize grain yields after the previous plantain systems thus providing some explanations of the differences.

The highest AWC in the control could be explained by the highest proportion of fine soil particles (clay + silt), which are generally positively related to AWC (Pidgeon, 1972; Bouma et al., 2003), better soil structure expressed by greater soil MWD, GMD and the proportion of soil macroaggregates (Das and Gupta, 1987) and larger pore space (Bouma et al., 2003) expressed by the lowest soil bulk density. Yet, AWC in the former plantain systems did not follow the ranking of maize grain yields, thus other consequences of cropping history appear to have stronger impact on maize grain yield formation.

The absence of significant differences in soil physical properties between tilled and no-till plots was contrary to reports by Hill (1990), Gill et al. (1996) and Lal (1997). This may be explained by the fact that tillage was done by hand or a small tractor and only once. Stronger effects might be expected if tillage is repeated (Hill, 1990; Lal, 1997; Guzman et al., 2006). The absence of differences between fertilizer levels might have been due to the relatively low amount of N applied (60 kg ha^{-1}) and the fact that N was applied only once and no application had been done on this land in the past. The absence of differences in bulk density between tilled and no-tilled plots may be surprising, yet, here the generally low bulk density of around 1.0 Mg m^{-3} is unlikely to allow further reductions by tillage. Arable soils usually have bulk densities of >1.2 Mg m^{-3}.

The few correlations between soil physical properties and maize yield parameters indicate that the soil was possibly too loose and that there were problems of either water supply (capillary connection) or anchorage of plants in the soil. This notion is confirmed by the fact that in no-till plots bulk density was not correlated with maize grain yield while in the tilled plots it was positively correlated. The fact that tillage increased yields across the previous plantain systems by a larger margin than N fertilizer might be an indication that decomposition of SOM is a more important function in nutrient supply than N application which may be highly susceptible to leaching and volatilization.

3.6 Conclusion

The results of this study show that farmers may use plantain fields immediately after harvesting the plantain plant crop and that it is not necessary to fallow after the plantain, as is usually done in the region. *Pueraria* and the natural regrowth systems appear to be the most productive systems, whereby the *Pueraria* system can be developed into a permanent fallow crop rotation. The relatively low cost of the single axle roto-tiller tractor may provide options to increase production in smallholder systems in sub-Saharan Africa. However, long term effects on soil properties and crop production would need to be investigated before wide spread use can be recommended.

Chapter 4

Tillage and Varietal Impacts on tomato (*Solanum lycopersicum* L.) production on an Ultisol in central Cameroon

4. Tillage and varietal impacts on tomato (*Solanum lycopersicum* L.) production on an ultisol in central Cameroon[3]

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4.1 Abstract

Across Africa the production of high value horticultural crops is being recognized as a possible route out of rural poverty. To determine at which level of intensification tomato yields were maximized and which tomato cultivar responds best to intensification, an on-farm, factorial trial was conducted at Essong Mintsang in the central region of Cameroon on a Rhodic Kandiudult. Current farmer practice of manual tillage yet not destumped was compared with either reduced input (no tillage, not destumped) or increased input (no tillage yet destumped, manual tillage and destumped, mechanical tillage and destumped). Yields and yield components of three tomato varieties were determined to assess if changes in intensity of land preparation can improve soil physical properties and thus yields. At 6 weeks after planting, cultivar Rossol had more flowers (521126 ha^{-1}, p=0.09) than cv. Rio Grande (403930 ha^{-1}), with cv. Roma (504718 ha^{-1}) not being significantly different from either variety. At harvest, across land preparations the cv. Rossol produced higher yields (8.12 Mg ha^{-1}, p=0.005) than cv. Roma (6.05 Mg ha^{-1}) and cv. Rio Grande (4.46 Mg ha^{-1}); the latter being

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significantly different (p=0.03) from both others. Tomato total and marketable yields were significantly higher in the destumped tractor till, destumped manual till and stumps-retained manual till treatments than in the stumps retained no-till treatment. Yields in destumped no-till treatment were not significantly different from any of the treatments. Total fresh yields of cvs Roma and Rossol increased when the soil was tilled, while cv. Rio Grande had no response to land preparation. Tomato pest and disease damages were not affected by land preparation. Weeding took less time (p=0.05) in destumped manual till (153 hrs ha^{-1}) and tractor till (157 hrs ha^{-1}) than in not destumped manual till plots (243 hrs ha^{-1}). Soil aggregates were least stable in the destumped, tractor till treatment, with significantly lower MWD (p=0.02), and higher mesoaggregate proportions (p=0.05) than in the other treatments. Across tomato cultivars and treatments, the marketable fruit yield could be predicted by clay, macroaggregates and bulk density in the 0-10 cm layer: marketable yield = 0.12 Clay - 0.14 Macroaggregate +12.20 (with r^2=0.50, n=15, p=0.016) and for the 10-20 cm soil layer: marketable yield = 0.17 Clay + 5.15 Bulk density -10.25 (with r^2=0.58, n=15, p=0.005). Early flowering and fruit production combined with nematode resistance were probably the main contributing factors to the high yields of cv. Rossol.

Keywords: destumping; manual tillage; soil physical properties; tomato; tractor tillage.

4.2 Introduction

In many sub-Saharan African countries, smallholder agriculture is increasingly market- rather than subsistence-orientated and the horticultural sector is expanding. For example, in Cameroon, annual tomato (*Solanum lycopersicum* L.) production in 1998 was estimated to be 76,000 tonnes (Temple, 2001), valued at 40 million Euros (recalculated from Temple, 2001) of which only 5000 tonnes were exported. By 2009, annual production in Cameroon was estimated at 420,000 tonnes, with average fresh yields of 8 Mg ha^{-1} (FAO, 2009). Seasonal price variation is one order of magnitude, due to insufficient supply, and high perishability. Across Africa the production of high value horticultural crops is being recognized as a possible route out of rural poverty. For example, in Kenya, cultivating kale, tomatoes, and onions increased net profits of smallholders from US$91 to US$1665 ha^{-1} year^{-1} (Sanchez et al., 2001). Furthermore the health benefits of diversifying diets and including horticultural products have been recently emphasised by Keatinge et al. (2010).

A household survey conducted in the surroundings of Yaoundé, central Cameroon in 1997, identified tomato as the most important horticultural crop (36%), followed by dessert bananas and green maize (24%) (Gockowski and Ndoumbé, 2004). Fifty-seven percent of the households produced their most important market crop in intensive monocrop systems, the remaining 43% used the traditional "*mixed food crop field*" intercrop system to produce surpluses for the market (Gockowski and Ndoumbé, 2004). The traditional mixed food crop field is managed by women, whereas intensive horticultural monocrops tend to be managed by men. Intensified systems have only been recorded since the 1970's (Guyer, 1984). Diseases are the major constraints in intensive tomato systems with *Alternaria solani*, (early blight) and *Phytophthora infestans* (late blight) causing up to 100% yield loss (Fontem, 2003). In addition, the fruit fly *Dacus punctatifrons* Karsch (Diptera: Tephritidae), locally called "*mouche grise*" causes puncture marks, damaging the fruits and rendering them non-marketable (Tindo and Tamo, 1999).

In central and southern Cameroon, manual tillage using hand hoes is commonly done by women cultivating the mixed food crop field dominated by groundnut. For other crops tillage is avoided due to the high labour demand and the additional obstacles such as unburned debris and tree and shrub roots and stumps. However, in tomato production farmers frequently till, sometimes mound, because they consider it to increase yields and reduce weed competition. Manual tillage is highly labour-demanding, thus impacts labour productivity strongly negatively in the labour-constrained environment of smallholder agriculture. Tillage, depending on the type and frequency, can change soil physical properties and contributes to increased crop yields (Wanas, 2006; Tueche and Hauser, 2011), while Couper et al. (1979), Lal and Dinkins (1979), Lal (1997), on the contrary, obtained higher crop yields on no-till than on tilled plots. However, changes in soil physical and chemical properties due to tillage may lead to soil loss, increased fertilizer demand (Richardson and King, 1995; Schumacher et al., 1999; De Gryze et al., 2008; Stevens et al., 2009), shifts in the weed flora and with climate change becoming a global issue, to reduced C accumulation (Six et al., 2002a). The response to tillage of physical properties such as changes in porosity, disruption of soil aggregates, alteration of soil aggregate size, changes in temperature and moisture regimes is well documented (Odjugo, 2008). For farmers however, labour or capital input versus yields and gross returns need to ensure sufficient income. Farmers tend to change practices as yields decline, yet not necessarily are these changes based on verified knowledge and consideration of all technical options available.

For tomato farmers in southern Cameroon one option is to reduce labour input and move to no-till systems that may produce lower yields but potentially permit cultivation of more area. The contrary option is intensification through destumping the land after fallow periods and ensuring that all land is used and benefiting from the elimination of competition from sprouting stumps. Further intensification would comprise manual or mechanized tillage, whereby destumping offers the option of mechanized tillage with a tractor. After the initial labour investment of destumping, this would offer a lower labour input and thus the possibility to cultivate more area, if available.

To determine the yield response of tomatoes to various types of land preparation intensification, we conducted an on-farm experiment with a farmer group producing tomatoes in a village close to Yaoundé in the Lekié region. The working hypotheses were: (1) every step of intensification increases tomato yields and (2) tractor tillage increases yields to levels higher than the comparable manually tilled treatment; (3) soil physical properties degrade with every step of intensification and (4) tractor tillage degrades soil physical properties to levels lower than in the comparable manually tilled treatment. Our objective was to determine at which level of intensification tomato yields were maximized and which tomato cultivar responds best to intensification. We tested the response to intensification of three commonly used tomato varieties, monitored weed growth, pest and disease damage, tomato yield and yield components and changes in soil physical properties to recommend to farmers the intensification level most suited to maximize income while minimizing negative effects on soil physical properties.

4.3 Materials and Methods

4.3.1 Location

The study was carried out at Essong Mintsang (N 04^0 05’, E 11^0 35’) in the Central region of Cameroon on farmers’ land. The soil is classified as a Rhodic Kandiudult (Champetier de Ribes and Aubague, 1956, quoted in Koutika et al., 2008). The average annual rainfall is approximately 1570 mm year^{-1} in a bimodal distribution. The rainy seasons typically last from mid-March to mid-July and from mid-August to end of November. A short dry spell of about 4 weeks occurs in July and August. The major dry season is from the end of November to March.

4.3.2 Land preparation and experimental design

The experiment was a two-factorial split-plot blocked design with three replicates. The main plot factor was land preparation at five levels: (i) no destumping no tillage, (ii) destumping no tillage, (iii) no destumping with manual mound tillage, (iv) destumping with manual mound tillage, and (v) destumping with mechanical tillage. The sub-plot factor was the tomato cultivar: (1) Roma vf, (2) Rio Grande, the most common cultivar grown in Cameroon (Fontem et al., 1998), and (3) Rossol, a cultivar resistant to *Meloidogyne* spp. nematodes (Taylor, 1975).

Main-plot size was 12 m x 13.5 m and sub-plots were 12 m x 4.5 m. The land was under four-year-old fallow dominated by the common shrub *Chromolaena odorata* (L.) (King and Robinson, 1987). The *C. odorata* fallow was slashed using machetes in June and July 2005. The biomass was burned in August 2005 during the short dry season. The experiment was blocked according to stump density sorted into three categories of around 1000 stumps ha^{-1}; 900 stumps ha^{-1} and 600 stumps ha^{-1}. In September 2005, and on “destumped plots”, the soil around stumps and roots was dug and all stumps and vertical and lateral roots were cut at below 20 cm depth, using machetes and pick axes. Stumps and roots were discarded from the plots. Tillage was conducted either with a small single axle roto-tiller tractor to a depth of around 8-12 cm or with a hand hoe in late September 2005.

4.3.3 Tomato husbandry, pest and disease control and data collection

A tomato nursery was established in late August 2005 and plants were sprayed weekly using a 15 l knapsack sprayer with a mixture of Ridomil Gold plus (60g kg^{-1} metalaxyl-M $C_{15}H_{21}NO_4$ and 600g kg^{-1} Cu_2O), plantineb (80% Maneb) and cypercal 50 (50g/l cypermethrine).

Tomatoes were transplanted on 28 September 2005 at one plant per stand on a rectangular 0.75 x 1.0 m pattern, resulting in 13333 plants ha^{-1}. Pest and disease were controlled by a total of 11 weekly applications of 560 g ha^{-1} Ridomil Gold plus, 3100 g ha^{-1} plantineb and 60ml ha^{-1} cypercal, until 2 weeks before harvesting. At 6 weeks after planting (WAP), 7 g of NPK (20-10-10) fertilizer were applied around each tomato plant, being the equivalent of 18.7 kg ha^{-1} N and 9.3 kg ha^{-1} P and K.

Plots were weeded on 10 and 11 November 2005 by hand-pulling. Weeding time per sub-plot was recorded and there was one weeding team per block to avoid any bias due to different weeding practices or speeds between individuals. Weed fresh biomass per main-plot was weighed and a sub-sample taken for dry matter determination. Samples were dried at 40°C to constant mass, weighed and weed biomass (Mg ha^{-1} DM) was calculated.

A growth and health assessment was made on 16 plants in the middle of each subplot in mid November 2005 (6 WAP). The number of flowers, fruits, insect- damaged fruits and fungus-damaged fruits were counted.

Market ripe tomatoes were harvested on 9, 15 and 22 December 2005 and 6 January 2006. Yield was determined on 40 plants per subplot, excluding border plants. Fruits were separated into marketable and non-marketable, counted and fresh mass was recorded.

4.3.4 Soil measurements

Soil samples were collected before land preparation in June 2005 and in November 2005, at 4 weeks after planting. In June 2005, prior to plot establishment, soil sampling was conducted along two diagonals across the rectangular field at 10 m intervals. In November 2005, 16 samples were collected at 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm depths per main plot on a diagonal pattern using 5 cm long 100-cm^3 cylinders. Samples were oven dried at 40°C to constant mass for bulk density determination. All the samples were successively and systematically passed through a 10 mm sieve, and part of these were retained on a 4 mm sieve. Soil aggregates retained on the 4 mm sieve were thoroughly mixed and about a quarter (w1) was used for aggregate stability determinations. For accuracy in the analyses, the remaining soil was added to only 3 quarters of soil that were not retained on the 4 mm sieve (W), while the residual quarter was discarded. These fractions (W) were passed through a 2-mm sieve to separate coarse particles from fine earth and subsamples were used for particle size analysis (hydrometer method, Gee and Bauder 1986) and for available water capacity (AWC) (Cassel and Nielsen, 1986).

Aggregate stability was determined according to Angers and Mehuys (1993). The proportion of water stable aggregates (WSA_i) in each of the size fractions was calculated from the formula:

$$\mathbf{WSA_i = (w2_i - w3_i)/(w1/(1 + wc) - \sum w3_i)} \qquad (1)$$

Where i = 1, 2, 3, …, n-1, n and corresponds to each fraction in each sample; wc is the gravimetric water content; w1 is the weight of soil sub-samples dried at 40ºC and that had passed through a 10 mm sieve and retained on the 4 mm sieve; $w2_i$ is the weight of the aggregates on each sieve of the nest (4 mm; 2 mm; 1 mm; 0.250 mm 0.125 mm and the one that has passed the finest sieve: below 0.125 mm), dried at 105 ^{o}C; $w3_i$ is the weight of primary particles dried at 105°C collected from 0.053 mm sieve.

The mean weight diameter (MWD) used to express the size distribution was then determined as:

$$\mathbf{MWD = \sum\nolimits^{n}_{i=1} X_i\, WSA_i} \qquad (2)$$

Where i = 1, 2, 3, …, n and corresponds to each fraction collected, including the one that passes the finest sieve. $\mathbf{X_i}$ is the mean diameter of each size fraction (i.e., mean inter-sieve size); and $\mathbf{WSA_i}$ is as defined in (Eq.1).

The geometric mean diameter (GMD) was calculated after Mazurak (1950) as:

$$\mathbf{GMD = exp[\Sigma^n{}_{i=1}\ WSA_i \log X_i / \Sigma^n{}_{i=1}\ WSA_i]}$$

The proportion of wet stable aggregates (WSA) were separated into macro- meso- and microaggregates of the following size categories ($WSA_4 + WSA_2$); ($WSA_1 + WSA_{0.25}$) and ($WSA_{0.125}$ and below) respectively.

