NITROGEN BIOVAILABILITY IN MAURITIAN SOILS UNDER SUGARCANE CULTIVATION AMENDED WITH AGRICULTURAL COMPOSTS

by

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DECLARATION

I, Patricia Laurent-Ragavan declare that the dissertation, which I hereby submit for the degree MSc (Agric) Soil Science at the University of Pretoria, is my own work and has not yet been submitted by me for a degree at this or any other tertiary institution.

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DATE: 25/08/2017

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LIST OF ABBREVIATIONS

ACP	Africa Caribbean Pacific
ANOVA	Analysis of Variance
APSIM	Agricultural Production Systems Simulator
CEC	Cation Exchange Capacity
CMS	Consolidated Molasses Stillage
CV	Coefficient of Variation
DON	Dissolved Organic Nitrogen
DSSAT	Decision Support System for Agrotechnology Transfer
DW	Dry Weight
EON	Extractable Organic Nitrogen
EU	European Union
FAO	Food and Agricultural Organization
FC	Filtercake
FW	Fresh Weight
HDM	Harvestable Dry Matter
IFSM	Integrated Fertility Soil Management
IRSC	Industrial Recoverable Sucrose
LSD	Least Significant Differences
MAE	Mean Absolute Error
MAP	Mono Ammonium Phosphate
MFED	Ministry of Finance & Economic Development
MOP	Muriate of Potash
MRT	Mean Residence Time
MSIRI	Mauritius Sugar Industry Research Institute
N	Nitrogen
N_0	Nitrogen Mineralization Potential
NUE	Nitrogen Use Efficiency
OM	Organic Matter

PL	Poultry Litter
PM	Poultry manure-sugarcane thrash
Ppm	Parts per million
PVC	Polyvinyl chloride
RBD	Randomized Block Design
RMSE	Root Mean Square Error
SD	Standard Error
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SON	Soil Organic Nitrogen
STASM	*Société de Technologie Agricole et Sucrière de Maurice*
SWB	Soil Water Balance
TDM	Total Dry Matter
TSP	Triple Superphosphate
USDA	United States Department of Agriculture

ABSTRACT

Nitrogen (N) plays a vital role in plant metabolic processes, and may cause severe economic losses in crop production if deficient. When agricultural composts are used to counteract soil impoverishment and supply crop nutrients, it is crucial to understand the dynamics of nitrogenous compounds to optimize N uptake. Five major soil groups of Mauritius were amended with three types of compost, filtercake (FC), poultry litter (PL), and poultry manure-sugarcane thrash (PM), at application rates to supply 140 kg N ha^{-1}in a laboratory incubation experiment over 215 days. In each soil group, only specific types of agricultural composts resulted in a statistically significant ($P < 0.05$) increase in cumulative N mineralized, relative to the control: PM in the Low Humic Latosol (L), PM and PL in the Humic Latosol (H), PL in the Humic Ferruginous Latosol (F), PL in the Latosolic Reddish Prairie (P) group, and FC and PL in the Latosolic Brown Forest (B) group. In general, the $N\text{-}NO_3^-$ form was dominant in all the treatments across the soil groups. Only in the H soil amended with PM and PL was the $N\text{-}NH_4^+$ form pre-dominant. The index of N availability, N_0k, showed that in control soils, the daily N availability (mg N kg^{-1} soil day^{-1}) was in the order B (1.242) > H (0.975) > F (0.674) > P (0.637) > L (0.524). The relatively high N availability in the B may explain why sugarcane cultivated in this soil islowly responsive to increments in N fertilizers. Relative to the control soils, FC resulted in a decrease in N availability, mostly due to a relatively slower rate of N mineralization. Poultry litter compost increased daily N availability in all the soil groups. Increased N availability was also noted in all soils amended with PM, except in the P soil. In general, the percentage of organic N mineralization in control soils varied from 2% to 4%. In FC-amended soils, between 2% and 5% of the organic N from soil and compost mineralized. Applied in the weathered soil groups (H, L and F), PM resulted in an appreciable increase in organic N mineralized that varied between 6% and 9%. However, in the immature soil, PM had a relatively mitigated effect, with 1% of total N mineralization in the amended P soil, and 3% in the B soil. Across the soil groups amended with PL, from 4% to 8% of the total soil and compost organic N mineralized.

The three field experiments showed that in the plant cane, the input of inorganic fertilizers caused a spike in the concentration (up to 457 mg N kg^{-1} soil) of soil inorganic N, six days following application. In the blended treatments, the rate of inorganic N fertilizer was reduced by 25% and complemented with compost at rates varying from 9.0 t ha^{-1} for FC to 5.5 t ha^{-1} for PM and 3.5 t ha^{-1} for PL in the cane row at planting. Out of the three blends, only that with PL produced an inorganic N spike higher than inorganic fertilizer in the three soil groups.

In the plant cane, relative to the control treatment where no N was applied, cane yield response to inorganic fertilizer was as low as 6% at in the P soil, 8% in the H soil, and 10% in the L soil. No significant differences ($P > 0.05$) were observed amongst the control, compost-inorganic fertilizer, and compost treatments of the same site. The combined use of compost with or without inorganic fertilizers therefore produces statistically similar yields than just inorganic fertilizers in a plant cane crop. It can be inferred that SOM contributes substantially to N nutrition in the plant cane crop and that the present rates of inorganic N fertilizers applied at planting need to be adjusted. Relative to the control treatment, the strongest yield responses were obtained with FC in the P soil (14%), PM-inorganic fertilizer in the H soil (25%) and PL-inorganic fertilizer in the L soil. The differences in IRSC between treatments of the same site were not statistically different ($P > 0.05$).

From a general perspective, it was observed that cane yield responses to fertilization were greater in the first ratoon than in the plant cane. In the first ratoon, only in the P soil were differences in yield between treatments significant ($P < 0.001$), mostly due to the low yield of the control treatment. In the experimental sites, agricultural composts were applied in the cane rows at planting only at rates varying from 36 t ha^{-1} (FC), to 22 t ha^{-1} (PM), and 13 t ha^{-1} on a fresh weight basis. In the first ratoon, compost application was discontinued to evaluate the residual effect of compost N on cane yield. The residual N effect on cane yield was strongest in the P soil whereby FC resulted in a numerically higher yield response (46%) than inorganic fertilizer (40%), relative to the control. The yield responses to compost treatments were 2% to 25% higher than the control treatment in the L soil, and did not exceed 2% in the H soil. In the first ratoon, the differences in IRSC between treatments of the same site were not statistically significant.

Hydrogen (H^+)-saturated cation (Dowex 50WX8 50-100; Manufacturer) and chloride (Cl^-)-saturated anion resins (Dowex 1X8 50-100) were placed at the base of Poly vinyl Chloride (PVC) corers to a depth of 0.2 m during 125 days. The results indicate that in both the H and L soil groups, the cumulative concentration of N ions in the resins was lowest in plots amended either partially or fully with compost. The dual use of FC, PM or PL with reduced rates of inorganic N fertilizer can therefore potentially decrease the risks of N losses by leaching. The concentration of inorganic N trapped by the resins in the control soilsalso indicate that in the high rainfall zone of the H soil, losses of N from SOM mineralization may be more considerable than in the drier zones where the P and L soils are located.

The Soil Water Balance model (SWB-Sci) predicted only moderately well the changes in soil inorganic N following the application of compost, overestimating the concentration of inorganic N in amended soil during the first 40 days. The initial quick organic N mineralization was mainly attributed to the fact that similar C:N ratios and generic half-lives were attributed to the three OM fractions of compost. The model simulation of different fertilization practices over 10 years showed thatyearly applications of agricultural composts such as FC, PM and PL mitigated the drop in total N and OM reserves that occurs naturally in soils under crop cultivation. Poultry litterwhich had the highest OM content of the three composts even increased SOM to levels higher than the initial soil level after 10 years of application. The simulation therefore highlighted the potential of exogenous sources of OM such as agricultural composts to conserve soil fertility in the long run for sustainable crop production.

INTRODUCTION

Situated in the Indian Ocean, Mauritius is a small volcanic island of 1900 km^2 with land, water and a tropical climate as the only natural resources. Agriculture utilizes 46% of the island's terrestrial resources, and of the 85400 ha of arable land, 51477 ha of landunder sugarcane cultivation were harvested in year 2016 (MFED 2011, Mauritius Chamber of Agriculture 2016). Nitrogen (N) is considered to be the major element for sugarcane (*Saccharum officinarum*) nutrition as it is active in plant photosynthesis, metabolic processes, and contributes to tillering and stalk elongation (Koochekzadeh et al. 2009). Therefore, if deficient, N can severely limit crop growth and be detrimental to cane and sugar yields, the sources of revenues for cane growers (Dametie and Adenew 2009).

As underlined by Parish and Feillafé (1965), the intrinsic fertility of Mauritian soils is low, andto sustain commercial sugarcane production and conserve the soil N pool, N fertilization is a necessary practice. Both inorganic and organic sources of N are known to contribute to the build-up of the element in soil, thereby mitigating excessive mining of the existing N pool (Robertson and Vitousek 2009). Increases in the topsoil available N ranging from nine to 33% have been reported following 15 years of inorganic fertilization (Meng et al. 2013). On the other hand, regular application of organic residues, particularly those with a relatively wide C:N ratio, has resulted in the accumulation and immobilization of N in the organic form from which increasing concentrations of mineralized N can be expected throughout the years (Gutser et al. 2005). Field studies carried out in Mauritius have shown that as much as 85% of N taken up by the crop may originate from mineralized soil N (MSIRI 2001). Similar studies in Brazil indicated that although uptake of N from fertilizer was low in the above-ground parts at harvest, the uptake of N-fertilizer at the early stages of development was as high as 40% in plant cane and 70% in ratoon (Franco et al. 2011). While these findings confirm the participation of N-fertilizer in sugarcane nutrition, it stands out that soil N plays a major role in crop growth and development. Attempts to predict N release from organic matter (OM) in Mauritian soils were unsuccessful due to the interplay of environmental variables such as moisture, temperature and aeration (MSIRI 1995). This study has therefore been initiated to bridge this gap in knowledge, so that in the future, the amount of potentially mineralizable N from the soil is considered when establishing fertilization plans. With the vibrant need to conserve the soil N reserves, and increasing application of agricultural composts to sugarcane land, it also becomes pressing to assess how these composts affect N bioavailability, and whether they can be integrated with inorganic fertilization to support cane and sugar yields.

Reducing the cost of sugar production is a major concern to the local sugarcane-producing community since the progressive phasing out of the Sugar Protocol between the European Union (EU) and the Africa, Caribbean and Pacific Group (ACP) of countries which started in 2005. The Sugar Protocol was of an indefinite duration and ensured a quota of 491 000 t of sugar export, access to the EU market, and guaranteed sugar prices that were on average three times the world market price (BDO 2010). In 2009, the price of sugar had dropped by 36%. The difficult economic situation instigated by the reform of the EU sugar regime lead to the establishment of a roadmap by the Mauritian Government that stretched from year 2006 to year 2015(AGRECO consortium 2007). The plan targeted the evolution of the sugar sector to a diversified industry where sugarcane and its by-products are used for value-added sugar products and electricity production. One component of cane production that may be reviewed to address this challenge is fertilization. To maintain profitable sugarcane yields and the fertility of cultivated soils, it is important to ensure that management practices are sustainable. Bholah (2008) confirmed the poor residual value of fertilizer N in soil and the need to consider organic sources of N for sustainable sugarcane production. Besides sugar-oriented activities, a number of companies also run plural production units that generate organic products rich in OM and nutrients, and which can act as fertilizers (Appendix I). For example, poultry production which is an economic unit of sugar-producing companies generates poultry litter and manure as waste which can be further composted and utilized in sugarcane fields as alternate sources of N. Although the composting of agricultural organic wastes requires an initial capital investment, the eventual increase in yield derived from a sustained improvement in soil fertility may economically justify this investment. Synergy between the sugar and livestock/poultry units can therefore optimize the cost of sugar production by diminishing reliance on expensive inorganic N fertilizers.