The values for 0-10 cm and 10-20 cm were obtained from the mean of 0-5 and 5-10 cm and 10-15 and 15-20 cm depths respectively.

4.3.5 Data analysis

Data were analysed using SAS v 9.1. Analysis of variance (ANOVA) was performed using General Linear Procedure "Proc GLM" with the random statement appropriate for split-plot designs. The Least-Means/PDIFF option was used to test the significance between land use systems and treatments. Data expressed as percentages were transformed such that Y = arcsine ($\sqrt{y}$) where $0 \leq y \leq 1$ as is appropriate for proportions (Sokal and Rohlf, 1995). All other data analyses were performed on untransformed data. Differences up to $p<0.05$ are reported as "significantly different". Differences up to $p=0.1$ are presented as "different".

Correlations were computed with Proc CORR, multiple regressions with proc REG using stepwise selection with an entry / exit limit of $p= 0.1$.

4.4 Results

4.4.1 Labour requirements for destumping and tillage

Destumping is a labour intensive operation and required on average 1250 hours ha^{-1}. Manual tillage required 216 hours ha^{-1}, while tractor tillage was conducted within 39 hours ha^{-1}. Thus labour input for intensification ranged from 0 hours ha^{-1} (no-destumping , no-till) to a maximum of 1466 hours ha^{-1} (destumping & manual tillage) with only manual tillage (no destumping) at 216 hours ha^{-1}, destumping without tillage at 1250 hours ha^{-1} and destumping & tractor tillage at 1289 hours ha^{-1}.

4.4.2 Tomato growth parameters, pest and disease assessments and yield

Tomato establishment was 94% on average without differences between treatments. At 6 WAP, cultivar Rossol had more flowers (521126 ha^{-1}, P=0.09) than cv. Rio Grande (403930 ha^{-1}), with cv. Roma (504718 ha^{-1}) not being significantly different from either variety. Cv. Rossol produced more fruits (200497 ha^{-1}, P=0.07) than cv. Roma (142014 ha^{-1}) and cv. Rio Grande (132270 ha^{-1}).

In the destumped tractor till system tomatoes had more flowers (623275 ha^{-1}, P=0.03) than in the stumps-retained no-till (428547 ha^{-1}) and in the destumped no-till (290689 ha^{-1}) systems; which were not different from one another. Tomatoes in the destumped manual till system (507522 ha^{-1}) and the stumps-retained manual tilled (532924 ha^{-1}) did not differ in flower numbers from each other but had significantly more flowers than in the destumped no-till system (Figure 4.1).

Tomatoes in the destumped manual till system had more fruits (236001 ha^{-1}) than in the stumps-retained manual till (162055 ha^{-1}), in the destumped no-till system (104420 ha^{-1}) and in the stumps-retained, no-till (107687 ha^{-1}) systems. The number of fruits in the destumped tractor till treatment (171136 ha^{-1}) was not different from any other treatment (Figure 4.1). Across treatments, 3.4% of fruits were attacked by larvae or punctured by flies and 13.7% of fruits had symptoms of fungal infection without significant differences between treatments.

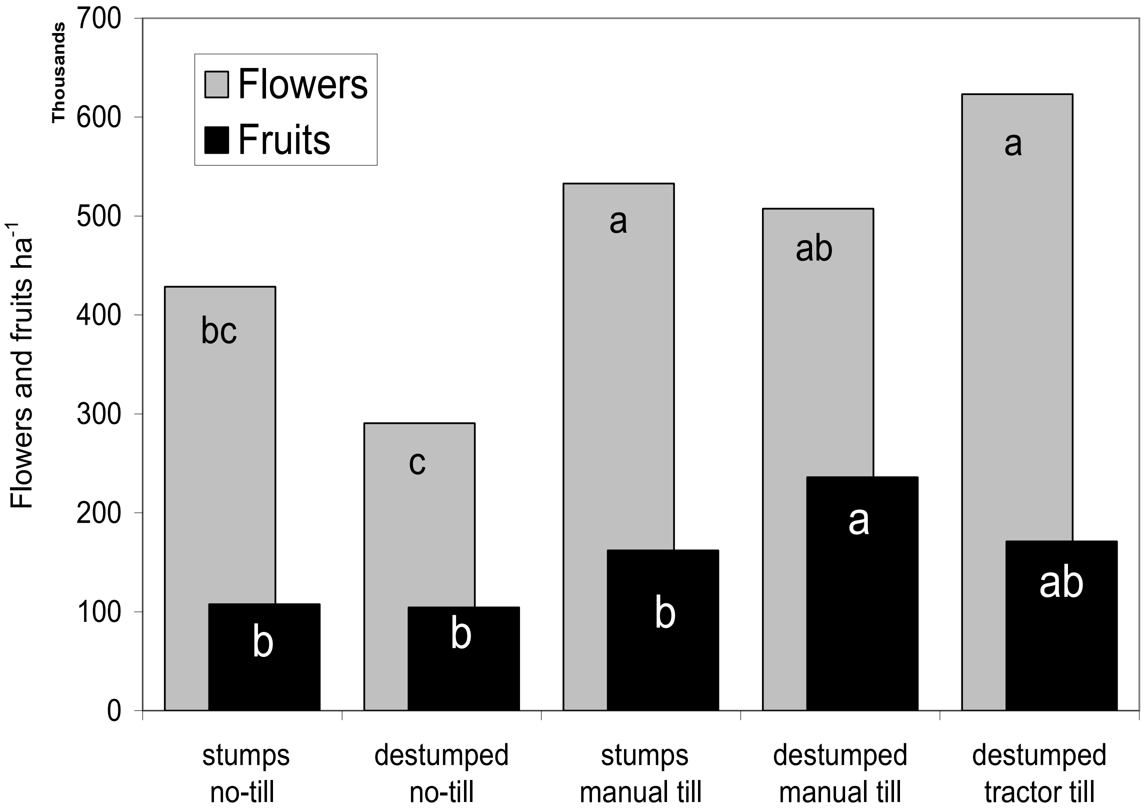

Figure 4.1: Effects of land preparation on number of flowers and fruits at 6 WAP. Columns of the same type labelled with different letters are significantly different at *P*=0.03 for flowers and *P*=0.07 for fruits.

Total fresh yield of cv. Rossol (8.12 Mg ha^{-1}) was significantly higher (*P*=0.005) than that of cv. Roma (6.05 Mg ha^{-1}) and cv. Rio Grande (4.46 Mg ha^{-1}); the latter two being significantly different (*P*=0.03) from one another. The marketable yields of cv. Roma (3.65 Mg ha^{-1}) and cv. Rio Grande (2.68 Mg ha^{-1}) were not different but significantly lower (*P*= 0.005) than that of cv. Rossol (5.28 Mg ha^{-1}).

Total tomato yields were higher in the destumped tractor till, the destumped manual till and the stumps-retained manual till treatments than in the stumps-retained no-till treatment (Figure 4.2). The yield in the destumped no-till treatment was not different from any of the treatments. The marketable fresh yield was not significantly affected by tillage and destumping. The increased intensification through tillage and destumping increased the non-marketable yield (Figure 4.2). The proportion of non-marketable yield increased from 33% in stumps retained and tilled to 39% in destumped and tilled and 41% in the destumped and tractor tilled treatment.

Tomato cultivar by land preparation interaction was not significant. However, the fruit number (not shown) and the total fresh yield of cv. Rio Grande showed no noticeable response to land preparation, while cvs. Roma and Rossol had visibly increased total fresh yields when the soil was tilled (Figure 4.3).

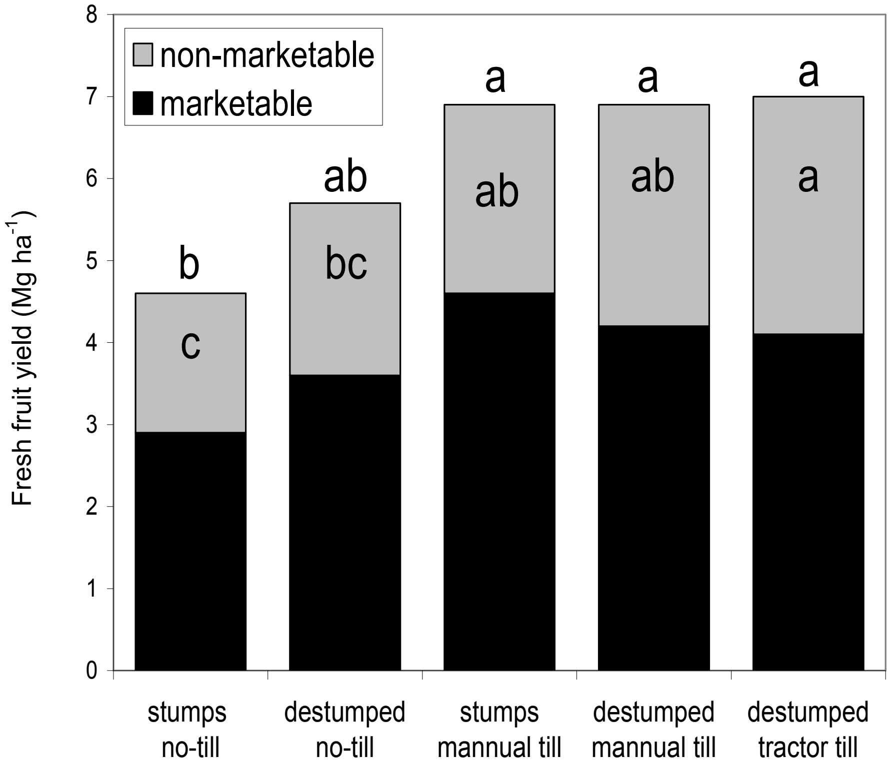

Figure 4.2. Effects of land preparation on tomato marketable, non-marketable and total fresh fruit yields (Mg ha^{-1}). Marketable fruit yields were not significantly different, different letters in non-marketable columns indicate significant differences at *P*<0.033, different letters above columns indicate significant differences of total fruit yields at *P*<0.016.

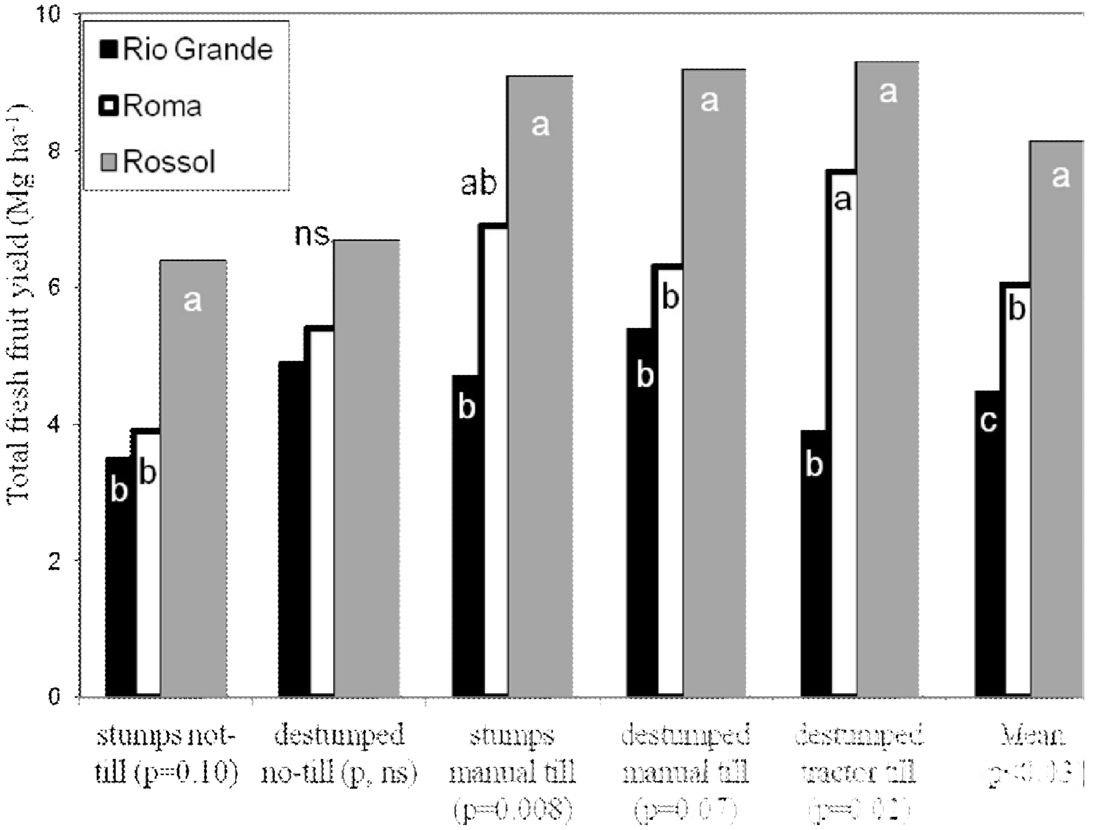

Figure 4.3. Effects of land preparation and cultivar on tomato total fresh fruit yields (Mg ha^{-1}). Different letters in columns for indicate significant differences at the indicated *P* values.

4.4.3 Weeds

The average weed biomass was 524 kg ha^{-1} and lowest in the tractor-till treatment (327 kg ha^{-1}), yet without significant differences between land preparation treatments (Table 4.1). The time required for weeding was less in destumped manual till (153 hrs ha^{-1}) and tractor till (157 hrs ha^{-1}) treatments than in stumped retained manual till plots (243 hrs ha^{-1}, *P*=0.05). The other treatments were not significantly different from each other (Table 4.1).

Table 4.1: Effects of land preparation method on weed biomass and weeding duration. n=3, values within the same column followed by different letters are significantly different at $P < 0.05$. Mean ± standard error of the treatment mean.

Land preparation	Weed dry mass (kg ha^{-1})	Weeding duration (hrs ha^{-1})
Stumps retained no till	584 ± 148	168^{ab} ± 50
Destumped no till	578 ± 251	184^{ab} ± 18
Stumps retained manual till	676 ± 172	243^{a} ± 2
Destumped manual till	660 ± 161	153^{b} ± 25
Destumped tractor till	327 ± 147	157^{b} ± 19
P (land preparation)	ns	0.05

ns, not significant. Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

4.4.4 Soil physical properties

The soil was sandy clay with 47.5% sand, 11.6 % silt and 40.9 % clay across the 0-20 cm depth, without significant changes with depth. Prior to land preparation soil bulk density was 1.0 and 1.3 Mg m^{-3} at 0-10 and 10-20 cm depth, respectively. The soil had a high proportion of soil macroaggregates (77.3 %), a MWD of 5.2 mm and a GMD of 1.6 mm and a low proportion of soil mesoaggregates (10.6 %) and microaggregates (12.1 %). Soil AWCs were 0.17 Mg Mg^{-1} and 0.21 Mg Mg^{-1} for 0-10 and 10-20 cm depths, respectively.

Bulk density was unaffected by the treatments. The destumped manual till treatment had significantly higher available water capacity (AWC) than the stump retained manual till treatment at 0-10 cm (P=0.03) and the stumps retained no tilled treatment at 10-20 cm (P =0.05) depths. The other treatments had similar AWC, and were not significantly different from each other (Table 4.2).

Table 4.2: Effects of land preparation method on bulk density (BD, Mg m^{-3}), available water capacity (AWC) in cm m^{-1}, % of soil macro.- meso.- and microaggregates, soil Mean Weight Diameter (MWD, mm) and Geometric Mean Diameter (GMD, mm) in the 0-10 and 10-20 cm soil depths. n=3, values within the same column followed by different letters are significantly different at $P < 0.05$.

Depth	0-10 cm						
Property	BD	AWC	Macro	Meso	Micro	MWD	GMD
	Mg m^{-3}	Mg Mg^{-1}	---------------------(%)-------------------			-----------mm----------	
stumps retained no till	1.05 ± 0.05	0.14^{ab} ± 0.01	81.0^{a} ± 5.7	10.4^{b} ± 3.4	8.6 ± 2.9	5.3^{a} ± 0.4	1.7^{a}± 0.1
destumped no till	1.10 ± 0.07	0.14^{ab} ± 0.00	75.9^{a} ± 6.6	14.6^{b} ± 5.6	9.5 ± 1.0	5.0^{a} ±0.4	1.7^{ab}± 0.1
stumps retained manual till	1.00 ± 0.07	0.13^{b} ± 0.01	83.0^{a} ± 3.6	7.3^{b} ± 1.5	9.7 ± 2.2	5.4^{a} ± 0.2	1.8^{a}± 0.1
destumped manual till	1.08 ± 0.03	0.15^{a} ± 0.01	75.7^{a} ± 6.0	14.9^{b} ± 4.6	9.4 ± 1.5	5.0^{a} ± 0.4	1.6^{ab}± 0.1
destumped tractor till	1.07 ± 0.02	0.15^{ab} ± 0.01	60.2^{b} ± 2.0	26.8^{a} ± 1.5	12.9 ± 1.6	3.7^{b} ± 0.1	1.4^{b}± 0.0
P (land preparation method)	ns	0.03	0.056	0.05	ns	0.02	0.03

	10-20 cm	
	BD	AWC
	Mg m^{-3}	Mg Mg^{-1}
stumps retained no till	1.22 ± 0.01	0.11^{b} ± 0.02
destumped no till	1.23 ± 0.02	0.13^{ab} ± 0.01
stumps retained manual till	1.29 ± 0.07	0.12^{ab} ± 0.01
destumped manual till	1.16 ± 0.03	0.14^{a} ± 0.01
destumped tractor till	1.24 ± 0.07	0.12^{ab} ± 0.01
P (land preparation method)	ns	0.05

ns, not significant. Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

Soil aggregates were the least stable in the destumped, tractor till treatment. This treatment had significantly lower MWD (*P*=0.02), macroaggregate proportions (*P*=0.056) and higher mesoaggregate proportions (*P*=0.05) than the other treatments; which were not different from each other (Table 4.2). GMD in the stumps-retained treatments, both no till and manual till, were significantly (*P*=0.03) larger than in the destumped tractor till treatment. The other treatments had similar GMD and were also not different from each other (Table 4.2). The proportion of soil microaggregates were unaffected by land preparation methods (Table 4.2).

4.4.5 Productivity gains through intensification

Compared with the not destumped no-till system, only the not destumped manual tillage system made considerable gains per extra hour labour. Destumping appears too labour intensive to return adequate gains. Although not statistically confirmed it appears that the cultivar Rio Grande has the poorest response in yield gains from intensification while Roma showed strong fruit mass gains per hour labour spent on manual tillage (Figure 4).

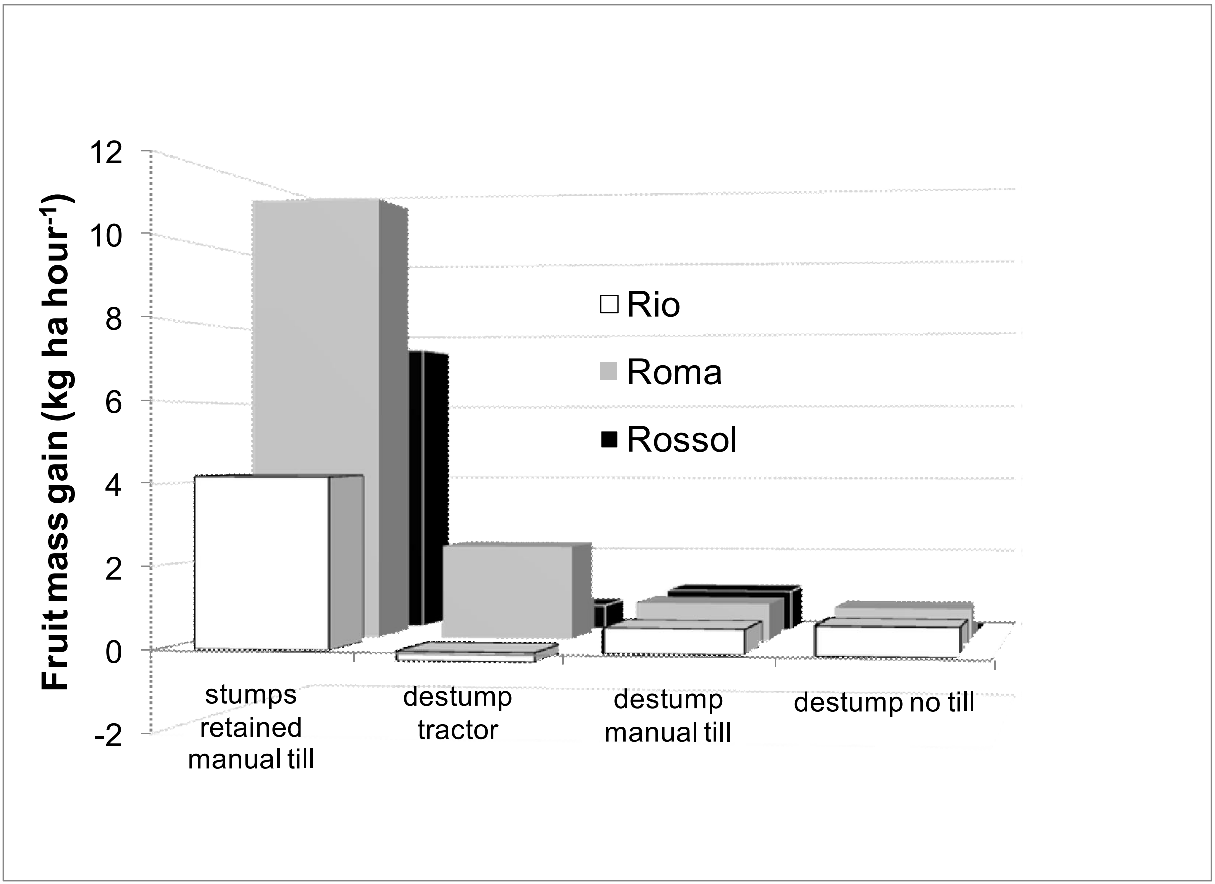

Figure 4.4: Marketable fruit mass gain per ha and hour of extra labour of three tomato varieties by combinations of destumping and manual or tractor tillage.

Roma and Rossol had similarly strong fruit number gains from manual tillage (Figure 5) with virtually no response by Rio Grande. Not considered here is the 60-90 hours ha^{-1} higher labour demand for weeding in the not destumped manual tillage treatment (Table 1). However, compared to the > 1000 hours ha^{-1} difference between retaining stumps and destumping, these differences appear small and thus negligible.

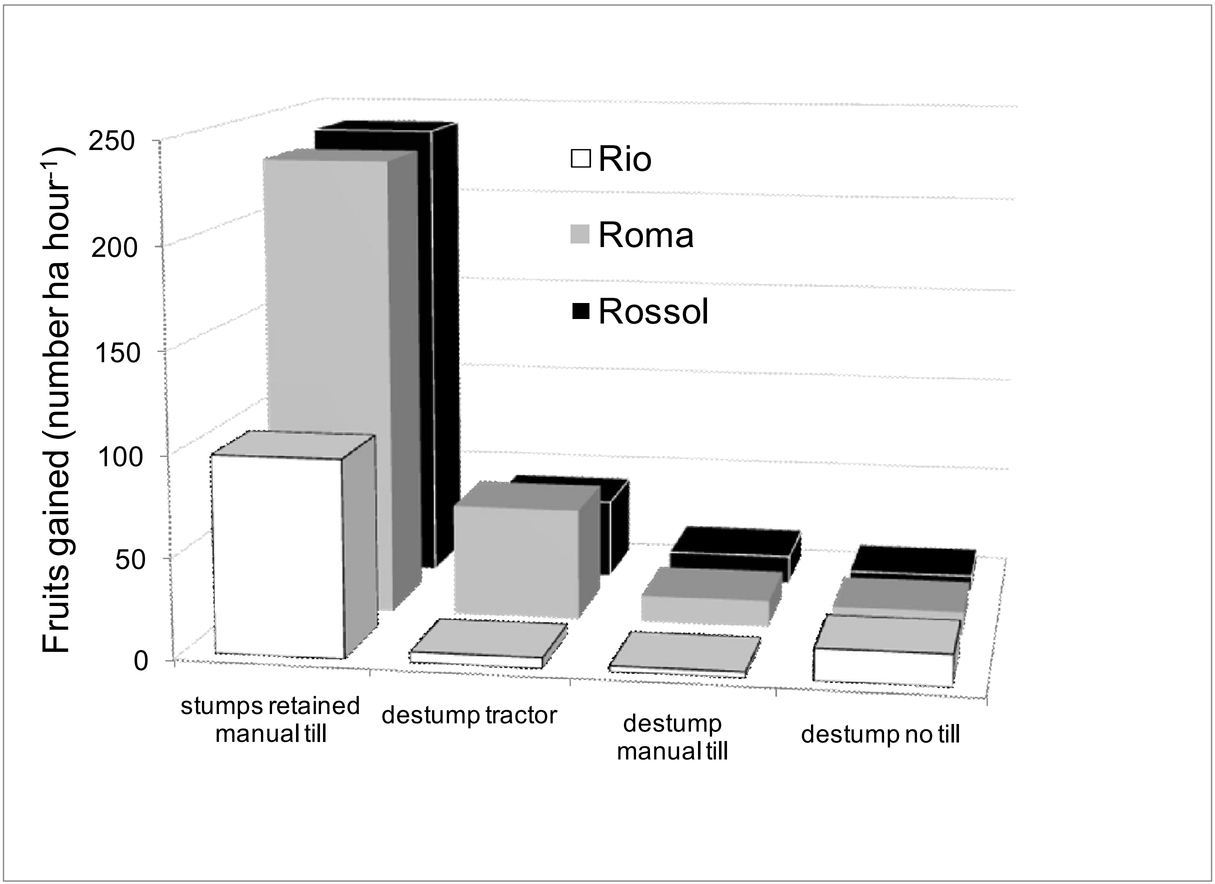

Figure 4.5: Marketable fruit number gain per ha and hour additional labour of three tomato varieties by combinations of destumping and manual or tractor tillage.

4.4.6 Correlations between soil physical properties and tomato yield

Across tomato cultivars and treatments, tomato yields were significantly negatively correlated to sand and silt contents, MWD, GMD and the proportion of macroaggregates, with r ranging from -0.51 to -0.64 and from $p \leq 0.05$ to 0.01. The proportion of meso- and microaggregates, clay content and AWC were significantly positively correlated to yields, with r ranging from +0.50 to +0.68 and $p \leq 0.05$ from 0.01 (Table 4.3).

Marketable yield was positively correlated with clay content and bulk density and negatively with macroaggregate proportions such that:

For 0-10 cm soil layer:

Marketable yield = 0.12 Clay - 0.14 Macroaggregate +12.20

(with R^2=0.50, n=15 & P=0.016)

For 10-20 cm soil layer:

Marketable yield = 0.17 Clay + 5.15 Bulk density -10.25

(with R^2=0.58, n=15 & P=0.005)

4.5 Discussion

Across cultivars and land preparation methods the fruit yield of ~6 Mg ha^{-1} was similar to that determined by Adekiya et al. (2009) who studied the effects of tillage methods on yield of tomato on an Alfisol of Southwestern Nigeria. However, because our results were cultivar dependant, comparisons should be made with caution. The importance of cultivar by environment interaction is demonstrated by the fact that cultivar Rio Grande produced lowest yields in our trial while it produced twice as high yields than cv. Rossol at Foumbot on a deep Andosol in the Western Highlands of Cameroon under similar rainfall conditions but greater daily temperature fluctuations (decreasing to 12.3° C at night) at an altitude of 1100 m absl (Tonfack et al., 2009). The yield differences between cultivars in our study could not be explained by insect pest and disease damage. Insect damage on 3.4% of fruits was much lower than the 12.2 - 16.0 % reported by Tindo and Tamo (1999). Cultivar Rossol produced more flowers and may have benefitted from earlier flowering and fruit set, which might be crucial in rainfed agriculture when the rainy season is short, as in our situation. Earlier flowering and fruit set combined with nematode tolerance or resistance are probably the main contributing factors to the high yields of cv. Rossol. It can be assumed that only cultivars with functional

Table 4.3: Correlations coefficients (r) between soil physical properties (sand, silt and clay contents, the proportions of soil macro.-, meso.-, and microaggregate, MWD, GMD and AWC) and tomato yield across tomato cultivars and treatments. n=45.

	NMF[1]	TNF[2]	MFFM[3]	TFFM[4]
0-20 cm				
Sand	-	-	-0.61*	-0.59*
Clay	-	-	0.67**	0.65**
Silt	-	-0.50*	-	-
0-10 cm				
Sand	-	-	-	-0.52*
Clay	-	-	0.61*	0.64**
Silt	-0.54*	-	-0.56*	-0.51*
Macroaggregates	-0.56*	-0.54*	-0.52*	-0.55*
Mesoaggregates	-	0.53*	-	0.53*
Microaggregates	0.57*	-	0.60*	-
MWD	-0.55*	-0.53*	-	-0.52*
GMD	-0.61*	-0.55*	-0.58*	-0.58*
10-20 cm				
Sand	-	-	-0.64**	-0.57*
Clay	-	-	0.68**	0.63**
AWC	-	-	0.63**	0.54*

** = $0.001<p\leq0.01$; * = $0.01<p\leq0.05$; [1]number of marketable fruit; [2]total number of fruit; [3]marketable fruits' fresh mass; [4]total fruits' fresh mass

root systems are capable to benefit from higher nutrient availability after tillage (or any other form of intensification). Nematode pressure is high in the area. Banful et al. (2008), working at two sites within the same village found >100 individuals of *Helicotylenchus* spp., a major tomato pest, 100 cm^{-3} soil under *C. odorata*. However, nematode damage was not measured in our trial. For the tomato producer a change to cv. Rossol appears appropriate in areas with comparable soil and climate.

Although not all yield parameters had a significant response to the land preparation treatments, tillage, irrespective of whether manually or by tractor, resulted in higher tomato yields. This agrees with results reported by Adeoti and Olarewaju (1990) who compared no-tillage, manual tillage and tractor tillage on tomato grown on a sandy loam soil in the humid savannah of Nigeria. Similarly, Adekiya et al. (2009), working on a Luvisol in humid tropical Nigeria found that no till systems yielded 5 Mg ha^{-1} compared to 7 Mg ha^{-1} under manual mounding. Considering that the higher total yields in tilled treatments found in this study did not correspond with higher marketable yields, suggests that regarding income, manual till without destumping is a sufficient level of intensification. Additional destumping or tractor tillage only increased the proportion of non-marketable fruit. The data on labour productivity confirm this recommendation. Labour is a limiting factor and prices for hired labour are relatively high in peri-urban areas. Thus farmers need to abstain from unproductive labour investment.

Tillage, whether manual or by tractor, was associated with a higher proportion of soil mesoaggregates and a reduction in macroaggregates. Aggregate stability was reduced in the tractor till treatments. These results agree with those of Jiang et al. (2011) who found that tillage reduced the macroaggregate fraction, reducing aggregate stability by 35% more than no till systems. While the reduction in aggregate stability had no negative impact on yield in the current trial, it might affect soil erosion rates and thus yield in future. Kirchhof and Salako (2000) found that, in spite of six-years of fallow and cover crop use, soil erosion was 30% higher on plots that had been ploughed previously compared with no-till plots. Tractor tillage might disrupt macroaggregates, which are probably constituted of smaller aggregates bound together by cementing agents like clay, organic matter, Fe_20_3 (Tisdall and Oades, 1982), Ca and Mg (Salako and Hauser, 2001; Tueche et al., 2007), or by fungal hyphae and/or some type of organic or amorphous material (Gupta and Germida, 1988). This disruption of macroaggregates may contribute to the release of nutrients contained in the cementing agents. There will also be a change in microbial dynamics (Six et al., 2006) accelerating mineralization of the previously entrapped organic matter. In such a soil sphere, the spread of roots will be easier and the uptake of nutrients will be facilitated justifying higher tomato yields in the tractor tilled treatment. However, there is a balance to be found to maximise the proportion of mesoaggregates by breaking up macroaggregates yet avoiding a high proportion of microaggregates and thus soil structural loss. In our trial, whether or not plots were destumped had no consistent effect on yield.