Despite the fact that agricultural composts are a rich source of nutrients, integrated fertilization plans with inorganic and organic fertilizers have not been widely adopted. Knowledge about the N mineralization pattern of composts has impeded such dual schemes. According to Eghball et al. (2002), the use of an organic material as a fertilizer requires knowledge about the mineralization and immobilization of its nutrients following field application. As these processes regulate the concentration of plant-available ammonium (NH_4^+) and nitrate (NO_3^-) in soils (Er et al. 2004, Baitilwake et al. 2012), the absence of knowledge on the trends of N mineralization, may result in either over- or under- fertilization. In natural ecosystems, N mineralization is a dynamic process that is a function of soil characteristics, environmental conditions and human alteration, all of which determine the amount, pattern and form of inorganic N released or lost (Vitousek et al. 1997, Zech et al. 1997). In such an environment, it is difficult to measure the magnitude of each component of the ecosystem on net N mineralized. For this reason, experimentations under controlled conditions in the laboratory are common practice (Stanford et al. 1974, Wang et al. 2003). In this study, a laboratory incubation experiment was carried out to obtain estimates of the nitrogen mineralization potential (N_0) of the major soils under sugarcane cultivation amended with agricultural composts. The $N_{0,}$ an estimate of the maximum amount of N that can mineralize under optimal moisture and temperature (Stanford and Smith 1972), will provide information about the fertilizing power of different composts in soil-specific conditions and can, in future works, be used to assessthe robustness of chemical indices to predict N mineralization. Since laboratory conditions are not always representative of those in the field, especially when soil is disturbed during sampling and sieving (Raison et al. 1987), field trials were also carried out to assess N bioavailability in relation to other soil processes and budgets (Noe 2011). World-wide, numerous field experimentsusing a range of organic materialshave strongly underlined the need to determine N release under site-specific conditions before a successful integrated fertilization plan can be devised and implemented (Zou et al. 1992, Weinhold 2007, Abera et al. 2012a). Although laboratory incubation and field trials may be potentially lengthy, they generate useful datasets for the calibration of models that can forecast the effects of fertilization practices on N dynamics, and are indispensable for the validation of simulations. One such model is the Soil Water Balance model (SWB). Including a recently incorporated N sub-routine, the SWB-Sci model can be parameterized and calibrated to simulate long-term effects of compost application on N dynamics (Van Der Laan 2009, Tesfamariam et al. 2012). Nevertheless, it was noted that while total dry matter (TDM) and yield were well simulated, the levels of soil inorganic N simulated were much higher than those measured in field. Therefore, to investigate the potential use of SWB-Sci at simulating N mineralization in Mauritius, field trials are essential to validate the simulated trends of N mineralization, and may also provide indications for model improvement. Besides modeling the patterns of N release, SWB-Sci model can be a strong tool by providing complementary information about the implications of compost usage on the evolution of soil organic matter (SOM) in the long-term.

The importance of SOM for the soil's biological, physical, and chemical properties through the preservation of microbial biomass, soil structure and cation exchange capacity (CEC) have been well highlighted (Huber and Schaub 2011). From an environmental perspective, the increased CEC of soil upon incorporation of organic residues implies an enhanced availability of cation exchange sites for the adsorption of NO_3^- and NH_4^+, ions that are prone to leaching losses from the root zone to groundwater (Van Der Laan et al. 2013). During the last decade, the average yield of sugarcane in Mauritius has declined. This phenomenon has been attributed to the impoverishment of soils resulting from the shift from manual agricultural operations that left the field's fertile topsoil undisturbed to mechanized operations and intensive tillage (Ng Cheong 2007, MSIRI 2010). Conventional tillage increases the decomposition of soil organic carbon (SOC) (Chen et al. 2009); during tillage, the soil is disturbed, and organic matter (OM) which was once occluded becomes exposed to oxygen, and undergoes faster oxidation than it would have in an undisturbed state. While the rapid loss of the SOM and disruption of soil biota is enhanced by land preparation, the mechanization of cultural practices may not be the only factor responsible for yield decline. Soil impoverishment may also be linked to changes in fertilization practices because in the early 20th century, before the intensive use of inorganic fertilizers, organic materials such as farmyard manure and guano from the coral islands and atolls in the south west Indian Ocean were widely used (Parish et al. 1955). While some of these products are still available, they are applied to a lesser extent, thereby amplifying the deleterious effects of intensive tillage and soil N mining on soil fertility. It is well-known that the systematic use of inorganic fertilizers acidifies agricultural soils in the long run (Meng et al. 2013), and may cause a drop in cane yield. It is therefore essential to bring back more organic materials to sugarcane fields to replenish the dwindling stocks of OM, and conserve the fertility of Mauritian soils in the long term.

The soil fosters important, but not bottomless N reserves. Provided that the soil N pool is constantly recycled by the application of fertilizers, the soil may contribute appreciable amounts of N to sugarcane. Although figures about the N-supplying capacity of soil in Mauritius has been reported (Anthony 1998), the effects of exogenous organic products on N availability in soil still need to be studied to allow the integration of composts in sugarcane fertilization. The changes in N dynamics that occur upon application of compost to the different soil groups was investigated during both an incubation study and under field conditions. Laboratory experimentsprovide the necessary controlled conditions to derive soil N_0, and field trials are pertinent to describe N fluxes *in situ* and yield responses to different fertilizer regimes. Following parameterization of the SWB-Sci model and testing against historical data to gain confidence in the model's simulation, the datasets obtained in the laboratory were used to compare N mineralization simulated by the model. The impact of compost usage on soil total N and the evolution of SOM was also enquired using SWB-Sci. Predictions of plant-available N are essential to the implementation of an organic fertilization plan for sugarcane and optimization of N use efficiency (NUE) from both organic and inorganic sources (Griffin 2008).

Hypotheses

A study to investigate N bioavailablity under sugarcane soils amended with agricultural composts was proposed on the basis of the statements elaborated in the introductory part, and the following hypotheses were postulated:

(a) The amount of N that mineralizes from soil is strongly correlated to the C:N ratio and OM content of soil.

(b) The combined use of inorganic fertilizer together with compost to meet the N requirements of sugarcane will produce equalcane and sucrose yields as when using inorganic fertilizers only.

(c) Leaching losses of N-NO_3^- in soils are agronomically insignificant in soils under sugarcane cultivation.

(d) SWB-Sci model can be used to predict N mineralization from organic fertilizers.

Aim and objectives of the study

The aim of this study was to describe the N mineralization pattern of three types of agricultural composts (FC, PM and PL) in Mauritian soils under sugarcane cultivation, with a view to optimally integrate compost in sugarcane fertilization plans.

To address the aims of the study, the following objectives were set:

a) To determine the pattern and rate of NH_4^+ and NO_3^- release of three different agricultural composts in five major Mauritian soil groups, in a laboratory incubation study.

b) To investigate the changes in soil inorganic Nunder field conditions when compost is applied as the single source of N or is used in combination with inorganic N fertilizers.

c) To evaluate the influence of soil and compost chemical and physical properties on N mineralization potential in compost-amended soils.

d) To explore the use of the SWB-Sci model to predict N mineralization under different fertilization regimes.

e) To simulate theimpact of long-term organic and inorganic fertilization on SOM, total N, and inorganic N in soils under sugarcane cultivation.

CHAPTER 1: LITERATURE REVIEW

Fertilization is a major component in the management of soils for crop production and has a direct impact on the soil's biological, chemical and physical properties. Any ramification asa result of fertilization is therefore likely to change one or more of these properties. The magnitude of change will affect the soil's fertility in the short-, medium- and long-terms (Rasmussen et al. 1998). In Mauritius, in the early 20th century, before the intensive use of inorganic fertilizers, organic materials such as filtercake (FC), farmyard manure and guano from the coral islands and atolls in the south west Indian Ocean were widely applied in sugarcane (*Saccharum officinarum* L.) fields (Parish et al. 1956). While some of these products are still available, they are applied to a lesser extent, and this may amplify the deleterious effects of intensive tillage on soil fertility. A comparison between soils subjected to conventional tillage, conservation tillage and uncultivated soils showed that the amount of organic carbon (C) in soil was highest in uncultivated soil and lowest in soil where tillage was common practice (Blanco-Moure et al. 2011). The conservation of soil C in the less disturbed system was attributed to the protection of organic matter (OM) from microbial breakdownby soil micro-aggregates. Higher soil organic matter (SOM) is related to improved soil structure, increased water- and nutrients- holding capacity and microbial diversity (Hongwei et al. 2012). In addition to soil preparation practices that contribute to the conservation of SOM, the application of organic amendments constitutes a dual means of C and nutrient input that confers sustainability to crop production systems (Whalen et al. 2008).

1.1 Role of nitrogen in sugarcane nutrition

The essential role of nitrogen (N) in the composition of amino acids which are the building blocks of compounds such as proteins, and nucleic acids confers it a value of high agronomic importance (Tejera et al. 2006). Nitrogen also forms part of the chlorophyll molecule (Bakker 1999), and is actively involved in plant metabolic processes, tillering and stalk elongation, and is therefore considered to be the main element for sugarcane nutrition, and can limit crop growth if deficient (Dametie and Adenew 2009, Koochekzadeh et al. 2009). Using ammonium sulphate as a source of N, Parish and Feillafé (1959) showed that sugarcane yields increased with incremental rates of fertilizer.A deficiency of the element may cause severe stunting. As shown by Hartt (1970), the yellowing or chlorosis of leaves is also a characteristic symptom of N stress (Figure 1.1). In conditions of low N availability, N in older plant tissues is solubilized and translocated to younger, actively growing tissues; for this reason, older leaves yellow before less mature ones (Bakker 1999).

FIG. 1.1: Chlorotic sugarcane leaf (right) as compared to green-coloured leaf of a healthy crop (left) (Courtesy of the Mauritius Sugar Industry Research Institute)

While the commercial value of sugarcane lies mostly in the sucrose content of the stalks, it has been found that increasing the rate of N applied from 56 kg ha^{-1} to 107 kg ha^{-1} and 268 kg N ha^{-1} caused a significant ($P < 0.05$) linear increase in sugarcane yield (t ha^{-1}) and a decrease in the sucrose content in fresh stalks (Muchow et al. 1996). Nevertheless, the same author concluded that the effect of N on sucrose levels was less significant when compared to its effect on sugarcane biomass which increases with high levels of N. Biomass accumulation was due to the higher interception and utilization of solar radiation by N-rich chlorophyll (Muchow et al. 1994), but also, owing to a bigger canopy, provided that water and solar radiation are not limiting.