The significantly higher AWC in the destumped manual till treatment than the stump retained manual till treatment at 0-10 cm and the stumps retained no tilled treatment at 10-20 cm depths was associated with the highest proportion of fine soil particles (clay + silt), which are generally positively related to AWC (Pidgeon, 1972; Bouma et al., 2003).

Bulk density was not affected by tillage and this agrees with results of Tueche and Hauser (2011), working on similar clayey, kaolinitic, Typic Kandiudult. On soils with high BD of around 1.6 Mg m^{-3}, Adekiya and Ojeniyi (2002) and Adekiya et al. (2009), found reduced BD after tillage on Alfisol in Southwestern Nigeria. However, at low BD of around 1.0 Mg m^{-3}, it is unlikely that it can be further reduced by tillage. The correlations indicate that all factors related to water retention had a positive effect on yields. On a very loose soil, factors increasing unsaturated conductivity may be important to ensure water supply to the crop. Under the conditions encountered here any further loosening did not contribute to yield increases. Tillage increased yields and this might be related to improved nutrient supply, which might be due to enhanced SOM decomposition, nutrient mineralization, and microbial activity associated with tillage (Hendrix et al., 1986; Stevens, 1986 cited by Follett and Peterson, 1988; Mishra, 2010) rather than to better soil physical conditions. MWD was negatively correlated to yield, as also found by Tueche and Hauser (2011). On the contrary, Lal et al. (2000) and Jagadamma et al. (2008) found that MWD positively correlated to yield. However, in the present study, MWD ranged from 3.7 to 5.4 mm, while Lal (2000) reports 1.3 to 2.7 mm and Jagadamma et al. (2008) found MWD of about 0.4 to 1.0 mm. Thus it is likely that in the present study the MWD was too large to ensure sufficient water supply (through capillary connection) and anchorage in a firm soil.

Lal (1997) found as well positive correlation of crop yield with clay content, however only up to a clay content of about 18% yet on a relatively fertile Alfisol. In the present study the positive correlation between clay content and tomato yield covered a range of higher clay contents of 31 to 50 %, thus, land management should prevent the decline of soil clay content to sustain soil quality and productivity.

The currently used amount of fertilizer is obviously too small to supply a sufficient amount of N, P and K, favouring a potential positive effect of tillage on nutrient mineralisation.

4.6 Conclusion

Tillage rather than destumping had positive effects on yields and labour productivity of the tomato cvs. Roma and Rossol. Cultivar Rossol is recommended for the area. Tractor tillage did not increase yield and thus cannot be recommended, based on our results. The high proportion of non-marketable fruit would warrant more research on crop protection and improved pest and disease diagnosis as the current practice is to spray by the crop calendar rather than to use a targeted pest and disease control approach. Increased and well timed fertilizer applications may further increase yields.

Chapter 5

Residual effects of previous tillage system on maize growth and soil physical properties in central Cameroon

5. Residual effects of previous tillage system on maize growth and soil physical properties in central Cameroon[4]

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5.1 Abstract

The objectives of this study were to assess the residual effects on maize growth and yield as well as impacts on soil physical properties, from the previous land preparation (PLP). The PLP consisted of five treatments: (1) stumps retained no till; (2) destumping no till; (3) stumps retained manual till; (4) destumping manual till, and (5) destumping tractor till. The experiment was conducted on an Ultisol at Essong Mintsang, where a relay crop of maize followed that of tomato. At tasselling, chlorophyll content (*p*=0.069) was significantly lower in stump retained non tilled treatments. Manually tilled treatments generally had the highest values. At harvest, maize fresh cob yield was significantly (*p*<0.05) lower in stump retained no till treatments. The equivalent maize dry grain yields varied from 2.35 Mg ha^{-1} in the stump retained no-till treatment to 4.16 and 4.33 Mg ha^{-1} in the manual till stump retained and destumped treatments, respectively. Soil aggregates were the least stable in the destumped tractor till treatment, with significantly lower (*p*=0.10) geometric mean diameter than in the

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[4] This chapter will be submitted for publication to a journal.

destumped manually till treatment. Maize fresh cob yield could be determined by soil aggregation and cone resistance to soil penetration (R^2~0.50 and p=0.037).

Keywords

Cameroon, destumping; maize, manual tillage; no destumping; soil physical properties; tractor tillage; Ultisol.

5.2 Introduction

Maize is the world's second most important crop in terms of production per annum, which was estimated to be 429 million tonnes in 2009 (FAO, 2009). In West and Central Africa, it occupies 21% of the area devoted to cereals and mean annual consumption is 43 kg per capita (Pingali, 2001). Maize grain yields in the humid zone of West and Central Africa tend to be low at 0.9 – 2.4 Mg ha^{-1} (Jones and Thornton, 2003).

In Cameroon, maize production, particularly in the vicinity of cities, is increasingly market-orientated and consumed as fresh cobs rather than as dry grain. In a household survey conducted in 1997 in the hinterland of Yaoundé, central Cameroon, of 34 horticultural crops ranked as the first or second most important source of revenue, green maize was cited by 24% and was amongst the top three crops (Gockowski and Ndoumbé, 2004). Nutritionally, maize is higher in protein (8-11% of kernel dry mass) (FAO, 1992) than cassava (1 to 6.4% of dry mass) (Ceballos et al., 2006), cassava (1.8%), plantain (3.1%) and yam (7.7%) (Payne, 1969), the other common staples consumed in this agroecozone.

While some farmers in North West Cameroon use mechanical tillage, where entrepreneurs may own a tractor and better-off farmers hire tractors by the day, the ownership and use of tractors is rare in the humid south of the country, where small field size, forest regrowth and tree and shrub stumps render their movement difficult.

In this region, agricultural systems are crop-fallow rotations derived from the traditional shifting cultivation system (Hauser and Norgrove, 2001). Farmers traditionally rely on stumps of re-growth, as well as fallow seed banks for the re-establishment of fallow (Buresh and Cooper, 1999). In general, adoption of mechanical tillage tends to be slower in forest areas. However, as population densities increase, according to Pingali et al. (1987), farmers will destump their land when their use of short bush-fallows starts to give low returns to labour. In central and southern Cameroon, tillage using hand hoes, has been traditionally done by women in mixed food crop fields dominated by groundnut and stumps tend to be avoided in the field or, if those areas are rich in ash, planted to pockets of nutrient-demanding crops (Büttner and Hauser, 2003).

Manual till compared with no-till systems are highly labour-demanding and thus have a strong impact on productivity in this labour-constrained environment. However, the effects of tillage on crop yield and soil properties seem not to be consistent across crop species and soil types. For example, Couper et al. (1979), working on an Alfisol in the forest-savannah transition zone of south west Nigeria, found that maize grain yields were three times higher on no-till than on tractor-tilled plots for six consecutive years. Furthermore, tillage is likely to lead to soil surface roughness. Depending on its frequency and kind, tillage can destroy soil aggregates and result in degradation of soil structure, with immediate consequences on the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Mamman and Ohu (1997) observed a regular increase in soil bulk density and penetrometer resistance and a reduction in air permeability as tractor usage increased. Crop yield and leaf area index (LAI) decreased sharply when the degree of compactness exceeded values of ~ 91 and 88%, respectively (Lipiec et al., 1991).

Yet in spite of many studies on soil loss from erosion plots in the tropics, only a few included the traditional farmers' practice of mound tillage (Salako et al., 2006). Tillage has been shown to alter microbial communities in the soil. Jansa et al (2003) demonstrated how tillage, compared with no till, altered the community structure of mycorrhizae by depressing colonization of maize roots by one genus but promoting colonization by another. Furthermore stumps retained in fields may be sources of mycorrhizae so their removal would also impact this dynamic. Clearly yield, labour and ecological trade-offs need to be understood to optimise systems.

Here we conducted an on-farm experiment in association with a farmers' group (GIC) to compare current farmer practice of tomato cultivation (stumps retained, manual mound till) with: stumps retained, no till; destumping, no till; destumping, manual (mound) till; and destumping, tractor till. Results from the tomato cultivation are in Tueche et al. (2013). We then followed tomato cultivation with a relay crop of maize to assess any residual effects of land preparation on maize growth, yield and yield components as well as medium term impacts on soil physical properties.

5.3 Materials and Methods

5.3.1 Location

The study was carried out at Essong Mintsang (N 04º 05', E 11º 35') in the central province of Cameroon on farmers' land. Soil is classified as Ultisol, Rhodic Kandiudult (Champetier de Ribes and Aubague, 1956, quoted in Koutika et al., 2008). The soil was a sandy clay with, on average, 47.5% sand, 11.6 % silt and 40.9 % clay at 0-20 cm depth (Tueche et al., 2013). The average annual rainfall is approximately 1570 mm p.a. in a bimodal distribution. The first and second growing seasons last typically from mid-March to mid-July and from mid-August to end of November, respectively. A short dry spell of about 4 weeks occurs in July. The major dry season is from the end of November to March.

5.3.2 Land preparation and experimental design

The experiment had a one-factorial design with land preparation at five levels: stumps retained no till; destumping, no till; stumps retained, manual (mound) till; destumping, manual (mound) till; destumping, tractor till. Plot size was 12 m x 13.5 m. The experiment was conducted in six replicates. Three replicates were placed in a four- year-old fallow dominated by the common shrub *Chromolaena odorata* (L.) King and Robinson, 1987), a perennial shrub which often dominates the weed flora in open fields (de Rouw, 1991) and in young fallows (Slaats et al., 1996). The remaining three replicates were placed in a ten-year-old forest fallow dominated by *Trema orientalis* (L.) Blume, a pantropical tree, which, as a pioneer, dominates recently disturbed forest (e.g. Eilu and Obua, 2005, Styger et al., 2009).

The experiment was blocked by fallow type and the density of tree and shrub stumps: sorted into three categories, in the *C. odorata* fallow: around 1000 stumps ha^{-1} 900 stumps ha^{-1} and 600 stumps ha^{-1}; and in the forest fallow: around 1800 stumps ha^{-1} 1500 stumps ha^{-1} and 1000 stumps ha^{-1}. In addition to the experimental treatments, there were three areas per fallow type where the fallow vegetation was retained as undisturbed controls. Slashing of the *C. odorata* fallow and the forest fallow was conducted using machetes. Clearance was conducted in June and July 2005. The field was burned in August 2005 during the short dry season. In September 2005, and on "destumped plots", shallow holes were dug around the tree stumps and roots using pickaxe and shovel. All tree stumps, vertical and lateral roots were cut with machetes or chainsaw at below 20 cm depth. Stumps and roots were discarded from the plots. Tillage was conducted either with a small single axle roto-tiller tractor to a depth of around 8-12 cm or with a hand hoe. Plots were tilled in late September 2005 and cropped to tomato at 13333 plants ha^{-1}. Pest and disease control was done on a weekly basis until 2 weeks before harvesting, following farmer practice. This comprised 560 g ha^{-1} of Ridomil Gold Plus (60 g kg^{-1} of metalaxyl-M $C_{15}H_{21}NO_4$ and 600g kg^{-1} Cu_2O), 3100g ha^{-1} of plantineb (80% of Maneb) and 60 ml ha^{-1} of cypercal 50 (50 g l^{-1} of cypermethrine) per application, and there were 11 applications during the cropping season. 7g of 20-10-10 fertilizer (20 % N, 10 % P and 10 % K) was placed around each tomato plant, being the equivalent of 18.7 kg ha^{-1} N and 9.3 kg ha^{-1} P and K in mid-November, 2005 at 6 weeks after tomato planting (WAP). Tomatoes were harvested from December 2005 - early January 2006. In late February 2006, the fallow regrowth was slashed. It was dominated by *C. odorata* in the previously short fallow plots and *Trema orientalis* in the previously forested plots. Sub plots were disregarded. Plots were planted to *Zea mays* (L.) sub-species *mays* c.v. CMS 8704, a 100-day open pollinated yellow-grained hybrid, in mid-March 2006. CMS 8704 is the most commonly grown cultivar of maize in Cameroon (Aroga, et al. 2001). Planting density and pattern was 0.75 m intrarow spacing, 0.5 m interrow spacing and 2 seeds per pocket. Due to good growth, no weeding was required during the season. No fertilizer or pesticides were applied to the maize.

5.3.3 Maize growth and yield assessments

On 4 and 5 April 2006, establishment rates were assessed throughout the plots, missing plants counted and reseeded where missing.

Plant growth was evaluated at tasselling from 12-18 May 2006 in 6 pockets (12 plants) per plot. Plant height, circumference at ground level, and the number of living leaves were measured. Chlorophyll was measured on six plants per plot on the first and second fully matured leaf per plant and at 20 positions per leaf near the centre. Chlorophyll readings were made with a Hydro-N tester. This meter measures the relative amount of chlorophyll present (Piekielek and Fox, 1992). Chapman & Barreto (1997) used chlorophyll meter readings to estimate leaf N concentration in maize in tropical Mexico and found a linear correlation of $r^2 = 0.81$.

Maize was harvested on 14 June 2006 in the selected pockets. Living plant numbers, density, height, living leaves, girth, number of cobs and fresh mass of the cobs were recorded in 6 pockets per plot. Leaf area was measured on two plants per plot on all living leaves per plant using a LICOR LAI 2000 leaf area meter. Necrotic leaf area was excluded. LAI (m^2 leaf m^{-2} ground) was calculated as leaf area per plant multiplied by actual plant density. Cobs from the whole plot were collected on 18 June 2006 and yields were calculated by combining data from the sampled area and the whole plot.

5.3.4 Soil measurements

Soil samples were collected before land preparation in June 2005 (Tueche et al., 2013), before tomato harvest in November 2005, before maize planting in February 2006 then during the resultant fallow phase after maize in April 2007. In June 2005, prior to plot establishment, soil sampling was conducted in the two diagonals were made on the whole rectangular field and soil samples and field measurements were carried out at every 10 m on these diagonals. Subsequently, in 2005, 2006 and 2007, 16 core samples were collected per plot using a 100-cm^3 cylindrical soil core of 5 cm depth. Samples were taken at depths of 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm, in a diagonal pattern. Soil was dried at 40ºC to constant mass and weighed.

Soil temperature and soil volumetric water content were measured simultaneously at 0-10 cm and 0-5 cm depths respectively at three points per plot in May 2006 once per week for 2 consecutive weeks. Temperature was read with a hand-held thermometer. Soil moisture was measured with a three-pronged Thetaprobe. The readings were made twice per day in the morning (t1) (at around 8.30-9.00am), and in the afternoon (t2) (2.00-4.00pm).

Soil strength was measured before the establishment of the plots (June 2005) and in May 2006 using the hand penetrometer Eijkelkamp type. The cone of penetrometer resistance was pushed at right angle in the ground at constant rate of 2 cm sec^{-1}. Readings were made in nine positions per plot at 5 cm depth intervals down to a depth of 20 cm. The cone resistance (CR) (kN/cm^2) was calculated as:

CR = manometer reading / base area of cone………..(Eq.1)

The manometer pointer was adjusted to zero with the help of an adjusting screw. The values in kN cm^{-2} were converted to kilo-Pascals (kPa), considering that 1 kN cm^{-2} = 1 x 10^4 kPa, (Bradford, 1986; Nyobe, 1998).

Aggregate stability was determined according to Angers and Mehuys (1993). The proportion of water stable aggregates (WSA_i) in each of the size fractions was calculated from the formula:

$\mathbf{WSA_i = (w2_i - w3_i)/(w1/(1 + wc) - \sum w3_i)}$ ……………………………………….(Eq. 2)

Where i = 1, 2, 3, …, n-1, n and corresponds to each fraction in each sample; wc is the gravimetric water content; w1 is the weight of soil sub-samples dried at 40ºC and that had passed through a 10 mm sieve and retained on the 4 mm sieve; $w2_i$ is the weight of the aggregates on each sieve of the nest (4 mm; 2 mm; 1 mm; 0.250 mm 0.125 mm and the one that has passed the finest sieve: below 0.125 mm), dried at 105 °C; $w3_i$ is the weight of primary particles dried at 105°C collected from 0.053 mm sieve.

The proportion of water stable aggregates (WSA) were separated into macro- meso- and microaggregates of the following size categories (WSA_4 + WSA_2); (WSA_1 + $WSA_{0.25}$) and ($WSA_{0.125}$ and below) respectively. The mean weight diameter (MWD) used to express the size distribution was then determined as:

$$\mathbf{MWD} = \sum_{i=1}^{n} \mathbf{X_i\, WSA_i} \quad \text{…………………………………………………………(Eq. 3)}$$

Where i = 1, 2, 3, …, n and corresponds to each fraction collected, including the one that passes the finest sieve. $\mathbf{X_i}$ is the mean diameter of each size fraction (i.e., mean inter-sieve size); and $\mathbf{WSA_i}$ is as defined in (Eq.2).

Geometric mean diameter (GMD) was calculated after Mazurak (1950) as:

$$\mathbf{GMD} = \exp\left[\sum_{i=1}^{n} \mathbf{WSA_i} \log \mathbf{X_i} / \sum_{i=1}^{n} \mathbf{WSA_i}\right]$$

The values for 0-10 cm and 10-20 cm were obtained from the mean of 0-5 and 5-10 cm and 10-15 and 15-20 cm depths respectively.

5.3.5 Data analysis

Crop yields and yield components were analysed in v 9.1 (SAS, 2001) using the Proc GLM procedure in a one-factorial design, with land preparation at five levels, replicated in six blocks. For soils data, where there were comparisons with undisturbed controls, the model used was a one-factorial design at six levels. Where the factor was significant at $P \leq 0.1$, the

Least-Means/PDIFF option was used to test significance of difference between treatments. Data expressed as percentages were transformed such that Y = arcsine ($\sqrt{y}$) where $0 \leq y \leq 1$ as is appropriate for proportions. Leaf number data were transformed such that Y = $\sqrt{y}$ as is appropriate for counts (Sokal and Rohlf 1995). All other data analyses were performed on untransformed data. Correlations were computed using Proc CORR and multiple regressions in the REG procedure using stepwise selection with an entry / exit limit of $P = 0.1$, on n = 30 across all factors, n=15 and n = 6 when separated by fallow and by land preparation method respectively.

5.4 Results

5.4.1 Maize yield and yield components

Maize establishment rate was 93% after chromolaena fallow and 81% after forest fallow. There was no significant effect of land preparation method on establishment rates. At tasselling, there were no significant treatments effects on plant height (average of 2.79 m). Leaf number (P= 0.061) and chlorophyll (P=0.069) were significantly affected by the previous land preparation method with fewer leaves and lower chlorophyll levels in stump retained non tilled treatments (Table 5.1). Manual till treatments generally had the highest values.

At harvest, maize fresh cob yield was significantly affected (P<0.05) by previous land preparation with lowest yields in stump retained no till treatments (Figure 5.1). Actual plant density at harvest was significantly lower in the destumped no till treatment than in all other treatments (Table 5.1). Leaf area at harvest was significantly lower in the stumps retained no till treatment (3758 cm^2 per plant) and in the destumped tractor till treatment (4408 cm^2 per plant) than in the manual till treatments (averaging 6907 cm^2). Leaf area indices at harvest were significantly lower in no till (average of 1.69) than in manual till (average of 3.12) treatments with the tractor till treatment not significantly different from any of the other treatments (2.12).

While yields here are given fresh, equivalent maize dry grain yields, based on a conversion factor of 0.33 (Hauser et al. 2000), vary from 2.35 Mg ha^{-1} in the stump retained no-till treatment to 4.16 and 4.33 Mg ha^{-1} in the manual till stump retained and destumped treatments, respectively. Cob yield was positively and linearly correlated to chlorophyll level (Chl) at tasselling, such that:

Cob yield (g) = 0.61 (Chl) + 12.54, $R^2 = 0.40$, n = 30, $P = 0.00019$.

Table 5.1. Number of living leaves and chlorophyll reading on maize at tasselling, plant density, leaf area and LAI (leaf area index) at harvest (mean ± standard error). n=6.

	Tasseling Chlorophyll	Tasseling No. leaves per plant	Harvest Plant density (m^{-2})	Harvest Leaf area (cm^2 $plant^{-1}$)	Harvest LAI
Stumps retained no till	420^{a} ± 39	10.70^{a} ± 0.62	4.52^{b} ± 0.14	3758^{a} ±1002	1.68^{a} ± 0.44
Destumped no till	526^{b} ± 16	11.65^{ab} ± 0.65	3.63^{a} ± 0.18	4848^{ab}±1050	1.70^{a} ± 0.34
stumps retained manual till	541^{b} ± 25	12.30^{b} ± 0.39	4.52^{b} ± 0.27	6928^{b} ± 458	3.11^{b} ± 0.23
destumped manual till	535^{b} ± 61	12.60^{b} ± 0.44	4.59^{b} ± 0.19	6886^{b} ± 689	3.13^{b} ± 0.30
destumped tractor till	512^{b} ± 20	11.52^{ab} ± 0.65	4.52^{b} ± 0.31	4408^{a} ± 927	2.12^{ab} ± 0.54
P (land preparation method)	*0.069*	*0.061*	*0.05*	*0.062*	*0.031*

Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

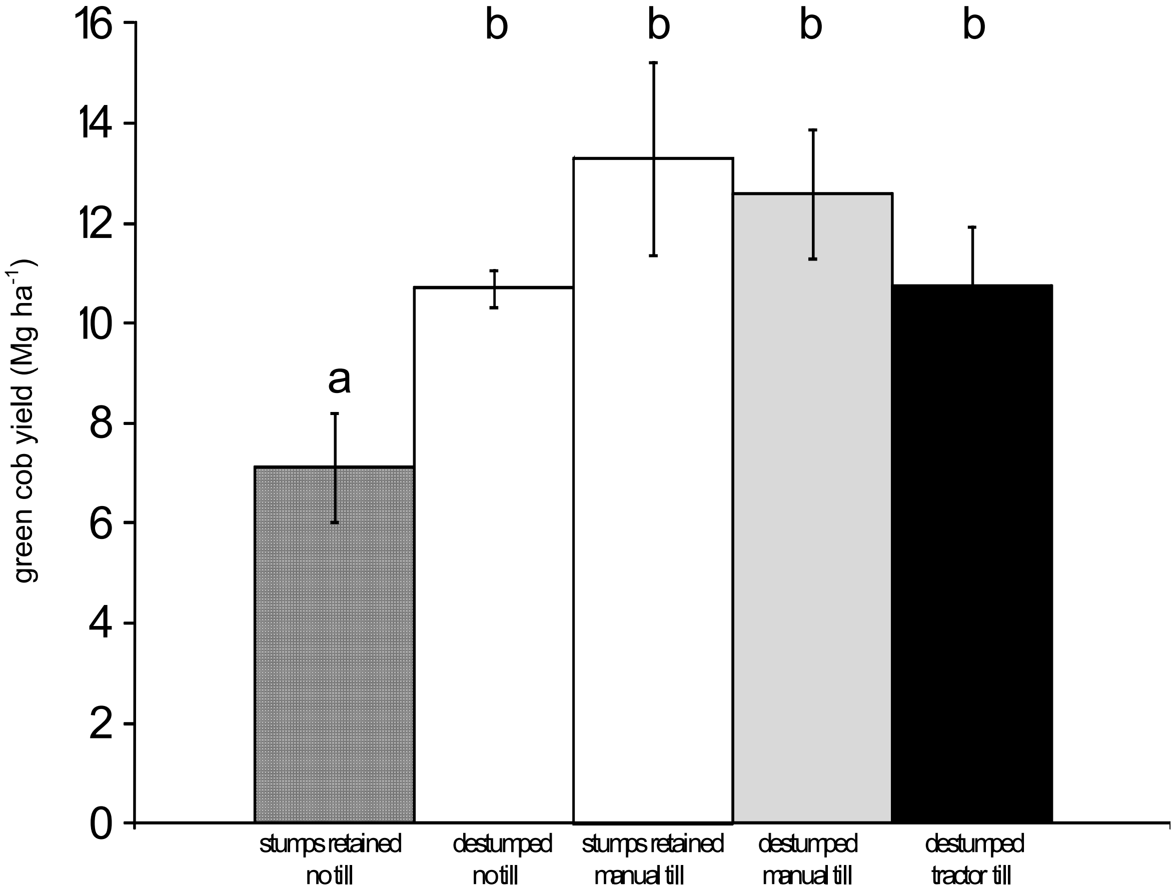

Figure 5.1. Effects of land preparation on green cob yield. n=6. Figures labelled with different letters are significantly different at $P < 0.05$. Bars denote standard error of the mean, by treatment.

5.4.2 Residual effects of previous land preparation on soil physical properties in central Cameroon

The undisturbed controls had significantly lower ($P<0.0001$) soil temperature than any other treatments, which were not different from one another. There was no significant impact of the previous land preparation on soil water content. The cropped and the undisturbed areas displayed similar soil water contents (Table 5.2).

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Soil aggregates were the least stable in the destumped tractor till treatment, with significantly lower ($P=0.10$) macroaggregate proportions and GMD and higher ($P=0.05$) microaggregate proportions than the destumped manual till treatment. The other treatments had similar aggregates stability parameters and did not differ from one another. The previous land preparation methods had no significant effect on cone resistance to soil penetration (CR), mesoaggregate proportions and MWD (Table 5.3).

Table 5.2. Effect of land preparation on soil temperature (ºC) and Volumetric water content in (%) (mean ± standard error). Values within the same column followed by different letters are significantly different at the indicated *P* value. n=6.

Treatments	Temperature ºC	Water content (%)
Stumps retained no till	$26.3^b \pm 0.2$	27.5 ± 1.2
destumped no till	$26.3^b \pm 0.2$	28.4 ± 1.0
stumps retained manual till	$26.0^b \pm 0.2$	28.5 ± 0.7
destumped manual till	$26.3^b \pm 0.2$	28.6 ± 1.5
destumped tractor till	$26.1^b \pm 0.3$	29.5 ± 0.7
Control	$24.2^a \pm 0.2$	27.6 ± 1.1
P (land preparation method)	<0.0001	*ns*

ns, not significant. Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

5.4.3 Correlation maize yield and yield components with soil physical properties

In the previously chromolaena site, cob yield was positively and linearly correlated to water stable aggregates in the 2 mm sieve size (Eq. 4) and negatively correlated to CR (Eq. 5) respectively in 0-5 and 5-10 cm soil depths. In the previously forest fallow site, cob yield was negatively and linearly correlated to water stable aggregates in the 0.250 mm and below 0.125 mm sieve and to CR (Eq. 6). These correlations with aggregates stability and CR were as follows:

Cob yield (g) = 86.14 (WSA_2) + 7.87, R^2=0.56, n=15, P=0.0013. …………….(Eq. 4)

Cob yield (g) = -8.3(CR) + 38.1, R^2=0.294, n=15, P=0.0367………………….. (Eq. 5)

Cob yield (g) = - 60.3($WSA_{0.25}$) – 108 x (Below0.125) – 4.5×10^{-4}(CR) + 15.1, R^2=0.531, n=15, P=0.0341……………………………………………………….(Eq. 6)

Table 5.3. Cone resistance to soil penetration (CR) in MPa Soil macro.- meso.- and microaggregate proportions in (%) mean weight diameter (MWD) and geometric mean diameter (GMD) in (mm) in 0-10 cm soil depth (mean ± standard error). n=6.

Depth	0-10 cm						10-20 cm
Property	CR	Macro.	Aggregates Meso.	Micro.	MWD	GMD	CR
	MPa	--------------------(%)-------------------			----------mm---------		MPa
stumps retained no till	0.52 ± 0.09	83.7^{ab} ± 2.3	8.3 ± 1.9	8.1^{ab} ± 1.3	5.7 ± 0.2	1.8^{ab} ± 0.1	1.54 ± 0.22
destumped no till	0.63 ± 0.10	82.4^{ab} ± 3.5	10.2 ± 2.6	8.0^{ab} ± 1.2	5.6 ± 0.2	1.8^{ab} ± 0.1	1.38 ± 0.18
stumps retained manual till	0.42 ± 0.10	82.6^{ab} ± 3.1	9.6 ± 1.6	7.9^{ab} ± 1.6	5.7 ± 0.2	1.8^{ab} ± 0.1	1.27 ± 0.33
destumped manual till	0.48 ±0.13	85.4^{b} ± 2.8	8.8 ± 2.4	5.9^{a} ± 0.7	5.8 ± 0.2	1.9^{a} ± 0.1	1.37 ± 0.31
destumped tractor till	0.60 ± 0.12	78.0^{a} ± 2.0	12.5 ± 1.8	9.6^{b} ± 1.4	5.3 ± 0.1	1.7^{b} ± 0.1	1.51 ± 0.30
P (land preparation method)	*ns*	*0.073*	*ns*	*0.047*	*ns*	*0.072*	*ns*

ns, not significant. Within columns, values followed by different lower-case letter are significantly different at the indicated *P* value.

5.5 Discussion

For smallholder conditions in the humid tropics, maize yields were high. Norgrove et al. (2003b), working on a Typic Kandiudult, after a two-year old *C. odorata* fallow found grain yields of 1.7 Mg ha^{-1} to 2.9 Mg ha^{-1} depending on whether plots had been burned or mulched prior to cultivation. Chabi-Olaye et al. (2008), working in the same village, similarly after *C. odorata* fallow, found that yields were 1.7 Mg ha^{-1} in unfertilized plots and 3.7 Mg ha^{-1} in plots fertilized with 60 kg ha^{-1} of N. Tueche and Hauser (2011) working on a clayey, kaolinitic, Typic Kandiudult at Mfou, central Cameroon, obtained 1.3 Mg ha^{-1} in untilled and unfertilized plots and 2.2 Mg ha^{-1} in plots tilled and fertilized with 60 kg ha^{-1} N.

Generally, manual till treatments had highest yields. Chlorophyll measurements and LAI suggested that tillage increased soil N availability, possibly by the breaking up of macroaggregates, increasing assumed leaf N concentration and leaf production. Furthermore, destumping led to significant increases in growth under no-till conditions whereas there was no significant effect of destumping if plots were tilled. This suggests that it was the soil breaking up aspect of destumping that was beneficial rather than any possible reduced competition from still living stumps.

Tueche and Hauser (2011) found a significant positive effect of tillage on maize yields from 1.73 to 2.54 Mg ha^{-1} ($P = 0.016$). This contrasts with similar work in the same ecoregion. For example, Hauser et al. (2000), working also in central Cameroon at Mbalmayo on a Typic Kandiudult found no significant effect of tillage on maize grain yield in a cassava intercrop. But in general, the effect of soil tillage on maize yield is in consistent (Table 5.4, just to name a few) and was usually site specific (soil type, soil condition and climate) and on the type of tillage equipment and the agricultural practices. In this study, maize growth and yield was best after farmer practice of mound tillage. Neither no till nor tractor tillage improved yield.

The absence of significant effects of the previous land preparation on soil resistance is surprising. Mamman and Ohu (1997) studying the effect of traffic on the production of pearl millet (*Pennisetum americanum* (L.) Leeke) in a sandy loam soil (Typic Ustipsamment) in the savannah zone of North Nigeria, observed an increase in soil penetration resistance in tractor tilled plots that was proportional to the number of tractor passes (0, 5, 10, 15, 20 passes). Yet, in the current trial, a light tractor was used (< 500 kg) so this may not have had much impact.

The disruption effect of soil aggregates by tillage was significant only with tractor tillage and not with manual tillage. The ranking in soil aggregate stability parameters and soil resistance did not follow that of maize cob fresh yield. Yet, there were significant correlations between soil aggregation and the resistance to soil penetration. High soil resistance appeared to be a limiting factor of maize cob fresh yield.