1.2 Sources of nitrogen for crop production

Field studies using the ^{15}N isotope dilution technique have shown that between 70 and 105 kg N ha^{-1} $year^{-1}$ can be mineralized from soil under sugarcane cultivation in Mauritius and that from 70 to 85% of N taken up by the crop may originate from mineralized soil N even when inorganic fertilizers are applied (MSIRI 2001). Similar studies in Brazil indicated that although the N from fertilizer was low in the above-ground parts at harvest (10% of total accumulated N in plant cane and 30% in ratoon), the presence of N-fertilizer at the early stages of development was as high as 40% in plant cane and 70% in ratoon (Franco et al. 2010). While these findings confirm the role of N-fertilizer in sugarcane nutrition, they also confer soil a valuable role in N nutrition. Due to the increasing price of N fertilizers, and deleterious implications of high N applications with regards to sugar quality and the environment, it is crucial to recognize soil as a key source of N, and consider this contribution when formulating fertilization programmes. In soil, N can be found in both inorganic and organic forms.In terms of nutrition, plants access three main inorganic forms of N, namely ammonium (NH_4^+) and nitrate (NO_3^-) (Gasser 1969). Generally, inorganic N constitutes two to five per cent of total soil N, and this pool is replenished by decaying SOM and inputs of inorganic N fertilizers. Linca et al. (2012) reported that because of the aerobic nature of nitrification, NO_3^- ions tend to be prevalent in well-drained, aerated soils, while NH_4^+ accumulates under waterlogged conditions. Nevertheless, NH_4^+ remains the preferred form of N accessed by plants because its utilization in protein synthesis requires less energy. While a high concentration of NH_4^+ may be toxic to plants, restricting germination or growth, high concentrations of NO_3^- are tolerated.

Soil organic matter contains roughly four percent N, and is composed ofan array of organic N-rich materials that include crop and animal residues, microbial biomass, microbial metabolites adsorbed to colloids, and stable humic substances (Roswall 1976, Campbell 1978, van Antwerpen et al. 2013). With the dominance of SOM in the plough layer, the concentration gradient of organic N in soil decreases naturally with depth (Ros et al. 2009). Unlike inorganic N, organic N cannot be directly absorbed by plant roots. In Reunion Island, between 0.76% and 2.68% of SOM N mineralizes annually to a depth of zero to 0.25 m (Chabalier et al. 2006). According to Ros et al. (2009), there are two main pools of organic N in soil, dissolved organic nitrogen (DON) and extractable organic N (EON). While DON is found in a dissolved form in soil solution, EON is still part of soil solids. Components of the EON pool will only dissolve in the soil solution under favourable soil conditions or can be extracted usingwater or chemicals such as KCl (Murphy et al. 2000). Sizes of the EON and DON pools vary, and have been related to the processes of mineralization, immobilization, adsorption-desorption, and the environmental and land management practices influencing these processes (Ros et al. 2009).

Before the import of inorganic N fertilizers for use in the Mauritian Sugar Industry, organic materials were the only source of nutrients in croplands.Heavy dressings of guano, fish meal, molasses and farmyard manure were widely utilized amongst farmers (Parish et al. 1955).When the *Surra* disease decimated cattle herds, and manure became scarce, FC which is obtained during the decantation of sugarcane juice, has been applied over a greater cultivated area. Until now, FCconstitutes the bulk organic material of agricultural origin produced in Mauritius. However, FC is no longer as freely-available. From 2006 to 2007 (Figure 1.1.1), the amount of FC produced in Mauritius dropped by 35% (MFED 2011) because of the adoption of the diffuser technology for sugar extraction by some mills, and a decline in the area under sugarcane cultivation. The remaining FC is either applied fresh in plant and ratoon crops, or is co-composted with vinasse.

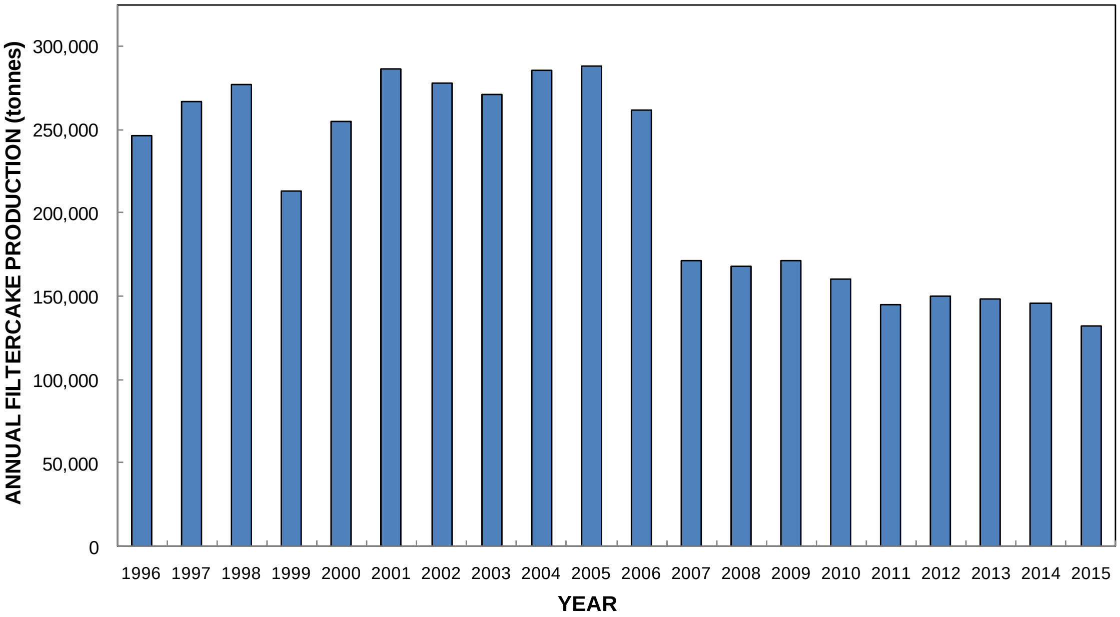


FIG. 1.1.1: Trend in the annual filtercake productionin Mauritius from 1996 to 2015(courtesy of the Ministry of Finance & Economic Development of Mauritius)

Vinasse is a by-product obtained from the fermentation of molasses during the production of industrial rhum or ethanol. Composting, a microbiological process during which decomposable organic materials are converted into a humus-like product (Mohee 2003), embodies a method of by-product management for effluents like vinasse. Soil conditioners produced from the co-composting of vinasse with FC are commonly used in India and Reunion Island (Partha and

Sivasubramanian 2006, Thomas 2012). Although statistics about other sources of agricultural organic products and composts produced from these wastes are not reported locally, a range of materials are commonly used by sugarcane growers. Generally, because of the high costs of transport, the organic materials are either obtained from neighbouring livestock producers or from animal wastes and crop residues generated on the same farm. The raw materials are either applied fresh, or composted for a few months before field application. As supported by Table 1.1, agricultural waste materials contain appreciable amounts of plant nutrients and organic material. Popular organic materials include poultry manure (PM) (layer production), poultry litter (PL) (broiler industry), cattle manure and horse manure. Manure collected from poultry farmsis usually composted with thrash recovered from sugarcane fields to facilitate mechanical application. The composting period extends to three months, during which, vinasse is regularly injected into the compost windrow. On the other hand, broiler litter consists of poultry excreta and bedding materials such as wood shavings or saw dust. Since the broiler litter is quite dry, either vinasse or water is injected into it during composting. The agricultural organic products are illustrated in Figure 1.1.2.

TABLE 1.1: Chemical characteristics of selected organic materials and composts produced in Mauritius (Cooperband et al. 2002, Chabalier et al. 2006)

Organic material	**Nitrogen**	**Phosphorus**	**Potassium**	**Organic matter**	**C:N**	**pH (H_2O)**	**Dry matter**
	% Dry weight						**%**
Poultry litter	3.5-5.7	2.7-3.5	3.2	80.2	6.3-12.6	7.8	58.5-63.3
Filtercake	1.8	1.0	0.4	48.0	20.0	6.0	29.0
Poultry manure (layer)	7.2	4.3	3.5	65.3	8.0	9.0	72.3

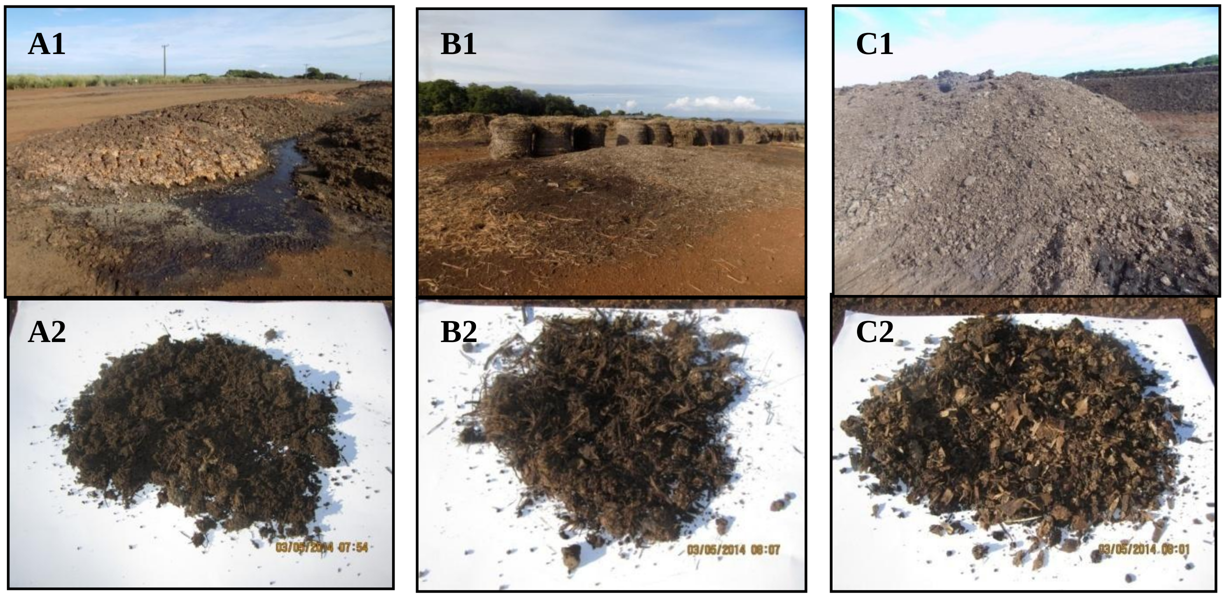


FIG. 1.1.2: Organic raw materials before and after composting (A1 and A2: filtercake, B1 and B2: poultry manure with thrash, C1 and C2: poultry litter)

In Mauritius, inorganic N nutrition of sugarcane was met over time by sodium nitrate ($NaNO_3$), ammonium sulphate $(NH_4)_2SO_4$, and urea $CO(NH_2)_2$ (Appendix II). Urea, which was first introduced to the island in 1956, is now the most widely used N fertilizer because of its lower purchase price and ability to produce yields comparable to those obtained with $(NH_4)_2SO_4$ (Parish and Feillafé 1959). When applied to the soil, urea is hydrolysed to ammonium carbonate which then undergoes nitrification. It is recognized that especially in alkaline soils, the NH_4^+ compound is highly unstable and is potentially rapidly converted to ammonia gas (NH_3) that is lost to the atmosphere (Brady 1999).

According to soil levels of the phosphorus (P) and potassium (K), blended fertilizers are also commonly applied. Examples of NPK formulations include 14-20-20, 19-0-19 and 17-8-20. More recently, concentrated molasses stillage (CMS) with spiked N, P and K has gained popularity as a liquid fertilizer, especially in dry regions where the broadcasting of urea on soil surface or sugarcane thrash can lead to N volatilization losses as high as 26%(MSIRI 2005).Inorganic fertilizers are syntheticand manufactured industrially, so when applied to natural system, alterations are prone to occur. Meng et al. (2013) observed that constant input of inorganic N fertilizer to croplands from 1990 to 2005 lead to a decline in the topsoil pH (by 0.29 to 0.89 units. Brady (1999) has rated the soil-acidifying power of N fertilizers as highest for $(NH_4)_2SO_4$, and lowest for $CO(NH_2)_2$, and ammonium nitrate (NH_4NO_3).