Table 5.4: A review of the effect of various tillage systems on maize yield

No	Authors	No-tillage versus manual tillage	No-tillage versus mechanical tillage	Manual tillage versus tractor tillage
1.	Couper et al., 1979.		Higher maize grain yields on no-till than on ploughed plots.	
2.	Ezeaku et al. (undated)	-	Higher maize yield after tractor tillage than with no-till	-
3.	Ike, 1986.	No significant difference	No significant difference	No significant difference
4.	Hauser et al., 2000.	No significant difference between manual tillage and no-tillage	-	-
5.	Kang et al., 1980.	-	Yield of no tillage maize was less than that of tilled maize with no or low rates of N application, but with adequate N fertilization yield from no-tillage maize equalled that of tilled maize.	-
6.	Lal, 1974.	-	No-significant differences between mechanical and no-tillage	-
7.	Lal, R., 1976.	-	No-significant differences between mechanical and no-tillage	-
8.	Lal,, 1979.	-	No tillage treatments yielded more than conventionally plowed plots in all three seasons.	-
9.	Lal and Dinkins, 1979.		Higher maize grain yields on no-till than on ploughed plots.	
10.	Lal et al., 1989.	-	Corn yield was greater in plow-till than in no-till treatments	-
11.	Ojeniyi, 1993.	Cob weight and grain yield were increased by tillage. The effect of hoe tillage and row (minimum) tillage was not significantly different.	-	-
12.	Tueche and Hauser, 2011.	Within the previous plantain cropping systems, tillage did not significantly increased maize yield. However, when the previously un-cropped control was included, tillage had significant interaction such that in the un-cropped control tillage increased grain yield from 1.73 to 2.54 Mg ha^{-1} (P = 0.016).		-
13.	Wanas, 2006.		Maize grain yield increased after tillage compared with no-tillage.	

5.6 Conclusion

It is possible to relay the cropping of maize to that of tomato as maize yield was higher compared to the normal smallholder conditions. The positive effect of tillage on tomato yields during the preceding seasons (Chapter 4) was still effective on the relay maize crop. The effects of destumping were inconsistent on maize yields and on soil physical properties. The low cost small tractor that was used, caused only minor degradation on soil physical properties but had a positive effects on yields and be a good option for smallholder farmers in the tropics. Soil physical properties controls maize yields and can be manipulated to increase the yield.

Chapter 6

General Discussion

6. General Discussion

6.1 Do soil physical properties deteriorate under cropping in southern Cameroon?

The results of this thesis research revealed that soil physical properties do not necessarily deteriorate under cropping. However, soil physical properties degraded with tillage operations (Chapters 3 and 4). This was manifested by a decrease in aggregate stability expressed by a significant reduction of the proportion of soil macroaggregates, MWD and GMD and an increase in the proportions of soil mesoaggregates and microaggregates (Table 3.3). The degradation of soil physical properties was amplified with the level of land preparation intensification (destumped and tractor tillage, Table 4.2). These results are similar to that of other authors (Nyobe, 1998; Nounamo et al., 2002; and Yemefack et al., 2002 and 2004). However, they are contrary to those observed during plantain cropping (Chapter 2), where soil physical properties showed a general (that is in all cropping systems, all fallow ages and villages) improvement. This improvement was manifested by an increase in soil clay content, silt content, proportion of soil macroaggregates, MWD and GMD, and a decrease in soil sand content, BD, the proportions of mesoaggregates and microaggregates (Tables 2.3, 2.4 and Figures 2.1, 2.2). Yemefack et al. (2004 and 2006) also found improved soil clay content and structural stability of soil aggregates in mature (>12 years) and old (>20 years) cocoa plantations. The reason could be found in the fundamentally different soil management in plantain and cocoa crops compared with any other food crop. Plantain fields for instance are not clean weeded and with increasing height of the plantains, farmers allow weed growth for rather long periods. In this trial, weeding was done with cutlasses four times a year, except for the pepper crop which was clean weeded in the first year. Therefore, while the plantains were growing, the soil was permanently covered because even after weeding the biomass left on the field served as dead mulch. Mulch can protect soil from sheet erosion that causes the selective loss of fine soil particles, nutrients and organic matter (Roose, 1977; Yemefack et al., 2004) or sheltering soil aggregates against disruption by the “splash effects” of rain drops. Furthermore the release of aggregating agents (Tisdall and Oades, 1982) during the decomposition and mineralisation of such dead mulch contributes to soil aggregation (Tueche et al., 2007); and lastly a higher level of soil macrofauna (earthworms, termites and ants) activity favour the bioturbation of fine materials (clay and silt) to the soil surface (Hauser, 1993) while the microfauna worked to increase aggregate stability (Tisdall, 1994). The degradation of soil physical properties can thus be related to soil management during cropping which actually depends on crop types.

6.2 Is tillage or any land preparation intensification useful for crops yield increase in southern Cameroon?

In general, the expectation of tillage is to generate a better environment for plant growth. In southern Cameroon, farmers frequently till, sometimes mound, because they consider it to increase yields and reduce weed competition. Manual tillage is highly labour-demanding, thus impacts on labour productivity strongly negatively in the labour-constrained environment of smallholder agriculture. Tillage is useful in the reduction of soil compaction (Adekiya and Ojeniyi, 2002; Adekiya et al., 2009) and in the increase of soil porosity and soil temperature (Adekiya and Ojeniyi, 2002). No-tillage has the advantage of not degrading soil physical properties. The loss of chemical fertility is also reduced. In fact, in this low CEC soil, a significant amount of nutrients released with the decomposition and mineralization of SOM favoured by tillage can be leached, accelerating soil impoverishment while these nutrients in no-tilled soil remain stabilised in SOM, yet in forms not available for crops. No-tillage offers the possibility to cultivate a larger area (for those who have enough land assets), as the time that ought to be allocated to tillage can be used to expand the farm, in spite of the vanishing of forest land which goes together with the loss of biodiversity and climate change. We have found (Chapter 3 and 4) that tillage does not automatically increase crop yield and from reports worldwide, this seems to be the general trend. In fact, the effects of tillage on crop yield are inconsistent: either crop yield was increased (Ezeaku et al. (undated); Kang et al., 1980; Ojeniyi, 1993; Wanas, 2006); or no effect was observed (Lal, 1974 and 1976; Couper et al., 1979; Ike, 1986; Hauser et al., 2000). Based on the results from our study, the two following processes were necessary for tillage to improve crop yield: i) if it did not led to better soil physical condition, but instead improved nutrient supply, which might be due to enhanced SOM decomposition, nutrient mineralization, and microbial activity associated with tillage (Hendrix et al., 1986; Stevens, 1986 cited by Follett and Peterson, 1988; Mishra et al., 2010), and ii) the appropriate cultivar characteristic: it has been demonstrated that for a given level of land preparation intensification (Chapter 4) crop yields were very different among cultivars from the same crop. The tomato cv. Rio Grande for instance, had the poorest response in yield gains from intensification while Roma showed strong fruit mass gains per hour labour spent on manual tillage (Figure 4.4). Roma and Rossol had similarly strong fruit number gains after manual tillage (Figure 4.5) with virtually no response by Rio Grande. Thus, the improved cultivars Roma (tolerant to fungi) and Rossol (resistant to fungi and nematodes) had a better response to land preparation intensification than cv. Rio. These results corroborate findings of Otsuka and Yamano (2005), where, with similar land preparation, improved crop varieties were higher-yielding and more yield responsive to increased fertilizer application than traditional crop varieties. Conway and Toenniessen (2003) also found that improved crop varieties could be more resistant to devastating diseases and as well as tolerant to nutrient-poor soils. The importance of cultivar by environment interactions is also demonstrated by the fact that cultivar Rio Grande produced lowest yields in our trial while it had twice as high yields than cv. Rossol at Foumbot on a deep Andosol in the Western Highlands of Cameroon under similar rainfall conditions but greater daily temperature fluctuations (decreasing to 12.38 C at night) at an altitude of 1100 m asl (Tonfack et al., 2009).

Finally, the choice of agricultural practice (whether to till or not; to destump or not and the combination) must integrate the farmer’s land assets, the labour force available, the cultivar to crop, soil properties and his concern for the environment. Tillage may not be necessary if chemical fertilizers and residue mulch are used (Lal, 1995); tillage is absolutely necessary on compacted soil (Adekiya and Ojeniyi, 2002; Adekiya et al., 2009) and on soil with suitable SOM but trapped in organo-mineral compounds.

6.3 Does major investment in establishing improved cropping systems improve profitability of subsequent crops?

In southern Cameroon, after two to three years, plantain yields decrease drastically forcing the farmers to move to new lands. However, with population increase, there is little virgin land available for some families. And where it still exists, there is the expensive cost to convert the dense rain forest into agricultural land and furthermore, the constraints for farmers to go (for farming) far from their homes (by foot or trekking, for most of them) or they have to relocate their homestead near the cultivated field. Our study revealed that the large investment in establishing of improved cropping systems (Chapter 2 and 4) could also have a positive impact during subsequent cropping seasons (Chapter 3 and 5). During the plantain growing phase for example, plantain bunch yield was better in the pueraria system (Chapter 2); while during the maize cropping phase (Chapter 3), maize grown in former pueraria system s' plots had grain yield similar to plots that were fallowed for 8 years. The better yields of these crops could be explained by the fact that the system which included pueraria produced high amounts of biomass, smothered other weeds and pueraria in association with *Bradyrhizobia* also fixes atmospheric N. Furthermore, there was a significant reduction in nematode populations in this system (for further understanding see sections 2.5 § 8 and 3.5 § 2). Similarly, tomato performed better in the destumped manually tilled plots (Chapter 3) than in the stumps retained no-tilled plots. This result was similar for maize that was later on cropped on these same plots. This actually suggests that the potential mobilisation of soil nutrients with tillage may be a progressive process (not a single instantaneous process) in this soil. Because, if soil nutrients released from the decomposition and mineralisation of SOM, were at once (instantaneous) released, inducing a better performance of tomato, an important portion of nutrients not taken up by the tomato crop, in this low CEC soil, could have been leached, leading to a poor yield of the subsequent maize crop. Lal (1995), investigating cropping on an Alfisol in Nigeria from 1979 through 1987, found that satisfactory maize yields with continuous and intensive cropping were possible with use of chemical fertilizers, residue mulch, and a no-till system. Thus, smallholder farmers can improve the intensity of cultivation by eventually passing from the usual shifting cultivation to semi-permanent to permanent cultivation.

6.4 Do soil physical properties control crop yields in southern Cameroon?

Our research revealed that soil physical properties control crop yields in the research area in southern Cameroon. This was demonstrated by significant positive or negative correlations between soil physical properties and crop yields (§ 2.2.4; 3.4.3; 4.4.6 and 5.4.3); and by soil physical properties values following the ranking of maize grain yields (Tables 3.1 and 3.4) and finally through regression equations between crop yields and soil physical properties (§ 4.4.6 and 5.4.3). Similar observations were made by Nyobe (1998) and Yemefack et al. (2002), working also in southern Cameroon, in Nigeria by Lal (1997) and Lal et al. (2000), and in the US by Jagadamma et al. (2008). Across these experiments, soil bulk densities (BD), clay content and aggregate stability were recurrent in their impact on crop yields and because they can also be controlled or be manipulated to maximise their benefit, they need special attention. In fact, BDs were generally around 1.0 Mg m^{-3} and positively related to yields, thus BD should be kept around 1.0 Mg m^{-3} in Ultisol soil because an increase in BD or soil compaction would actually mean an adverse effect on yield (Lipiec et al., 1991). Soil clay contents were also positively related to yield. Take note: clay here designates textural clay and not necessarily mineralogical clay, which is all soil particles < 2 µm; they are made off: mineralogical clay, oxides, oxihydroxides, organic matter and the like. This clay improved AWC to which it is generally positively related (Pidgeon, 1972; Emerson, 1995; Bouma et al., 2003; Tueche et al., unpublished). It is thus of critical importance for sustaining crop growth and enhancing yield preserving soil moisture between periods of rainfall of more than 4 days. Hence, soil clay should be maintained around 30 and 40 % by avoiding an excessive lost of soil clay through erosion. As far as aggregate stability was concerned, the proportions of soil macroaggregates, MWD and GMD were in general negatively related to yield while it was the opposite for the proportions of soil mesoaggregates and microaggregates. Tillage must be done in a way to reduce the proportions of soil macroaggregates as they are negatively related to yield. In fact, tillage disrupted macroaggregates, which are generally constituted of smaller aggregates and particles bound together by cementing agents like clay, organic matter, oxides (Tisdall and Oades, 1982), Ca and Mg (Salako and Hauser, 2001; Tueche et al., 2007), or by fungal hyphae and/or some type of organic or amorphous material (Gupta and Germida, 1988; Tisdall, 1994). This disruption of macroaggregates can contribute to the release of nutrients contained in the cementing agents. There will also be a change in microbial dynamics (Six et al., 2006) accelerating mineralization of the previously entrapped organic matter. In such a soil sphere, there will certainly be a better interconnectivity between poral spaces and the spread of roots will be easier and the uptake of nutrients will be facilitated justifying higher yields, explaining the negative correlation between the proportions of macroaggregates and yield. Tillage must equally, produce sufficient proportions of meso- and microaggregates for better crop yield without affecting soil erosion rates and thus yield in future. These results are of uttermost importance for they demonstrate that soil physical conditions can favor or impair crop yields. It compels the practitioners, the extensionists and researchers to closely watch on soil physical conditions by establishing land management practices (land preparation intensification, the fight against water erosion and the like) that give soil physics the best properties for sustained crop yields. While waiting for breeders to develop improved varieties that can do better in all or most soil physical conditions. It is the duty of the national and international scientific community, however, to determine a range of soil physical properties suitable for a range of crops for sustained yields. Nevertheless, according to these results in the humid forest with bimodal rain fall agro-ecological zone of Cameroon, sandy clay soils with values around: 1 Mg m^{-3} for BD; 3.4-5.4 mm for MWD; 1.3-1.8 mm for GMD; 50.0-83 %; 10.4-36 % and 8.6-14.8 % for the proportions of soil macro-, meso- and microaggregates respectively, 0.11-0.21 Mg Mg^{-1} for AWC and 0.42-1.54 kPa for CR can be favorable for plantain, maize and tomato cropping.

6.5 Outlook and recommendations

Improved crop management strategies must enable low input systems and favor high output. Thus, one of the key issues will be to appropriately time the period between land clearing and planting. The observed delayed planting after clearing may have been one reason of low plantain bunch yields, as nutrient leaching may take place and weed infestation could worsen the conditions at the start of the crop growth.

Improved management strategies in the cropping of plantain will be to intercrop plantain with pueraria for higher bunch yield compared to traditional systems (Chapter 2). Plantain can also be intercropped with other species like cowpea and maize (Shiyam, undated); cassava (Adetiloye, 2003); fluted pumpkin (Telfairia occidentalis, Hook. F) (Phillip et al., 2009) just to name a few. In general a successful intercropping will be achieved “when the intercrop yields the full yield of the main crop plus some yield because of the second crop or when the combined yield exceeds the greater sole crop yield or else when the combined yield of the intercrop exceeds the combined sole crop yield and finally when intercrop yields more financial benefits” (Cadisch, 2005).

Furthermore, pueraria can have other by-products: nematodes suppression (Banful et al., 2008) and weed control (Banful et al., 2007 and 2008), diminishing the time devoted to weeding; improve soil nutrient availability, stimulate soil biological activity, and to control soil erosion. This will lead to high soil productivity (Tian et al., 2001) and eventually a positive effect also on intercropped cassava (Duindam et al., 2010) and maize (Hauser et al., 2002) yields and even for subsequent crops. Thus there is less need abandoning the land to fallowing when plantain yields had drastically reduced, or through cultivating subsequent crops like maize or any crop less demanding in soil properties and fertility. At this level, incorporating adequate amounts of appropriate mineral fertilizers could compensate the fertility lost through harvest or soil degradation. In fact, N fertilizer increases maize yields (Table 3.2; Hauser and Nolte, 2002), or alternatively manure can be used (although it is less concentrated than chemical fertilizers) as it can be relatively cheap and improve the soil physically, chemically (Choudhary et al., 1996; Olatunji et al., 2012; Ojeniyi et al., 2013) and biologically (Hou et al., 2012), trough for instance, an integrated agricultural production system with livestock and poultry.

In case of tomato cropping for low input / high output systems, although there is a potential loss of planting area due to stumps, for farmers who have enough land assets, they should avoid destumping as it has no effect on yield but it is instead highly labour-demanding and may delay the natural vegetation succession during a subsequent fallow period. Furthermore, our research revealed that yield were the best in manually tilled soil during the tomato phase as well as during maize period.

Above all, farmers must select a suitable cultivar for their agro-ecological zone. On Ultisols in humid forests with bimodal rainfall, we recommend for tomato cropping the improved cv. Rossol which was the highest yielding variety tested.

It will be advisable for research to determine what should be the adequate tillage frequency that will sustain yield without favoring soil erosion; to define the suitable crops rotation or succession taking into consideration soil fertility decline, to establish the suitable type and amount of fertilizers for a given soil fertility state for a corresponding crop and finally to develop more improved crop cultivars capable to do well on a wide range of soil physical properties.

Chapter 7

Summary

7. Summary

Relationships between soil physical properties and crop yields in different cropping systems in Southern Cameroon

Crop yields in sub-Saharan Africa (SSA) has been more or less stagnant since 1961. This can be connected to the traditional slash-and-burn agricultural based system. A growing population has forced most farmers to cultivate the same fields repeatedly. The resulting rapidly declining crop yields led eventually to an accelerated conversion of forest land into agricultural land to cope with food demand. However, the integration of leguminous species, the use of fertilizer and tillage have been proven to increase yield especially in intensive cropping systems. Although, depending on its frequency and kind, tillage can destroy soil aggregates resulting in degradation of soil organic matter. Else, it is known that improved crop varieties can be higher-yielding and more yield responsive to increased fertilizer application than traditional crop varieties.

Information is scarce on the effects of soil physical properties on plantain, maize and tomato yield formation and on their changes during their cropping phase. This study aimed at understanding the relationships between soil physical parameters and crop yields in different cropping systems in southern Cameroon with the goal to identify improved management strategies. This led to the setup of 4 experiments:

In a first experiment, the effects of soil physical properties on plantain yield were determined in a factorial trial in three southern Cameroonian villages comparing four cropping systems comprising two planted legumes (1) *Flemingia macrophylla*, (2) *Pueraria phaseoloides,* as well as (3) a crop, i.e. hot pepper, and (4) natural regrowth, all planted with plantain, established after conversion of old forest versus young bush fallow. Between 2002 and 2006, clay and silt content, MWD, GMD and the proportion of macroaggregates increased, whereas relative sand content, bulk density, the proportions of mesoaggregates and microaggregates decreased (not absolute decreased for sand content) in all villages, fallows and cropping systems. Changes of aggregate MWD and GMD were larger in the *F. macrophylla* and natural regrowth systems than in *Pueraria* systems. Plantain fresh bunch yield was unaffected by village, fallow, and cropping systems. Plantain cultivation did not lead to a degradation of the determined soil physical properties.

In a follow up second trial at Mfou, it was evaluated, if maize cropped immediately after plantain was affected by the previous plantain systems and if tillage or N fertilizer would affect maize growth and grain yield and soil physical properties. In 2006, all plantain plots were cleared and split into 4 subplots, to assess the response of maize to tillage versus no–till, and of 60 kg ha^{-1} of N as urea compared to no N in a 2 x 2 factorial design. Freshly cleared eight years old bush fallow served as control. Maize grain yield was highest in the previously not cropped bush control and lowest in the previous *Flemingia* system. Grain yield in the previous *Pueraria* and natural regrowth systems were not different from the control. Maize grain yield was highest, when tillage was combined with fertilizer application, being significantly higher than in individual tillage or fertilizer application treatments. Soil physical properties were affected by tillage but did not remain different until the end of the maize growing phase.

In a third experiment the response of different tomato cultivars to different cultivation practices in an on-farm factorial trial was tested at Essong Mintsang in the central region of Cameroon on a Rhodic Kandiudult. Treatments were: current farmer practice of manual tillage yet not destumped, with either reduced input (no tillage, not destumped) or increased input (no tillage yet destumped, manual tillage and destumped, mechanical tillage and destumped). Yields of three tomato varieties were determined to assess, if changes in intensity of land preparation can improve soil physical properties and thus yields. At harvest, across land preparations the cv. Rossol produced higher yields (8.12 Mg ha^{-1}) than cv. Roma (6.05 Mg ha^{-1}) and cv. Rio Grande (4.46 Mg ha^{-1}). Tomato total and marketable yields were significantly higher on the destumped tractor till, destumped manual till and stumps-retained manual till treatments than in the stumps retained no-till treatment. Total fresh yields of cvs. Roma and Rossol increased, when the soil was tilled, while cv. Rio Grande had no response to land preparation. Soil aggregates were least stable in the destumped, tractor till treatment, with significantly lower MWD (p=0.02) and higher mesoaggregate proportions (p=0.05) than in the other treatments. Across tomato cultivars and treatments, the marketable fruit yield could be predicted by clay, macroaggregates and bulk density. Early flowering and fruit production combined with nematode resistance were probably the main contributing factors to the high yields of cv. Rossol.

In a fourth experiment, the residual effects of the previous land preparation methods on maize growth and yield as well as impacts on soil physical properties were assessed. Land preparation methods had been applied to the preceding tomato crop. At harvest, maize fresh cob yield was significantly ($P<0.05$) lowest in the stump retained no till treatment. The equivalent maize dry grain yields varied from 2.35 Mg ha^{-1} in the stump retained no-till treatment to 4.16 and 4.33 Mg ha^{-1} in the manual till stump retained and destumped treatments, respectively. Soil aggregates were the least stable in the destumped tractor till treatment, with significantly lower ($P=0.10$) GMD than in the destumped manual till treatment. Maize fresh cob yield showed a strong correlation ($R^2 \sim 0.50$, $P=0.037$) with soil aggregation and cone resistance to soil penetration.

In summary, the transition from shifting to permanent cultivation with acceptable yields is possible if an appropriate combination of crops (cultivar), use of leguminous species, tillage and fertilizers is implemented. Soil physical properties can control crop yield and hence can be manipulated to maximise yield. Tillage can contribute to yield increase if there is an adequate SOM content and a suitable crop cultivar is chosen. Yet, tillage is labour intensive and degrades soil physical properties. Therefore, it is crucial to identify a minimum tillage frequency for low labour demand and minimal soil degradation, but with improved yields in conjunction with optimised fertilization and the development of improved crop cultivars adapted to a wide range of soil conditions.

Zusammenfassung

Verhältnis zwischen bodenphysikalischen Eigenschaften und Ernteerträgen in verschiedenen Anbausystemen im südlichen Kamerun

Die Ernteerträge in Subsahara-Afrika (SSA) stagnieren größtenteils seit 1961, teilweise bedingt durch das traditionelle Brandrodungs-System. Eine wachsende Bevölkerung hat die meisten Landwirte dazu gezwungen, die gleichen Felder wiederholt zu bebauen. Der daraus resultierende rasche Rückgang der Bodenfruchtbarkeit und der Ernteerträge führte letztendlich zu einer beschleunigten Umwandlung von Waldflächen zu Ackerland um die Nachfrage nach Lebensmitteln zu befriedigen. Allerdings wurde bereits nachgewiesen, dass die Integration von Hülsenfrüchten in die bestehenden Fruchtfolgen, die vermehrte Verwendung von mineralischen Düngemitteln und eine verbesserte Bodenbearbeitung eine wichtige Rolle bei der Erhöhung des Ertrags spielen, besonders bei intensiven Anbausystemen. Dennoch kann die Bodenbearbeitung je nach Häufigkeit und Art und Weise Bodenaggregate zerstören, was zu einem Abbau organischer Substanz im Boden führt. Auch ist bekannt, dass verbesserte Sorten höhere Erträge generieren können, sowie auf einen erhöhten Einsatz von Düngemitteln besser reagieren als traditionelle Sorten. Zurzeit gibt es nur wenige Studien über die Auswirkungen der physikalischen Eigenschaften vom Böden auf die Erträge von Kochbananen, Mais oder Tomaten, sowie über deren Veränderungen während des Anbaus. Diese Studie zielte daher darauf ab, das Verhältnis zwischen physikalischen Parametern vom Böden und Ernteerträgen in verschiedenen Anbausystemen im südlichen Kamerun zu erfassen, um verbesserte Management-Strategien identifizieren zu können. In diesem Zusammenhang wurden vier Experimente durchgeführt:

In einem ersten Experiment wurden in drei Dörfern in Südkamerun die Auswirkungen der physikalischen Eigenschaften des Bodens auf den Ertrag von Kochbananen bestimmt. Diese Studie verglich vier Kochbananen Anbausysteme, zwei mit Leguminosen – (1) *Flemingia macrophylla*, (2) *Pueraria phaseoloides* –, (3) zusammen mit scharfem Pfeffer (*Capsicum* sp.), und (4) natürlicher Wiederaufwuchs; alle Systeme gepflanzt direkt nach der Umwandlung des Regenwaldes oder nach jungem brachliegendem Buschland dominiert von *Chromolaena odorata*. Zwischen 2002 und 2006 hat in allen Dörfern, Brachen- und Anbausystemen der Gehalt an Ton und Schluff – MWD, GMD – und der Anteil von Makroaggregaten zugenommen, während der relative Sandgehalt, die Bodendichte, und die Proportionen von Meso- und Mikroaggregaten verringert wurden (nicht absolute verringert für Sandgehalt). Die Veränderungen der Aggregate MWD und GMD in den Systemen mit *F. macrophylla* und natürlichem Wiederaufwuchs waren größer als in den *Pueraria* Systemen. Der Ertrag von Kochbananen war vom jeweiligen Dorf, Brachen- oder Anbausystem unbeeinflusst. Der Anbau von Kochbananen hat zu keiner Verschlechterung der physikalischen Eigenschaften des Bodens geführt.

In einer zweiten Folge-Studie in Mfou wurde untersucht, ob Mais, wenn er unmittelbar nach Kochbananen angebaut wurde, durch die vorherigen Anbausysteme beeinflusst wurde, und ob die Bodenbearbeitung oder die Verwendung von N-Düngern eine Auswirkung auf das Maiswachstum, den Kornertrag und die physikalischen Eigenschaften des Bodens haben. Im Jahr 2006 wurden alle Kochbananenpflanzen entfernt und die Felder in vier Parzellen unterteilt, um die Reaktion von Mais auf die konventionelle Bodenbearbeitung im Vergleich zu keiner Bodenbearbeitung zu bewerten, sowie die Reaktion auf 0 oder 60 kg N ha^{-1} Gabe in einem 2 x 2 Faktorendesign zu vergleichen. Eine geräumte Buschbrache von 8 Jahren diente als Kontrolle. Der Maiskornertrag war am höchsten in der zuvor nicht bestellten Buschbrachenkontrolle und am niedrigsten im vorherigen *Flemingia*-System. Der Kornertrag im vorherigen *Pueraria* und im natürlichen Wiederaufwuchs-System unterschied sich nicht von demjenigen der Kontrollparzelle. Der Maiskornertrag war am höchsten, wenn die Bodenbearbeitung mit Düngemitteln kombiniert war, und somit deutlich höher als bei den unabhängigen Behandlungen mit ausschließlicher Bodenbearbeitung oder Behandlung mit Düngemitteln. Die physikalischen Eigenschaften des Bodens wurden von der Bodenbearbeitung beeinflusst, haben sich aber erst zum Ende der Maiswachstumsphase verändert.

In einem dritten Experiment wurde auf der Basis einer On-Farm-Faktorenstudie in Essong Mintsang in der zentralen Region von Kamerun auf einem Rhodic Kandiudult die Reaktion verschiedener Tomatensorten auf verschiedene Anbauverfahren getestet. Die Verfahren waren wie folgt: aktuelle Bauernpraxis mit manueller Bodenbearbeitung ohne dem Entfernen on Baumstümpfen, entweder mit reduziertem Einsatz (keine Bodenbearbeitung – mit Baumstümpfen) oder mit erhöhtem Einsatz (keine Bodenbearbeitung – aber mit Entfernung der Baumstümpfe, manuelle oder maschinelle Bodenbearbeitung ohne Baumstöcke). Die Erträge der drei Tomatensorten wurden ermittelt, um zu bewerten, ob Veränderungen in der Intensität der Landbearbeitung die physikalischen Eigenschaften des Bodens verbessern und damit auch den Ertrag. Bei der Ernte produzierte der Kultivar *Rossol* in Verbindung mit Landbearbeitung höhere Erträge (8.12 Mg ha^{-1}) als Kultivar *Roma* (6.05 Mg ha^{-1}) und Kultivar *Rio Grande* (4.46 Mg ha^{-1}). Der gesamte marktfähige Tomatenertrag war deutlich höher bei der Traktoren-Bodenbearbeitung und der manuellen Bodenbearbeitung mit jeweiligem Entfernen der Baumstümpfen und bei der manuellen Bodenbearbeitung unter Beibehaltung der Baumstümpfe, als bei den Verfahren ohne Bodenbearbeitung, die Stümpfe beibehielten. Die Gesamt-Erträge von cvs. *Roma* und *Rossol* wurden erhöht, im Zusammenhang mit der Bodenbearbeitung, während *cv. Rio Grande* auf die Landvorbereitung nicht reagierte. Die Bodenaggregate waren weniger stabil in dem Verfahren Traktoren-Bodenbearbeitung ohne Baumstümpfe, mit einem deutlich niedrigeren MWD (p=0.02) und höheren Mesoaggregaten-Proportionen (p=0.05) als in den anderen Verfahren. Über die verschiedenen Tomatensorten und Bearbeitungsverfahren konnte der marktfähige Früchteertrag durch den Gehal an Ton, Makroaggregaten und Bodendichte vorhergesagt werden. Die frühe Blüte und Frucht-Produktion, die mit der Widerstandsfähigkeit gegenüber Nematoden verbunden waren, waren wohl die wichtigsten Faktoren für den hohen Ertrag von *cv. Rossol*.

In einem vierten Experiment wurden die Nachwirkungen der früheren Landvorbereitungsmethoden auf das Maiswachstum, seinen Ertrag sowie deren Auswirkungen auf die physikalischen Eigenschaften des Bodens ausgewertet. Die Landvorbereitungsmethoden waren die gleichen wie bei dem vorherigen Tomatenanbauversuch. Bei der Ernte war der Konertrag von Mais im Verfahren ohne Bodenbearbeitung, die Baumstümpfe beibehielt, deutlich am niedrigsten (P<0.05). Die Erträge der äquivalenten trockenen Maiskörner variierten zwischen 2.35 und 4.16 Mg ha^{-1} im Verfahren ohne Bodenbearbeitung mit Baumstümpfen, beziehungsweise 4.33 Mg ha^{-1} im Verfahren mit manueller Bodenbearbeitung, die Baumstümpfe beibehielt, und mit manueller Bodenbearbeitung mit Entfernung von Baumstümpfen. Die Bodenaggregate waren am wenigsten stabil im Verfahren mit Traktoren-Bodenbearbeitung ohne Baumstümpfe, mit einem deutlich niedrigeren GMD (P=0.10) als in der manuellen Bodenbearbeitung mit Entfernung von Baumstümpfen. Der Ertrag von Mais zeigte eine starke Korrelation (R^2~0.50 und P=0.037) zwischen der Bodenaggregation und dem Bodenpenetrationswiderstand.

Zusammenfassend ist der Übergang von einem vorübergehenden zu einem dauerhaften Anbau mit akzeptablen Erträgen nur möglich, wenn eine geeignete Kombination von Kulturpflanzen (Sorten), Verwendung von Hülsenfrüchten, angepasster Bodenbearbeitung und Einsatz von Düngemittel angewandt werden. Die physikalischen Eigenschaften des Bodens können Ernteerträge steuern und somit manipuliert werden, um den Ertrag zu maximieren. Die Bodenbearbeitung kann dazu beitragen den Ertrag zu erhöhen, wenn es einen angemessenen SOM-Gehalt gibt und geeignete Erntesorten ausgewählt werden. Auf jeden Fall ist dies arbeitsaufwendig und verschlechtert die physikalischen Eigenschaften des Bodens. Daher ist es von entscheidender Bedeutung eine minimale Bodenbearbeitungs-Frequenz, für einen niedrigen Bedarf an Arbeitskräften und die minimale Verschlechterung der Bodenqualität zu identifizieren, dies aber mit verbesserten Erträgen in Verbindung mit optimierter Düngung und der Entwicklung von verbesserten Erntesorten zu setzen, die sich einer Vielzahl von Bodenverhältnissen anpassen.