1.3 Nitrogen dynamics in soil

Compared to inorganic fertilizers which are mostly formulated to be immediately plant-available, composts have a heterogeneous composition and consist of OM fractions that vary in their turnover rates (Zech et al. 1997, Sohi et al. 2001). At some point in time, N from both inorganic and organic sources become integrated in the soil organic N (SON) fraction and the rate of release is a function of the influences of cultural practices, environmental conditions and soil characteristics on SOM degradation (Rasmussen et al. 1998, Blanco-Moure et al. 2011, Conant et al. 2011). Consequently, only a percentage of the N from applied organic and inorganic fertilizer is actually absorbed, or becomes available for absorption by plants during the same season, with a fraction being either lost to the atmosphere (volatilization, denitrification) and/or to water systems (leaching, runoff), and the remaining being incorporated in the organic pool for release in the long-term (Gutser et al. 2005). The integration of inorganic N in the organic pool occurs through the process of immobilization, which involves the assimilation of mineral N by microbes for their growth (Chowdary et al. 2004). Generally, the extent of immobilization is determined by the relative amounts of C and N (C:N ratio) in the compost and soil. Cooperband et al. (2002) reported that raw PL with a C:N ratio of 6.3 mineralized higher amounts of NO_3-N compared to composted litter of varying age which had C:N ratios from 12.2 to 18.7.

Composts represent a source of additional OM and nutrients, and when incorporated in soil, act as substrates that may either amplify or hamper N mineralization through enhanced microbial biomass or activity (Kuzyakov et al. 2000). This phenomenon is known as the priming effect.The exact mechanism of the priming effect is not clear, and it has been theorized that easily decomposable materials could trigger microbial activity, accelerate the turnover rate of SOM and increase the amount of inorganic N mineralized (Asmar et al. 1994). The opposite reaction may also occur. Soil microbial biomass may sequester easily available N from the added organic material, and cause a temporary unavailability of N (Cheng 1996). Under this condition, a negative priming effect is said to occur. Figure 1.1.3 depicts N transformations occurring in soil. When compost is applied, the organically-bound N is converted into inorganic forms by soil microbes, a process called mineralization. It is a two-step biological process which involves firstly ammonification and secondly nitrification. Ammonification is mediated by heterotrophic microorganisms and during this process, N which is usually in the form of an amino compound (protein), undergoes proteolysis, and NH_4^+ ions are produced (Brady 1999). The NH_4^+ produced can be absorbed by either plants or other microorganisms, or be subjected to nitrification whereby NH_4^+ is enzymatically oxidized to nitrite (NO_2^-) by the *Nitrosomonas* group of bacteria and NO_2^- is oxidized to NO_3^- by *Nitrobacter* bacteria (Roswall 1976, Brady 1999). Both NH_4^+ and NO_3^- are exposed to losses in certain conditions. When applied on the surface, the risks of NH_4^+ lost to the atmosphere by volatilization, which is the conversion to ammonia (NH_3) increases (Rawluk et al. 2001). On the other hand, NO_3^- may either be lost by leaching or biochemical reduction to N gases (N_2, NO_x, N_2O) in the absence of oxygen (as in waterlogged conditions), a process known as denitrification (Brady 1999, Weitz et al. 2001).

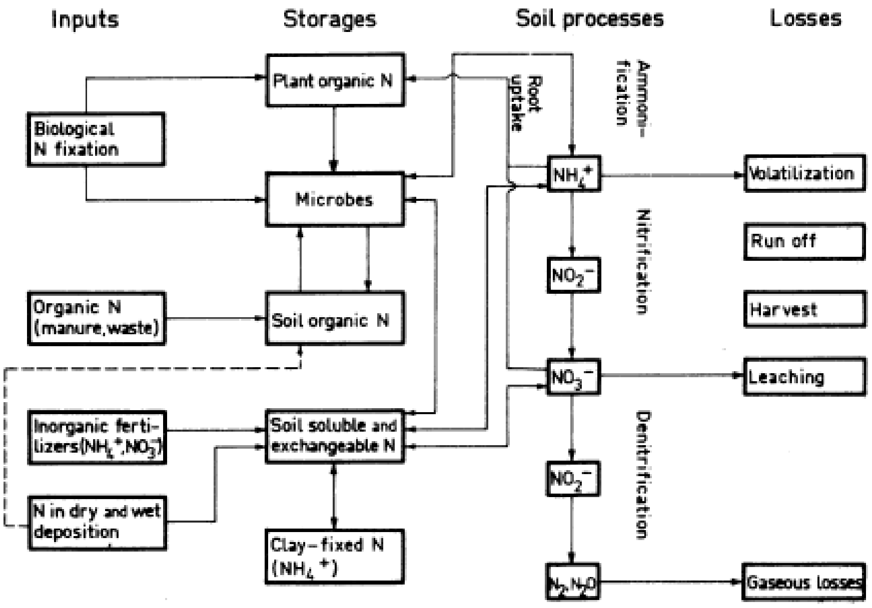


FIG. 1.1.3: Nitrogen (N) transformations in the soil (Keeney and Gardner 1975; Roswall 1976)

1.4 Exogenous application of organic materials

Intensive work on the use of exogenous organic materials for crop fertilization has been carried out in Reunion Island. Chabalier et al. (2006) defined the mineralization behaviour of a number of organic products and indicated that as much as 50% of organic N mineralization could occur within three to six months. On the other hand, Gutser et al. (2005) have reported a broad range of mineral-fertilizer equivalents for organic materials, from 0% for bio-compost to 100% for urine. There is evidence that regular application of organic residues, particularly those with a high C:N ratio, results in an accumulation of soil organic N from which increasing concentrations of mineralized N can be expected in later years (Gutser et al. 2005). An investigation on the effects of long-term cropping systems on changes in N mineralization also showed that cultural practices, including fertilization, strongly determines the stock of soil organic N and how much N will mineralize from this pool in the long-term (Rasmussen et al. 1998). Therefore, the exogenous input of organic residues constitutes a valuable means of conserving soil fertility. Following the application of composted cattle manure over five years, Whalen et al. (2008) concluded that at a yearly rate of 15 t ha^{-1}, the contribution of the organic residue to the total N pool was greater than for the NO_3^- pool. Nevertheless, the NO_3^- was comparable to that of inorganic fertilizers, suggesting that the major impact of compost application remains increased levels of total N, as a result of a gain in stabilized N compounds. More recently, Chalhoub et al. (2013) also supported the contribution of compost to increased availability of N through continuous yearly application. Baitilwake et al. (2012) studied the effect of organic manures on N mineralization in soil under controlled conditions of moisture and temperature. Figure 1.1.4 demonstrates that a maximum of 64 mg N kg^{-1} soil mineralized in the non-amended soil (Baitilwake et al. 2012), less than in soils amended with organic manure ($P < 0.01$).The pattern of N release of different organic materials applied on the soil surface and incorporated during incubation at 24°C and 85% field capacity is also described in Figure 1.1.4. Immobilization occurred between days 21 and 28 and peak N mineralization was recorded towards the end of the incubation period (Baitilwake et al. 2012).

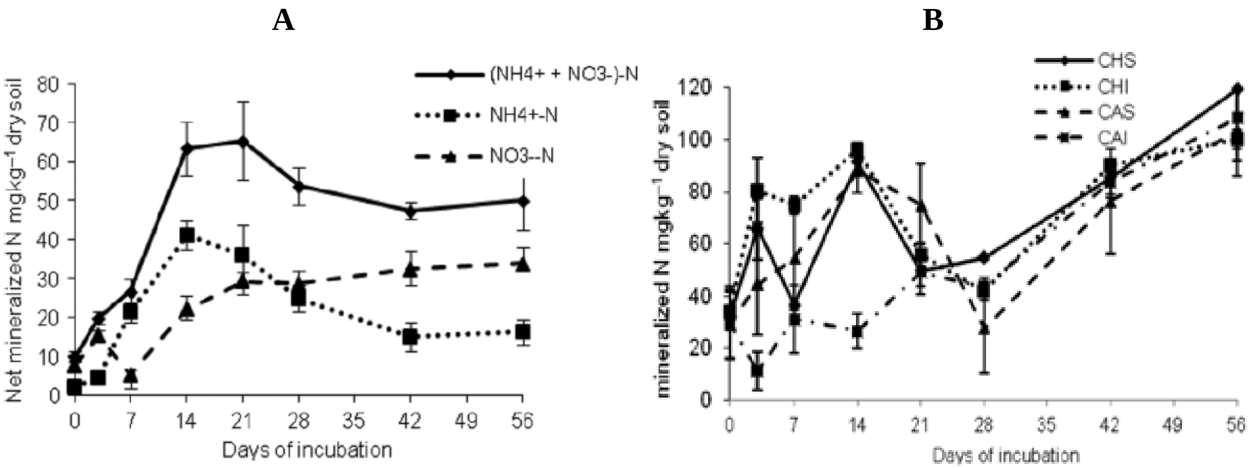


FIG. 1.1.4: Evolution of net nitrogen (N) mineralized, and concentrations of ammonium (NH_4-N) and nitrate (NO_3-N) in a non-amended soil incubated over 56 days at 24°C and 85% field capacity (A) and the evolution of inorganic N from surface-applied chicken manure (CHS), incorporated chicken manure (CHI), surface-applied cattle manure (CAS), and incorporated cattle manure (CAI)(B) (Baitilwake et al. 2012)

The application of an organic material may increase the concentration of bioavailable N in soil (Hartz et al. 2000). Nevertheless, in commercial crop production, it is essential to ensure the synchrony between N mineralization and crop uptake. For instance, in an experiment comparing N availability from sewage sludge and inorganic fertilizer for sugarcane fertilization, it was found that even when high rates of sewage sludge (60 t) were applied, the rate of N mineralization was too slow to satisfy the N requirements of the crop during the initial stage of growth (Ng Kee Kwong et al. 2005).

1.5 Factors affecting nitrogen mineralization in soils

The N cycle involves bio-chemical processes that occur both above- and below-ground and links the pathways of N transfer from the soil to the crop and the atmosphere (Canfield et al. 2010). Nitrogen transformations that occur below-ground are of major importance in agricultural systems as only NH_4^+ and NO_3^- are available for crop uptake. Harmsen and Kolenbrander (1965) observed that the ratio of inorganicN to total N in soil is low, lower than 2% in most cases.

Studies carried out in microcosms have underlined the impact of microfaunal composition and interactions between microorganisms on the amount of N mineralized (Clarholm 1985). The role of microbial communities in mineralization is represented in Figure 1.6. Inorganic forms of N are made available to plants either by the mineralization of organic materials or from N-fixing bacteria. For instance, in grassland and savannah, up to 20% of all N absorbed by plants annually may be derived from microbes (Van Der Heijden et al. 2008). For this reason, N mineralization is affected by factors that are likely to limit or enhance microbial activity, including environmental conditions such as temperature and moisture, soil type and chemical properties such as pH and C:N ratio (Meyer et al. 1986, Eret al. 2004).