Chapter 8

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APPENDIX A. Additional publications

(not related to this thesis but published during the same time frame of doctoral studies)

A.1. *Chromolaena odorata*: the benevolent dictator?[5]

Lindsey Norgrove[1,]*, Roberto Tueche[1], Julia Dux[1,2] and Prosper Yonghachea[1,3]

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INTRODUCTION

Cameroon is located from 1° to 14°N and 8° to 16°E, bordering Nigeria, Chad, Central African Republic, Congo, Gabon and Equatorial Guinea. In Cameroon, *Chromolaena odorata* (L.) King and Robinson reaches 3m height, flowering at the beginning of the dry season in December. It invades forest gaps, cropped fields, cleared forest land and fallows, open grasslands and savannahs. Susceptible to shade, it becomes less prominent and disappears as fallows age, being outcompeted by understorey Marantaceae and Zingiberaceae and pioneer tree species. However, where these species are absent, *C. odorata* may persist.

COMPETITION WITH MORE NOXIOUS WEEDS

Imperata cylindrica L. Rauesch is a pantropical grass of the tribe Andropogoneae, subtribe Saccharine. It infests nearly 500 million acres of plantation and agricultural land worldwide. In West Africa, it is common in the moist savannah belt between Senegal and Cameroon. Its origin is disputed and subspecies may be native to West and Central Africa or may originate elsewhere (den Breeyen, pers. comm.). *Imperata cylindrica* is difficult to manage as a fallow, dieback in the dry season creates a fire risk, and its sucrose-rich rhizomes attract rodents that eat crop seeds and destroy seedlings. In western Cameroon, where some of the largest expanses of *I. cylindrica* in the country are present, the local name in Mbo-o language is

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[5] Paper published in: Chromolaena odorata Newsletter 17, December 2008. pag. 1-3.

”mbuen” meaning something cruel that sterilises the soil. *Imperata cylindrica* land is avoided by farmers (Yonghachea, 2005). Farmers in Côte d’Ivoire reported that *C. odorata* helps to prevent the establishment of *I. cylindrica* (de Rouw, 1991). To assess competition with *C. odorata*, we planted *I. cylindrica* rhizomes in pots containing soils collected from savannah, *C. odorata*- invaded savannah and forest in Central Cameroon, and measured growth of *I. cylindrical* rhizomes and the relations of the grass with seedbank dynamics. We harvested emergent communities after six months, counting and weighing individual plants. *Imperata cylindrica* biomass production per pot was significantly affected by soil origin with the lowest imperata biomass produced in the *C. odorata* invaded soils. When *C. odorata* mass was added as a covariate in this model, it was significant ($P<0.05$) and was negatively correlated with the biomass of I. cylindrica, hence growth of imperata was reduced by the presence of *C. odorata* (Norgrove, 2007).

EFFECTS ON PLANT COMMUNITIES

In the North West province of Cameroon, we looked at the impact of *C. odorata* invasion on plant community composition in six paired invaded and non-invaded savannah sites. We found no effect of invasion on mean species number, yet community composition was affected. There was a loss of monocotyledonous species, including *Aframomum* spp. and *Murdannia simplex*, and accompanying co-invasion by some dicotyledonous alien weed species, notably *Oldenlandia* sp., *Stachytarpheta cayennensis* and *Ageratum conyzoides*. Areas invaded with *C. odorata* had twice the plant biomass (9.44 Mg ha^{-1}) of non-invaded areas (4.52 Mg ha^{-1}). Furthermore, *C. odorata* addition to savannah systems increased litter N and K inputs. *C. odorata* leaves contained 40 mg g^{-1} of N and 23 mg g^{-1} of K, compared with 6-10 mg g^{-1} N and 11-17 mg g^{-1} K for grasses (Yonghachea, 2005).

SOIL FERTILITY CHANGES?

Farmers in Cameroon have reported that they associate *C. odorata* presence with higher soil fertility (Yonghachea, 2005). Likewise, in Ghana, farmers consider both *C. odorata* and earthworm casts as indicating good soils and link these mechanistically by stating that *C. odorata* provides litter input, shade, and a moist environment which promotes earthworm activity

(Adjei-Nsiah et al., 2004). In southern Cameroon, Norgrove and Hauser (1999) found that weed biomass, dominated by *C. odorata*, explained 76% of variation in earthworm cast production in a cropped field. Subsequently, in an adjacent site, Norgrove et al. (2003) found that mulching with *C. odorata* resulted in an increase in cast production and that these casts were richer in nitrogen and potassium than those derived from non-mulched plots, probably due to feeding on the N- and K-rich *C. odorata* residue. To verify these observations, we measured soil biological, physical, and biochemical parameters in different land uses systems in replicated trials in central and northwest Cameroon. Soil compaction was assessed by bulk density and a static hand penetrometer. Topsoil (0-5 cm) bulk density was lower ($P<0.01$) in *C. odorata*-invaded areas (0.87 Mg m^{-3}) than in savannah (1.04 Mg m^{-3}). Soil resistance was lower ($P = 0.02$) under *C. odorata* (1742 kPa) than under savannah (3239 kPa). Morning, midday and evening topsoil temperatures were always lower ($P<0.0001$) under *C. odorata* (24.1; 25.3; 26.8 °C) than under savannah (27.1; 29.4; 28.5 °C) (Tueche and Norgrove, unpubl.). In the same sites, we also evaluated earthworm species richness (Norgrove et al., 2008). We found that earthworm species richness was higher in *C. odorata* invaded savannah than in non-invaded savannah and there was a significant increase in the earthworm density. Two pantropical species, Dichogaster annae and Nematogenia panamaensis, were found exclusively in *C. odorata*-invaded sites (Norgrove et al., 2008). Similarly, in land-use assessments in southern Cameroon, these species were found only in *C. odorata* fallow (Birang et al., 2003). Such widespread species may be better adapted to high nutrient environments such as that under a *C. odorata* canopy and such conditions may also permit increases in the population densities of native Eudrilidae. Beta (ß)-glucosidase is the final enzyme of the cellulose system which hydrolyses cellulose to glucose. Cellulose comprises 40-70% of total litter mass and its decomposition and mineralization rates may be limiting factors within the soil carbon cycle. We found that ß-glucosidase activity was twice as high in *C. odorata*-invaded savannah than in uninvaded sites of similar soil chemistry (10 compared with 20 ug g^{-1} soil h^{-1}). Furthermore, activity could be promoted by the addition of *C. odorata* residue whereas comparable amounts of grass residues did not increase activity (Dux, 2005).

DIFFERENT LIVELIHOODS, DIFFERENT PERCEPTIONS

In North West province, the dominant Aghem people use a shifting cultivation system whereby land is cultivated for four years and then abandoned for at least five years. In the first year of cultivation, referred to as “sùfuwo” (new farm), soil mounds called “ekang” are made, filled with vegetation and burned. Maize (*Zea mays*), cocoyams (*Xanthosoma sagittifolium*), sweet potatoes (*Ipomoea batatas*), cassava (*Manihot esculenta*) and beans (*Phaseolus vulgaris*) are planted. In the second year called “udung”, the mounds are rearranged into ridges and maize, cocoyams and cassava are cultivated. In the third year, known as “kibvo”, only groundnuts (*Arachis hypogeae*) and maize are planted. By the fourth year of cultivation, “tilù”, maize and cowpeas (*Vigna unguiculata*) are grown and then the field is abandoned. If the fallow is dominated by I. cylindrica rather than C. odorata, the land is only cropped with Vigna subterranea (bambara groundnut) in year 1, groundnut in year 2 and cowpea in year 3 before fallowing. The farming Aghem people consider *C. odorata* as the “least–worst” option for fallows. In these fields they grow a greater diversity of crops (Yonghachea, 2005). The use of a biological control agent for *C. odorata* in this zone would result in greater infestation of *I. cylindrica* and greater weeding drudgery. However, for their pastoralist transhumant neighbours, the Fulbe, relying on grazing savannah land, *C. odorata* negatively affects their livelihood strategy.

CONCLUSIONS

In conclusion, in the context of land users in Cameroon, *C. odorata* invasion in savannahs may have had both negative and positive effects. *Chromolaena odorata*-invaded areas are associated with higher topsoil N status, higher soil faunal densities and activities. This is an association, so cause and effect cannot be distinguished, yet there are plausible mechanistic models to offer an explanation. *Chromolaena odorata* maintains a canopy during the dry season so is less flammable (Norgrove, pers. obs) and prone to wild fires so N volatilisation in these areas is reduced. Therefore, N and C are retained and returned to the soil through litterfall and decomposition. Consequently, soils may have had higher soil faunal and soil enzyme activity. In these savannahs, *C. odorata* does cause species shifts with an increase in alien weeds and/or unpalatable species. Thus savannahs are rendered less useful for grazing and this negatively affects pastoralists’ livelihoods. However, for farmers, a reduction in *C. odorata* abundance through biological control or other mechanisms may result in a more problematic weed community dominated by *I. cylindrica*, so management options should be considered within cultural context.

A.2. Tackling black leaf streak disease and soil fertility constraints to expand *Musa* production onto short fallow land in Cameroon[6]

Short communication: Archives of Agronomy and Soil Science

Lindsey Norgrove[a,b*], J. Roberto Tueche[a], Kim S. Jacobsen[c,d], Alphonse Nkakwa Attey[e], Keith Holmes [b]

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Abstract

Effects of light level (full, 67%, 33% light), and N-amendment on Black Leaf Streak disease (BLSD)-tolerant (FHIA-21) and BLSD-susceptible (Batard) plantain cultivars planted on soil from paired grassland and forest sites were determined. BLSD was monitored at 3 months after planting (MAP). Growth was monitored until 5 MAP then leaves were divided into healthy and damaged areas and dry matter determined. 3 MAP, the leaf area attacked by BLSD on FHIA-21 was less than half that on Batard and was also affected by light such that plants grown under 33% and 67% light had lower percentages of area attacked (2.9% and 4.6%, respectively) than those grown in full light (7.3%). Total leaf area and dry matter content were higher under shade than in full light. Plantains grown on forest soils had a greater circumference, dry matter and leaf area than those on grassland soils. Positive correlations were found between total dry matter and soil K and Mg, suggesting a nutrient limitation across land uses. Compared to growing BLSD-susceptible plantain on forested land under shade, a shift onto grasslands and a reduction in shade use is predicted to reduce yields. Using FHIA-21 may limit, but not eliminate this yield loss.

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[6] This paper has been published in: *International Journal of Pest Management*, 58:2, pp. 175-181.

APPENDIX B. COURSES followed

(as a requirement for the doctoral program)

1. Advanced Crop Production Methods (M5104)
   Prof. Dr. G. Cadisch
   Grade: B-

2. Integrated Agricultural Production Systems (M5106)
   Prof. Dr. R. Schultze-Kraft
   Grade: B+

3. Matter Cycling in Agroecosystems (M7120)
   Prof. Dr. T. Streck
   Grade: A-

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Given Name:	TUECHE, Jacques Roberto
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Matrimonial Situation:	Married, 3 children (5, 4, <1)
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EDUCATION

2006-2014	Ph.D.(Dr. Sc. Agr.) – date of oral defence 18th July 2014. Faculty of Agricultural Sciences, Institute of Plant Production in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany. Dissertation: Relationships Between Soil Physics and Crop Yields in Different Cropping Systems in Southern Cameroon Supervisors: Prof. Dr. Georg Cadisch, Dr. Norgrove and Dr. Stefan Hauser
2002-2003	DEA (Diplôme d'Etude Approfondies) in Tropical Soil Sciences. Earth Sciences Department, Faculty of Sciences University of Yaounde I, Cameroon. Thesis (original title in French): Contribution à l'Etude des Propriétés, des Mécanismes de Transfert et d'Alimentation Hydrique des Aquifères de la Couverture Ferrallitique de Mbalngong au Sud-ouest de la Ville de Yaoundé. Main supervisors: Dr. Brunot Nyeck and Dr. Stefan Hauser
2000-2001	M.Sc. Soil Sciences. Earth Sciences Department, Faculty of Sciences University of Yaounde I, Cameroon. Thesis (original title in French): Contribution à l'Etude de la Susceptibilité à la Dégradation Physique et à l'Erosion des Sols Ferrallitiques du Plateau Sud-Camerounais. Main supervisor: Dr. Brunot Nyeck

1998 – 1999	Faculté des Sciences de l’Université de Yaoundé I Diplôme de Licence de Sciences de la Terre
1991-1992	Lycée de New-Bell à Douala Diplôme de Bachelier de l’Enseignement du Second Degré série D

INTERNSHIP AND PROFESSIONAL EXPERIENCES ALONGSIDE THE UNIVERSITY

2011-Present	Researcher at the Ministry of Scientific Research and Innovation-Institute of Agricultural Research for Development
2004-2010	Consultant at IITA-Cameroon (International Institute for Tropical Agriculture)
2002-2003	Internship at IITA-Cameroon (International Institute for Tropical Agriculture)
2000-2002	Teaching assistant at the Earth Sciences Department of the Sciences Faculty of Yaoundé I University

SCHOLARSHIPS

2004-2007	Ph.D. scholarship in Dr. Norgrove project funded by the Robert Bosch Stiftung, Hohenheim, Germany
2002-2003	Earth Sciences Department, Faculty of Sciences, University of Yaounde I, Cameroon.

PUBLICATIONS IN INTERNATIONAL PEER-REVIEWED JOURNALS

Tueche, J.R., Norgrove, L., Hauser, S., Cadisch, G., **2013**. Tillage and Varietal Impacts on Tomato (*Solanum lycopersicum* L.) Production. Tillage and varietal impacts on tomato (*Solanum lycopersicum* L.) production on an Ultisol in central Cameroon. Soil and Tillage Research Journal 128, 1–8, http://dx.doi.org/10.1016/j.still.2012.10.003.

Norgrove, L., **Tueche, J.R.,** Jacobsen, K.S., Nkakwa Attey, A., Holmes, K., **2012**. Tackling black leaf streak disease and soil fertility constraints to enable the expansion of plantain production to grassland in the humid tropics. International Journal of Pest Management, 58:2, 175-181.

Tueche, J.R., Hauser S, **2011**. Maize (Zea mays L.) yield and soil physical properties as affected by the previous plantain cropping systems, tillage and nitrogen application. Soil and Tillage Research, 115–116, pp. 88–93. Doi:10.1016/j.still.2011.07.004.

Tueche, J.R., Hauser, S., Banful, B., Cadisch, G., **2011**. Influence of different plantain cropping systems on soil physical properties and plantain bunch yield. Archives of Agronomy and Soil Science. 57, 7 pp. 789-803. DOI: 10.1080/03650340.2010.485986. http://dx.doi.org/10.1080/03650340.2010.485986.

OTHER SCIENTIFIC CONTRIBUTIONS

Norgrove L., **Tueche**, **R.,** J. Dux and P. Yonghachea, **2008**. Chromolaena odorata: the benevolent dictator? Chromolaena odorata Newsletter 17, December 2008. pag. 1-3.

Tueche J.R., S. Hauser, L. Norgrove, B. Banful, **2007**. Changes in soil Aggregation in a Plantain Cropping System. On: Farming Systems Design 2007, Int. Symposium on Methodologies on Integrated Analysis on Farm Production Systems, M. Donatelli, J. Hatfield, A. Rizzoli Eds., Catania (Italy), 10-12 September 2007, book 1 - Farm-regional scale design and improvement, pag. 133-134.

Tueche J.R., S. Hauser, L. Norgrove, B. Banful, **2007**. Effects of Land History and Tillage on Soil Physical Properties in a Maize Cropping System. On: farming systems Design 2007, Int. Symposium on Methodologies on Integrated Analysis on Farm Production Systems, M.

Donatelli, J. Hatfield, A. Rizzoli Eds., Catania (Italy), 10-12 September 2007, book 1 - Farm-regional scale design and improvement, pag. 135-136.

Invited reviewer for:
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LINGUISTIC PROFICIENCY

	Reading	Talking	Writing
French	Excellent	Excellent	Excellent
English:	Very good	Good	Good
German:	Basic	Basic	Basic

MISCELLANEOUS QUALIFICATIONS

Computer Literacy	Windows office: Word (very good), Excel (very good), Power Point (very good). Others: Corel Draw (good), SAS (good), EndNote (good) and Sigma Plot (basic),
Driving license:	Categories B

Statutory declaration

I herewith declare that I have composed and completed this doctoral thesis independently without having used any other sources or resources than those specified therein.

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Stuttgart, Hohenheim, 2014 ______________________________

Jacques Roberto Tueche