1.5.1 Soil temperature, moisture and aeration

Due to the multiple factors that influence the mineralization of SON and any added organic amendments, research has been conducted under a range of climatic conditions, in tropical, sub-tropical and temperate regions (González-Prieto et al. 1992, Weintraub and Schimel 2003, Abera et al. 2012a). According to Doran and Smith (1987), optimal mineralization rates can be expected between 25°C to 35°C. However, the form of inorganic N produced at different temperatures may vary. While nitrification is impeded at temperatures as high as 45°C, ammonification is found to persist (Harmsen and Kolenbrander 1965). A similar deduction was made by Tesfamariam et al. (2012), whereby high concentrations of NH_4^+ were noted at 45°C while NO_3^- predominated at a lower temperature of 25°C. This further supports the fact that temperature regulates the processes of ammonification and nitrification, and determines the extent to which these processes take place. Figure 1.1.5 illustrates how the rate of mineralization increases when soil is subjected to a constant incubation temperature of 40°C as opposed to 20°C. Although constant soil temperatures do not reflect conditions that would have been encountered in the field, Sierra (2002) demonstrated that high temperature amplitudes in the field, as commonly observed in the topsoil, exerted the same effect on N mineralization rates as constant temperatures.

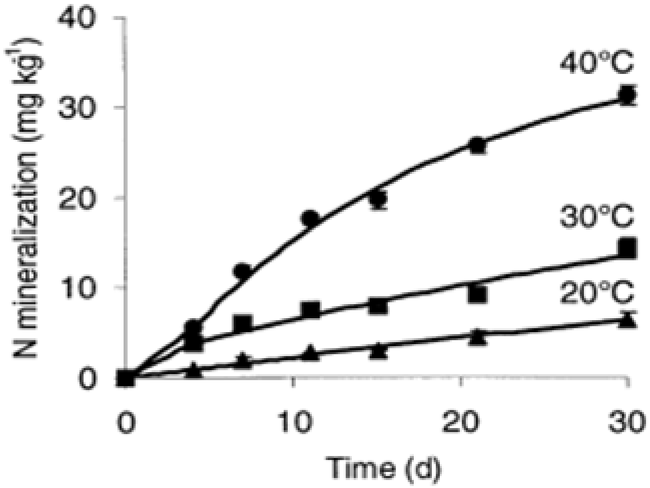


FIG. 1.1.5: Evolution of nitrogen (N) mineralization over time at three different constant temperatures in an Oxisol soil (Sierra 2002)

Exponential functions such as the Q_{10} factor can be used to quantify the effect of each ten degree rise in temperature on the rate of N mineralization (Stanford et al. 1973). Using this approach, Guntiñas et al. (2012) concluded that the measured amount of N mineralized at varying temperatures followed the trend described by the Q_{10} model. Generally, the Q_{10} factor varies from 1.80 to 2.42. In cases where OM is bound to clay and hydroxide particles and occluded from microbial breakdown as a result, a high Q_{10} factor is likely to be observed (Sierra and Marbán 2000). This was attributed to a higher responsiveness of recalcitrant SOM to increases in temperature compared to the more soluble SOM pool.

In a number of laboratory incubation studies, the evolution of inorganic N in amended or non-amended soils has been investigated under different regimes of temperature and moisture (Tian et al. 2010, Tesfamariam et al. 2012). This is because of the interaction that exists between these two variables (Sierra 1997). The latter author showed that as opposed to temperature, moisture had a smaller influence on net N mineralization, a finding supported by Guntiñas et al. (2012). Nevertheless, due to the linear relationship present between microbial activity and water potential (Orchard and Cook 1983), soil moisture is an important variable that should be considered in experiments on soil N mineralization. The impact of soil moisture on microbes is the basis of the well-known phenomenon called the 'Birch Effect', whereby successive wetting of the soil by precipitation or irrigation after an extended dry period results in a flush of N mineralization (Birch 1964, Wu and Brookes 2005, Jarvis et al. 2007). Generally, the rate of N mineralization is highest when soil moisture is between 80% and 100% of field capacity (Guntiñas et al. 2012). Following the observation of Orchard and Cook (1983) about the linear relationship between microbial activity and water potential, it can already be expected that N mineralization will also increase with increasing soil moisture, but only to a point as the system becomes anaerobic. This trend was noted in both *in situ* and laboratory experiments, but the critical point at which there is a drop or an increase in N mineralization rates also depends on the type of vegetation (Qi et al. 2011, Abera et al. 2012b).

Soil aeration is an essential process for the regulation of oxygen (O_2) and carbon dioxide (CO_2) concentrations in soil, both of which are involved in respiration. Oxygen is an important gas that is utilized by microorganisms for the oxidation of organic compounds, and under conditions of water-logging (Bray 1999), or in compacted soils with poor porosity (Van Antwerpen et al. 2013), soil aeration is hindered. Levels of gaseous O_2 in the soil may drop down to 5% after a heavy downpour (Patrick 1977). The impact of limited soil aeration on soil inorganic N concentrations is well-illustrated in paddy soils. When these soils are flooded, anaerobic conditions dominate and there is little or no oxidation of NH_4^+ to NO_3^- (Chowdary et al. 2004). Linca et al. (2012) reported a concentrationof 221 mg NH_4^+ kg^{-1} in a soil amended with compost under flooded conditions compared to 72 mg NH_4^+ kg^{-1} soil in dry soil under aerobic conditions. However, the concentration of NO_3^- was greater in the more aerated soil. Ammonification is initiated by heterotrophic facultative microorganisms, meaning that the process will still proceed under either anaerobic or aerobic conditions to produce NH_4^+ ions (Canali et al. 2011). However, *Nitrosomonas* and *Nitrobacter* that regulate nitrification and the production of NO_3^- are autotrophic aerobic bacteria, and their activity will be impeded by low levels of O_2, the result being low concentrations of NO_3^- as observed in waterlogged conditions. Extended or frequent rainfall events that fill the pore spaces (0.6 water filled pore space) following fertilization have also been linked to increased emissions of nitrous oxide (N_2O) that reflect the reduction or denitrification of NO_3^- to gaseous N in the absence of O_2 (Weitz et al. 2001).

1.5.2 Soil characteristics

Early work on soil classification and N recommendations for sugarcane in South Africa has underlined the varying N-supplying capacity of different soil forms (Meyer et al. 1983, Meyer et al. 1986). The topsoil diagnostic horizon of main soil forms was characterized in terms of OM content and it was observed soils with the highest OM content (> 4%) released the highest amounts of mineral N, 162 kg N ha^{-1}, in comparison to 61 kg N ha^{-1} for soils with lower OM. It was concluded that low yield response to fertilizer increments could be expected with high topsoil SOM. In Mauritius, soils have a common basaltic parent material, but due to geologic and climatic factors, have developed individual chemical and physical characteristics over time (Parish and Feillafé 1965). As in South Africa, it was also observed that soils with a high OM content (6.9% to 13.0%) were minimally responsive to fertilizer increments (Anon 1986). This indicates that SOM constitutes an important source of organic N that supplies the crop with appreciable amounts of inorganic N (Zech et al. 1997).

Owing to the biological sensitivity of microbes to pH, fluctuations in the levels of hydrogen ions (H^+) and hydroxide ions (OH^-) may influence the types and rates of N transformations (Brady 1999). Robinson (1963) reported that nitrification proceeds most rapidly around a pH of 8.0. This tendency was also observed by Khalil et al. (2005) in a high pH (KCl) soil of 7.8 where NH_4^+ levels dropped due to rapid oxidation to NO_3^-, but in acidic soils (pH 4.3), NH_4^+ increased, probably due to a hindrance of nitrifying bacteria activity. Therefore, a build-up of NH_4^+ will most likely occur in low pH soils (Roswall 1976). Brady (1999) attributed limited activity of nitrifiers in acid soils to the poor concentration of exchangeable base-forming cations at low pH. Nevertheless, compared to factors such as C:N ratio and temperature, soil pH in a soil amended with biosolid had less impact on the evolution of mineral N (Er et al. 2004).

Soil texture is determined by the proportion of different-sized particles in the soil, the main particles in order of diameter being gravel > coarse sand > medium sand > fine sand > silt > clay (Brady 1999). Generally, soil mineralogy has an influence on the exposure of organic molecules to microbial breakdown. Clay minerals are negatively charged and encourage the adsorption of organic molecules via cation exchange, hydrophobic bonding or polyvalent cation bridges depending on the charge of the organic molecule (Mortland 1986, Zech et al. 1997). Although soil texture is considered as a minor parameter controlling N mineralization, a silty clay texture has been shown to contribute to relatively poor mineralization rates (González-Prieto et al. 1992). In a study by Canali et al. (2011), N mineralization in a clayey texture was 9% higher than in a silty-clay texture soil. The same authors also reported higher mineralization in a sandy soil. This was attributed to lower adsorption of organic molecules, and higher availability for microbial breakdown; microbial activity may also have been favoured with by the higher aeration of a sandy texture. Aulakh and Singh (1997) relate the affinity of molecules for adhesion to clay particles in terms of lower risk of NH_4^+ leaching in clayey soils compared to a sandy soil where there is little or no adsorption. The complexation of SOM with aluminium (Al) and iron (Fe) constitutes a physico-chemical barrier against degradation by microorganisms, and may account for low rates of N mineralization (González-Prieto et al. 1992). Figure 1.1.6 illustrates how SOM can become occluded by aggregates and interactions with soil minerals, limiting microbial activity and mineralization (Conant et al. 2011). Even if ammonification occurs, the NH_4^+ ions produced can become fixed by soil particles, and be unavailable for plant uptake (Neider et al. 2011).

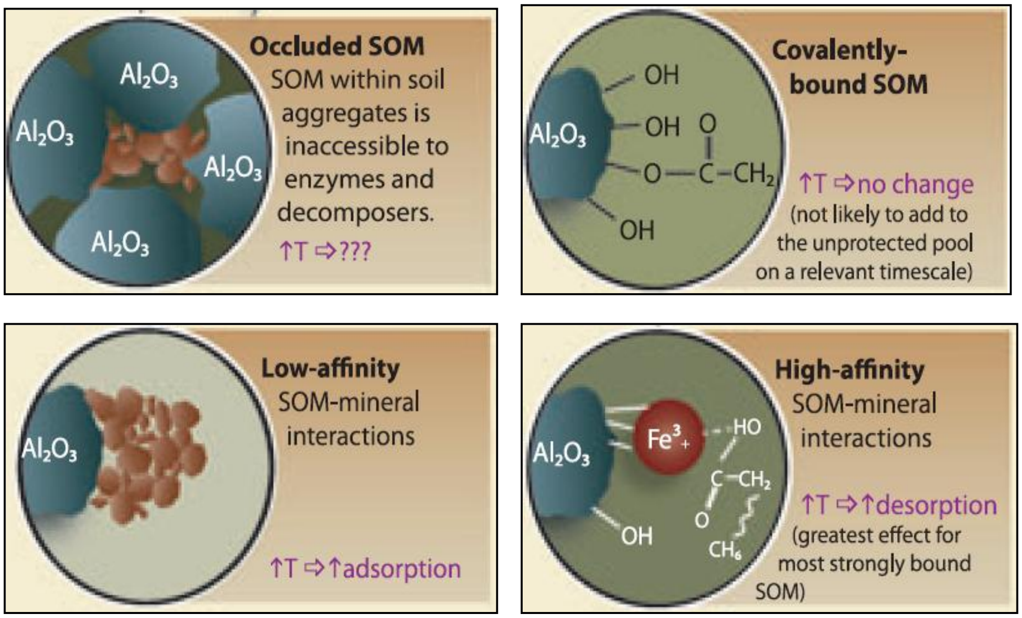


FIG. 1.1.6: Physico-chemical barriers to degradation of soil organic matter (SOM) by microbes (Conant et al. 2011)

1.5.3 Type of organic material applied

Hartz et al. (2000) determined the evolution of inorganic N in soils amended with 31 types of manure and compost. By the end of the six-month assay, 15%, 6% and 2% of organic N mineralized from manure, composted manure and composted plant residues respectively. In general, manures were characterized by rapid N mineralization rates, while in compost-amended samples, an initial period of immobilization preceded N release. For the composted plant residue, N immobilization and a slow N mineralization rate was the pattern observed upon mixing with soil. According to Alexander (1977), organic residues with a C:N ratio below 30 will likely undergo net mineralization while those with a higher C:N ratio cause immobilization. The C:N ratio threshold for N mineralization to occur is thought to be 15 or lower (Chadwick et al. 2000). Ross et al. (2004) reported that a C:N ratio above the range of 22 to 25 corresponded to limited nitrification. When different crop residues with C:N ratios in the range of 29 to 142 were mixed with a Vertisol (Australia), net immobilization occurred and was highest on day 14 of the incubation (Muhammad et al. 2010). The highest C:N ratio of sugarcane residues compared to other residues resulted in the highest net N immobilization, and also correlated in an increase in both microbial biomass C and N.

Bengtsson et al. (2003) have a contradictory concept, supported by experimental data, which show a stronger relationship between microbial respiration and N mineralization and immobilization rates than C:N. This may explain why high NH_4^+ immobilization rates were recorded in soils with low C:N ratio (Tietema 1998). Mary et al. (1996) also noted that the C:N ratio of plant materials were sometimes in disagreement with the generally-accepted rule that the greater the C:N ratios, the greater the amount of N immobilized per gram of carbon (C). To understand how N dynamics are influenced by the incorporation or organic residues on soil, the biochemical makeup of these residues need to be considered. For example, although cotton residues have a C:N ratio lower than 30, and would be expected to exhibit N mineralization, immobilization occurs, and this attributed to the crop’s high lignin content of 21% that lowers the rate of organic N breakdown (Muhammad et al. 2010).

1.6 Geology, climate and soils of Mauritius

The topography of Mauritius, as it stands presently, has been shaped by four distinct periods of volcanic activity that occurred eight million years ago (MYA). According to Willaime (1984), mountain ranges cropped from the Old Lavas (8.0 to 4.5 MYA) while the Central Plateau and coastal plains developed from Early Lavas (3.5 to 2.0 MYA). Being of agricultural interest, are the Intermediate Lavas (0.7 to 0.3 MYA) and Late lavas (0.3 to 0.02 MYA). Despite having a common parent material, the basaltic rocks from these two volcanic series have different geological ages, and upon exposure to the 26 microclimates and relief of the island (Halais and Davy 1994), no less than 13 soil groups have emerged (Parish and Feillafé 1965).The distribution of the soils groups over the island is illustrated by Figure 1.1.7.

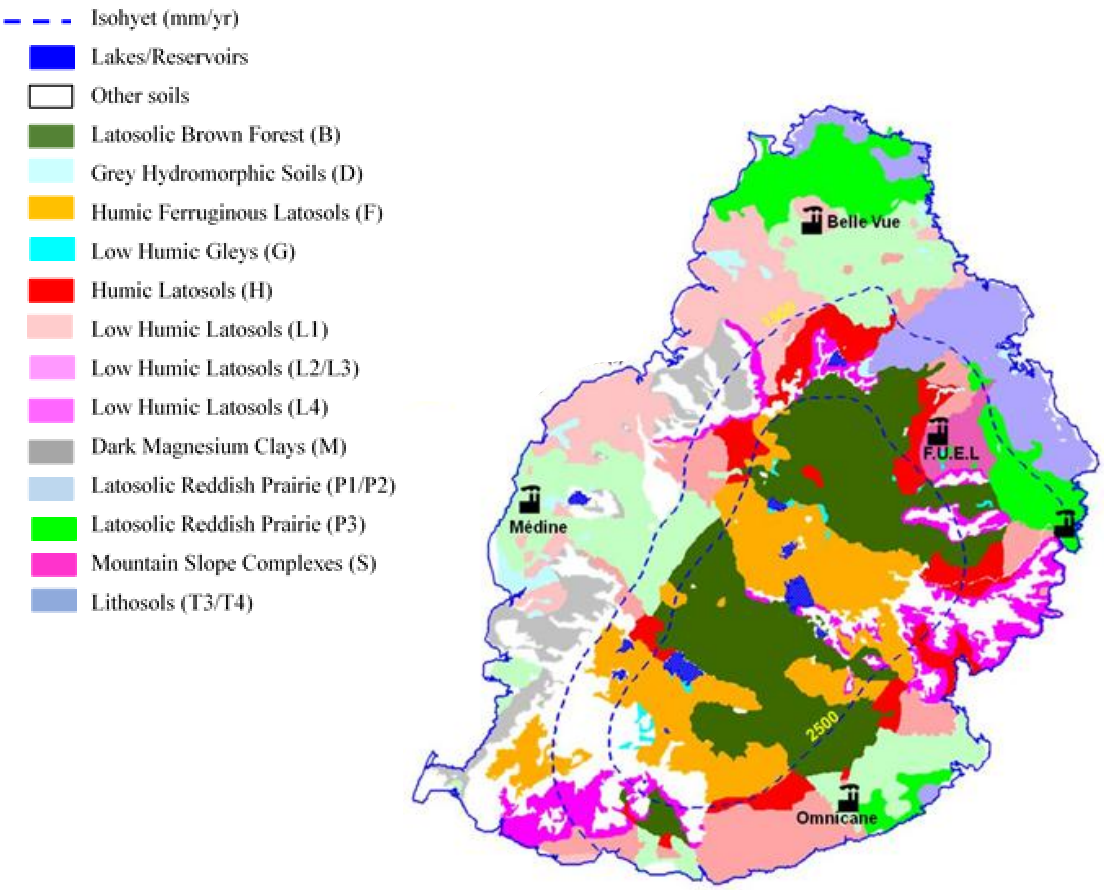


FIG. 1.1.7: Soil map of Mauritius with isohyets (Willaime 1984)

Parish and Feillafé (1965) classified Mauritian soils into two main groups:

1.6.1 The mature or weathered soil group

These soils have risen from the intermediate lavas, are highly weathered, and have developed into deep soils with good drainage. Mature soils include the weathered Low Humic Latosols (L), and HumicLatosols (H) which correspond to the Nitosols of the Food and Agricultural Organization (FAO) classification (2015), and the Humic Ferruginous Latosols (F) which is equivalent to the Acrisol. In general, the fertility of soils is lower in high-rainfall areas because of the pedogenetic process of ferrallitisation. Usually observed in super-humid regions, ferrallitisation involves severe leaching of silica and bases, andresults into the build-up of oxides and hydroxides of iron and aluminium (Van Breemen and Buurman 2002). The prevalence of kaolinite in clay mineral and low soil CEC are also characteristic of these soils. On the other hand, in drier region with limited drainage, the process of bisiallitisation occurred, resulting into soils with clay mineral montmorillonite and an associated high CEC. The leaching of silica and cations was also low in these soils.

1.6.2 The immature or less weathered soil group

The immature soils have developed from the highly vesiculated basaltic rocks of the Late Lavas, and include the Latosolic Reddish Prairies (P) and the Latosolic Brown Forest soils (B), that correspond to the Cambisols of the FAO (2015). These soils are shallow and rocky, and owing to the presence of minerals that are still undergoing weathering, are more fertile than the mature soils. The fertility gradient for immature soils is similar to that of mature soils, being highest in drier regions and lowest in high-rainfall areas.

The mature and immature soils of Mauritius are located in different agro-climatic regions of the island, where the zonal annual rainfall may range from 1000 mm to 5000 mm (Table 1.1.1). Sugarcane is presently cultivated on mostly the P and L soils of the relatively drier regions due to the comparatively higher sunshine hours. From one soil group to another, the chemical characteristics vary, and will therefore be used as a basis to explain any differences in N mineralization noted amongst the soils in this study.

TABLE 1.1.1: Characteristics of the five major soil groups of Mauritius (Parish and Feillafé 1965)

	Immature soils		Mature soils		
Soil group	Latosolic Reddish Prairie (P)	Latosolic Brown Forest (B)	Low Humic Latosol (L)	Humic Latosol (H)	Humic Ferruginous Latosol (F)
Area cultivated (%) †	30%	12%	28%	12%	11%
Zonal annual rainfall (mm)	≤ 1000 - 2500	2000 - 4000	≤ 1000-2750	1500 - 3750	2000 - 5000
Food and Agricultural Organization classification (2015)	Cambisol	Cambisol	Nitosol	Nitosol	Acrisol
Total Nitrogen (%)	0.28 - 0.50	0.30 - 0.80	0.18 - 0.32	0.24 - 0.31	0.20 - 0.34
pH (H_2O)	6.0 - 7.1	5.0 - 6.3	5.8 - 7.3	5.2 - 6.2	4.3 - 6.2
Organic matter (%)	6.0 - 7.7	11.0 - 13.0	3.2 - 6.0	4.8 - 7.0	6.9 - 10.4
C:N ratio	8.3 - 13.0	11.0 - 17.0	8.7 - 12.0	9.8 - 13.5	17.0 - 18.0
Texture	Silty clay loam	Silty clay loam	Silty clay to clay	Silty clay to clay	Silty clay loam

† Courtesy of the Mauritius Sugar Industry and Research Institute

1.7 Techniques to measure nitrogen mineralization in soils

For simplification purposes, SOM is generally described as being composed of three pools with varying turnover rates, thereby implying that the mean residence time (MRT) of N varies from one pool to another (Six and Jastrow 2002). For the management of organic fertilization, the process by which SON becomes plant-available during the growing season must be understood. Since mineralization is controlled by factors such as the C:N ratio of the decomposing material (Cambardella et al. 2003), soil moisture and temperature (Hongwei et al. 2012), soil texture and organic matter content (Meyer et al. 1986), the quantification of N release is challenging. In Mauritius, techniques such as the arginine ammonification assay and the determination of amino-sugar N level in soils have been used in an attempt to predict N release from SOM in soils, but were unsuccessful due to environmental variables like moisture, temperature and aeration that influence N dynamics *in situ* (MSIRI 1995, MSIRI 2001). Laboratory incubation may improve the understanding of the factors controlling N mineralization and field trials may confirm the extent to which environmental factors and residue quality determine mineralization rates (Bai et al. 2012). Together, laboratory and *in situ* incubations can generate useful independent datasets that can be used to initialize models to simulate N kinetics over the long-term.

1.7.1 Laboratory methods

In situ, it is difficult to measure the magnitude of each component of the ecosystem on net N mineralized. Therefore, the need to understand and quantify the effect of soil, environment and human factors in isolation on N transformations has geared research towards experimentations under controlled conditions in the laboratory. Laboratory work as early as 1964 was carried out to investigate the response of N mineralization to successive drying and wetting events, and for this purpose, soil samples were incubated with plant residues in a macro-respirometer (Birch 1964). It was concluded that N mineralization is enhanced when the decomposition of organic residues is interrupted by drying events. This finding, obtained in laboratory has implications for fertilization in field, and sharpens the understanding of the pattern of N mineralization from composted materials from one season to another.

Experiments at the laboratory scale can be easily implemented and allow the assessment of N release under specific conditions of water potential level, and temperature that would have been impossible to control *in situ*. Generally, laboratory studies involve the incubation of soil or soil amended with organic residues in different apparatus depending on the method of N extraction and the volume of soil. Leaching columns are preferred for small quantities of soil that will be leached intermittently and analyzed for inorganic N (Stanford et al. 1974). Where larger volumes of soil are dealt with, as when intact soil cores are studied, incubation is sometimes carried out in plastic containers (Adams and Attiwil 1982, Baitilwake et al. 2012) or canning jars (Sistani et al. 2008). In these cases, the evolution of soil mineral N is commonly investigated through destructive analysis, whereby soil samples are collected directly from the container and shaken with an extraction solution before measurement of inorganic N using the colorimetry (Abera et al. 2012b) or distillation method (Stanford et al. 1974), or with an auto-analyzer (Knoepp and Swank 1995). It is important to carry out incubation under controlled conditions of temperature and moisture to avoid corresponding fluctuations in N mineralization that may be attributed to one of these two factors, and for comparison between different sites or amendments to be possible (Verva et al. 2002). A widely used methodology to assess N mineralization fluctuations resulting from these factors is laboratory incubation of soil which involves regular extraction of inorganic N with chemicals such as 2M potassium chloride (KCl) and 0.01M calcium sulphate ($CaSO_4$) (Griffin and Hutchinson 2007, Canali et al. 2011). The incubation period must be at least two weeks long because initial mineralization and immobilization events of the first week of incubation provide inaccurate estimates of N mineralization potential (r^2= 0.74), when compared to N mineralized over 30 weeks (Stanford et al. 1974). To avoid erroneous N mineralization data that may arise from an increased in inorganic N concentrations upon rewetting of dry soil, a pre-incubation period is highly recommended (Wu and Brookes 2005).

Despite the care taken in the laboratory to bring soil samples to original initial bulk density, field capacity, and to minimize soil disturbance by incubating intact soil columns (Reddy 1982) to mimic field conditions, the rates of N mineralized in the laboratory are likely to differ to those measured in field, mainly due to assay conditions in the laboratory (Raison et al. 1987). Persson and Wirén (1995) attempted to scale up N mineralization results obtained in the laboratory under controlled conditions of temperature and moisture to field conditions by using correction factors for these two parameters. However, in their study, the estimated N mineralized based on the correction factors were not compared to measured field data to assess the reliability of the results. The same concept, but this time for temperature only, was adopted by Weinhold (2007) and it was found that even when the laboratory N mineralization rates were modified according to field temperatures, the estimated N mineralized was still higher than the measured rates *in situ*, 292 kg N ha^{-1} in the laboratory against 139 kg N ha^{-1} for field trials where the corer technique was used.

1.7.2 In situ methods

Since laboratory conditions are not always representative of field conditions, especially when soil is disturbed during, for example sampling and sieving (Raison et al. 1987, Eghball et al. 2002), *in situ* methods that minimize soil disturbance, despite being time-consuming and costly, are preferred. In literature, studies comparing both methods consistently show that the rates of N mineralization are overestimated for laboratory incubations. Lower mineralization values for *in situ* trials were explained by the increased prevalence of immobilization and conditions of precipitation and temperature that may enhance losses of N by denitrification (Adams and Attiwil 1986, Weinhold 2007, Sistani et al. 2008). Using the buried polyethylene bag technique, Westermann and Crothers (1980) established a proportional relationship between the rate of N mineralization and soil water content, a finding confirmed by Abera et al. (2012b). The latter author also supported that flushes in N release from SOM coincided with frequent precipitation events as observed earlier by Adams and Attiwil (1986).

For *in situ* trials, corers with resin are preferred over plastic bags for incubation in the soil profile. During the incubation period, buried bags are not subject to moisture equilibration as in the remaining soil profile, and thus, the accuracy of inorganic N measurement in the bags is questionable (Knoepp and Swank 1995). On the other hand, water movement in PVC corers is better, with varying moisture content during incubation. It is common to insert a nylon pouch filled with resin at the bottom of the cylinder to trap NH_4^+ and NO^-_3 moving from the rootzone (Zou et al. 1992, Doesken et al. 2007). Figure 1.1.8 describes the soil core-ion exchange resin method which was modified by Moberg et al. (2013), by increasing the diameter of the tube from the conventional diameter of 0.05 m to 0.10 m to minimize compaction during insertion in the soil, and including a second resin bag at the bottom of the core to reduce contamination from surrounding soil. In the core method used by Noe et al. (2013), three resin bags were placed at the top and bottom of the core. The outer bag aimed at preventing the entry of extraneous N from the core's immediate environment, the middle bag was an indicator of resin saturation for the outer and inner bags, and the inner bags were meant to absorb inorganic N mineralized from the soil core. Resins are expensive, and an alternative is to cover the soil core after insertion in the soil so as to prevent mineral N from moving down the tube during heavy rainfall (Raison et al. 1987). Johannes et al. (2001) recommend the use of combined anion-cation resin for satisfactory nutrient recovery from soil cores, but even so, incubation periods exceeding 180 days should be avoided to minimize the risks of resin saturation and by-pass flow (Weinhold 2007). The difference in soil temperature inside and outside metal cores is usually slight and this confirms the good heat conductivity of metal and its capacity to reflect the temperature of soil in the vicinity of the core (Raison et al. 1987). For example, while an average temperature of 20.7°C was reported inside the core, an average of 20.4°C was recorded for the surrounding soil (Moberg et al. 2013). The presence of weed roots or carbonaceous materials in the core will lead to erroneous data as the former may absorb newly mineralized N and the latter may immobilize inorganic N (Raison et al. 1987).

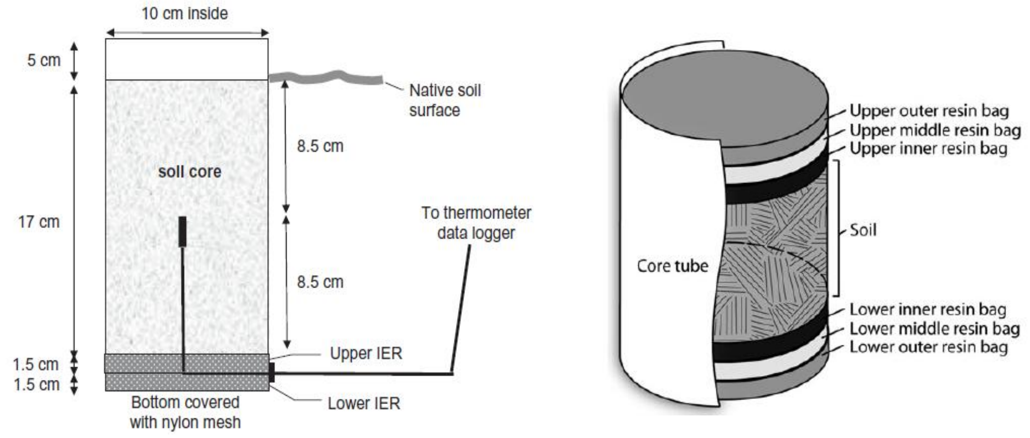


FIG. 1.1.8: On the left-hand side is a modified soil core fitted with two ion exchange resin (IER) bags, and upper bag containing 104 g resin and a lower bag containing 80 g resin (Moberg et al. 2013). On the right-hand side is a modified soil core with three resin bags above the soil and three more resin bags below the soil core (Noe et al. 2013)

1.8 General approaches to model nitrogen mineralization in soils

In a review of the methodologies used to model N mineralization, Benbi and Richter (2002) identified two main approaches, the first one using simple functions, and the second one using more mechanistic algorithms. With the functional approach, the N mineralization potential (N_0) is estimated from kinetic models that do not directly consider processes such as immobilization, denitrification or leaching that may affect this value. Functional models are based on empirical data obtained from laboratory incubation experiments. It has been found that estimates of N mineralization obtained from laboratory incubations were often overestimated compared to field conditions (Weinhold 2007). On the other hand, the mechanistic techniques aim to represent the key processes influencing the system through mathematical equations, and may simulate gross mineralization in response to multiple N transformations. By integrating the various components existing in natural systems, and accounting for pathways of N additions and loss, mechanistic models potentially address the problem of overestimation of mineralizable N encountered in functional models that are based on data from laboratory incubations.

1.8.1 Functional approaches

The functional approach constitutes a widely-used mathematical tool to forecast N mineralization for decision-making in agricultural system (Frankenberger and Abdelmagid 1986, Ros et al. 2011). In the functional model of Stanford and Smith (1972) for example, soil organic N is assumed to be a homogeneous pool with a single coefficient of decay that follows the first order kinetics. The first step to the simulation of N mineralization is the production of an independent dataset that can be fitted to the first order model. For instance, the measured cumulative soil N mineralized during a laboratory incubation experiment may be used to estimate the N_0 and the rate of the process (k) via a regression analysis. Following the same principle, Chaves et al. (2014) calculated an index of N availability by fitting the amount of N mineralized during an incubation study in the first order equation described by Smith et al. (1980) by means of non-linear regression.

The suitability of the first order model to describe N dynamics has beenchallenged by many researchers. On comparing the kinetic model proposed by Stanford et al. (1974) to a first order model with two mineralizable organic N pools to measured data, Seyfried and Rao (1988) obtained better fits with the latter. This finding is further supported by studies that highly recommend the consideration of at least two mineralizable N pools in the simulation equation (Molina et al. 1980, Diaz-Fierros et al. 1988).

Estimated net N mineralized during laboratory incubations has also been compared to the concentration of inorganic N measured over time with a number of soil tests to develop a mineralization index for predictive purposes (Ros et al. 2011). If there is a strong agreement between N mineralization and the parameters under study, then it is concluded that the given parameter set helps explain the pattern and magnitude of the N kinetics observed. This relationship provides for the development of an index from which N mineralization can be predicted. In this context, the Pearson's correlation coefficient established a significant relationship (-0.76; P = 0.01) between the percentage of sand in disturbed soil and the annual rate of N turnover in field (Kader et al. 2010). Aiming at developing a routine test to predict soil N-supplying capacity, Li et al. (2011) calculated total N uptake by rice crops and performed a correlation analysis with chemical indices such as C:N ratio, hot potassium chloride (KCl), acidified potassium permanganate ($KMnO_4$) and phosphate-borate buffer extractable N. The most promising index was C:N ratio, followed by hot $KMnO_4$ extractable N.

A major weakness of functional models is that they attempt to establish relationship between selected variables to explain a phenomenon, and often disregard controlling factors and mechanisms occurring in a living system. Although variables such as moisture and temperature are sometimes considered in the prediction of net N mineralized, they only represent a part of the system and cannot be considered individually. As underlined by Chertov and Komarov (2013), every living system is subject to instability (for example fluctuating environmental conditions) and when this occurs, the statistical model built by the functional approach is inappropriate. Only mechanistic, process-oriented models may potentially explain dynamics at the below- and above-ground levels that can significantly influence N mineralization.

1.8.2 Mechanistic Approaches

Being more complex than a functional approach, the mechanistic approach to modelling N mineralization relies on principles, theories and hypotheses of soil processes (Benbi and Richter 2002). The knowledge and assumptions about the mechanisms that govern a system are transcribed into hard-coded equations that are generally considered as remaining unchanged through time (Bristow et al. 1998). Parameters and initialization values that represent factors affecting the system are used as input to predict the system's response to these variables. A model's performance can then be evaluated using a number of statistical criteria, such as the square of coefficient and correlation (r^2), the index of agreement (D), and the mean absolute error (MAE), as proposed by Wilmott (1982) and De Jager (1994).

Since N mineralization is a biological process, it is affected by weather conditions and soil properties that limit or enhance microbial activity. Therefore, it is important that the modeller obtains a broad view of how the system functions and, of the interactions betweenthe above- and below-ground components. If N transformations in a sugarcane system are to be modelled according to the mechanistic approach, then potential N inputs and losses depicted in Figure1.1.9 are to be representedin the model. Sources of total N would include the trash layer on the soil surface to which newly senesced leaves, fertilizer, and OM would be added as the crop grows (Thorburn et al. 2005). Events such as burning of thrash, leaching, immobilization and denitrification would decrease the amount of N available for plant uptake. Other variables such as weather, soil characteristics and soil water content would also need to be represented.

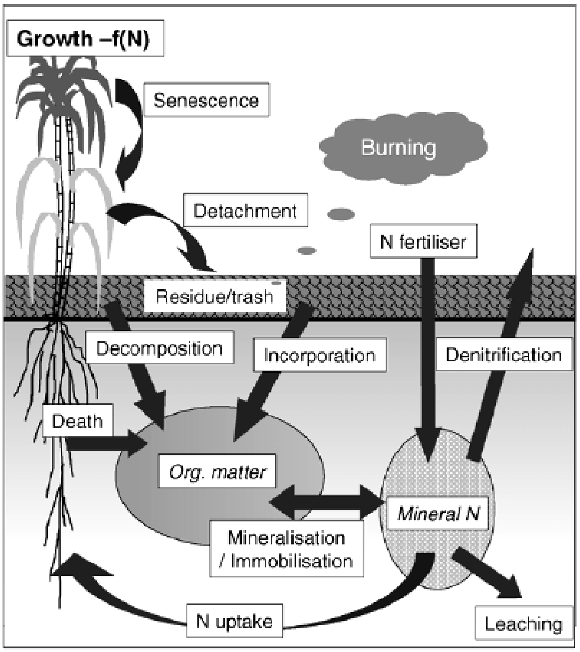


FIG. 1.1.9: Above- and below-ground processes that need to be considered to model nitrogen dynamics in soils under sugarcane cultivation (Thorburn et al. 2005)

1.8.3 Fractionation of soil organic matter into pools

Although existing mechanistic models differ with regards to the methodological basis used to simulate N transformations, they all adhere to the fact that soil SOM and N mineralization are intrinsically-linked. According to Six and Jastrow (2002), this is because the turnover rate of nutrients is largely dependent on the transfers that occur in and out of the SOM. Organic matter is not a homogeneous mix of floral and faunal residues that follows a defined pattern and rate of decomposition. Plant residues, being biochemically differentiated, are composed of groups of organic substances that vary in their decomposition kinetics (Thuriès et al. 2002). Organic residues have been broadly characterized in terms of their polysaccharide contents, cellulose being the least resistant to microbial breakdown and polyphenols the most resistant (Shukla and Singh 1984). Located in the cell wall of plants, these C compounds constitute a protective barrier between microbes and the intracellular nitrogenous materials. The proportion in which they are present is thought to exert an effect on degradability of the cell wall, and as a matter of fact, on the release of a cell's N content (Müller et al. 1988). Müller et al. 1988 obtained significant regression coefficients between N mineralization and cell wall components and showed that N mineralization tends to increase with high concentrations of cellulose and decrease with high levels of lignin. Palm and Sanchez (1991) observed that when the polyphenolic-to-N ratio was higher than 0.5, it could be expected that the formation of stable polymers between polyphenolics and amino groups would also increase, and lead to a slower rate of N mineralization.

The recalcitrance of SOM to microbial breakdown has also been explained by the occlusion of OM by aggregates and interactions with soil minerals, limiting microbial activity and mineralization (Conant et al. 2011, Neider et al. 2011). For these reasons, sub-models developed for N mineralization assume that SOM consists of different pools that decompose and release N at varying rates over time. Generally, the rates of decomposition of the pools are assumed tofollow firstorder kinetics, and depending on abiotic variables that are input or estimated by the model, the rate coefficients change (Benbi and Richter 2002).The numbers, sizes and methodologies of decay of SOM pools differ from one model to another.

To predict N dynamics during the growing season of wheat, Richter et al. (1985) developed a model composed of five sub-models to deal with the water balance, transport of nitrate (NO_3^-), N uptake, N mineralization and growth of wheat. The N mineralization sub-model is based on two N pools with different coefficients of decay that change with temperature and soil moisture. This model met limited success, principally because the system constructed did not integrate the role of microbes in the regulation of N mineralization and immobilization. On the other hand, there are models like ROMUL (Raw humus, mOder and MULl) in which the decomposition of SOM is simulated in successive stages, each corresponding to given microbial communitiesthat act on OM at a specific rate (Chertov et al. 2001, Komarov 2012). The need to consider biomass kinetics in models is further underlined by Pansu et al. (2014) who proposed the Modelling of Organic Matter of Soils (MOMOS) model which places microbial biomass at the core of N mineralization with five distinct compartments to regulate microbial growth and death. Nitrogen transformations are dictated by the growth of microbes as they assimilate labile and stable fractions, and the death of microbes to form humus. Figure 1.2 is a generalized basis to divide SOM into three fractions, namely an active, intermediate and passive/stable pool (Sollins et al. 1996, Von Lützow et al. 2006). The processes in Figure 1.2 show that as fresh residues/compounds move down the active pool to the passive pool, the products of microbial breakdown become more resistant to decay due to stabilization mechanisms such as aggregation with clay particles, organo-mineral interactions, complexation with metal ions and others.

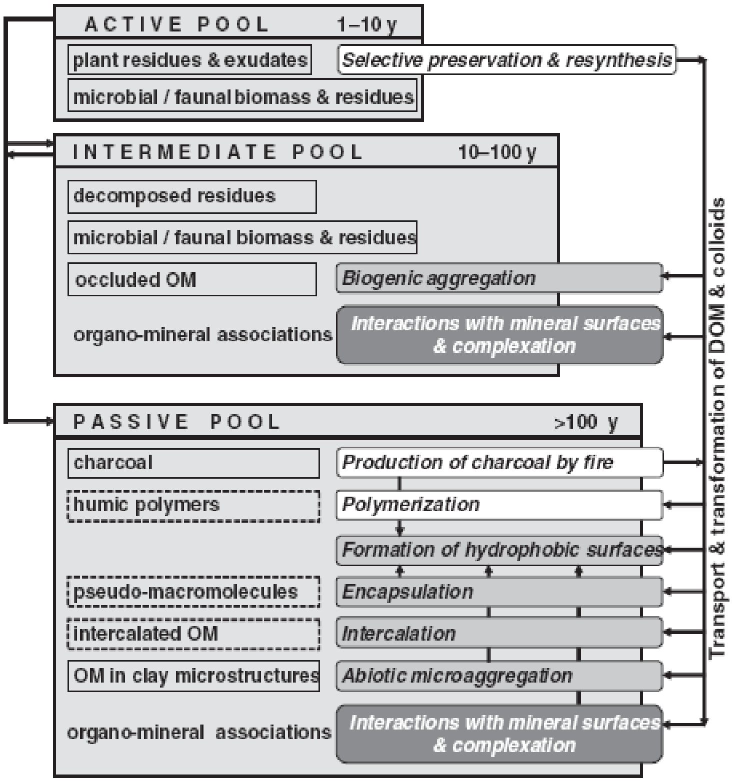


FIG. 1.2: Components of different pools of organic matter and factors accounting for their stabilization (Sollins et al. 1996, Von Lützow et al. 2006)

Model validation involves running a simulated dataset against and a measured one, and testing the statistical reliability of the simulated data. According to Zeigler (1976), structural validity is achieved when the model simultaneously forecasts the system’s real behaviour, and reflects the true mechanisms of the system. Model testing also implies that measurement of the parameters under study must also be accurately done. A common methodology used to characterize the components of different OM pools is fractionation, a procedure that involves testing the resistance of the stabilized OM components to selected treatments (Chertov and Komarov 2013). Organic matter can be physically-fractionated into coarse and fine fractions of different densities and sizes by techniques such as wet and dry sieving, dispersion and sedimentation (Hassink 1994, Von Lützow et al. 2007). Cambardella and Elliott (1992) stated that fractions that ranged from 53 to 2000 µm might correspond to the slow-cycling poolwhile those smaller than 53 µm gave an indication of the size of the passive pool. Organic residues may also be chemically-fractionated into their polysaccharide components, for example cellulose and starch or glycogen, to estimate the recalcitrance of OM pools (Vanlauwe et al. 1994, Corbeels et al. 1999, Von Lützow et al. 2007).

Nitrogen mineralization data can be obtained using techniques such as laboratory aerobic incubation that may also generate useful datasets on the effects of C:N ratio, SOM quantity and quality, temperature and water on the rates of N release. The most common methodologies to investigate N mineralization include incubation studies (Stanford et al. 1974), the buried-bag method (Zou et al. 1992), pot experiments (Soumaré et al. 2003) and microplot cylinders with ion exchange resins (Weinhold 2007).

1.9 Types of models used in agricultural systems

With the technological advent of information technology, agricultural challenges are now addressed with mathematical programs that are able to simulate natural processes such as nutrient dynamics, soil water balance and C sequestration in cropping systems. Assessing the risks of different management options from one area to another (Palosuo et al. 2011), and forecasting the long-term effects of fertilization on C and N dynamic in soil (Yang et al. 2013) without carrying out labour-intensive and costly experiments are now possible. The multifarious models developed over the years vary in the degree of sophistication of the mechanisms represented, the sensitivity to changes in input variables and the modular flexibility (Frissel and Van Veen 1982, McCown et al. 1996). In agricultural systems where organic materials are applied to fields, growers have expressed the need to have a routine decision-making tool to forecast soil N mineralization so that N fertilizer rates can be adjusted (Snapp and Fortuna 2003). Models constitute a promising tool to suit this purpose. Three mechanistic models, Agricultural Production Systems Simulator (APSIM), the Decision Support System for Agrotechnology

Transfer (DSSAT) and Soil Water Balance model (SWB-Sci) will be described and their suitability to simulate N mineralization in soils discussed.

1.9.1 Agricultural Production Systems Simulator (APSIM)

APSIM is a mechanistic crop software that is highly responsive to changes in input variables born from the ideology of McCown et al. (1996), being at the same time able to represent soils and crops with varying management practices, and flexible enough to allow changes to be made to the sub-routines. The sought-after model sensitivity was based on the crop and soil routines of the model PERFECT (Littleboy et al. 1992). The crop template of AUSIM (McCown and Williams 1989) was re-configured to construct independent modules for soil N, crop growth, and the soil water balance that would offer flexibility of recombinations according to the system under study. As a combination of AUSIM and PERFECT, APSIM has broad applications including the simulation of the effects of pasture, water and nutrient management on crop growth, as well as how the type of cropping system and climate affects various processes of the system (Lisson et al. 2000, Cheeroo-Nayamuth et al. 2000, Connolly et al. 2001). In the modular organization of APSIM (Figure 1.2.1), the biological (residue, crop, microbes), environmental (water, nutrients) and management modules are arranged as independent routines that are linked by a common, central engine (Probert et al. 1988). Since parameterization is limited to the modules, the plug in or pull out of modules does not affect the engine's code. The sole function of the engine is modular communication. As underlined earlier, APSIM provides flexibility to the user with regards to the growth routine that can be swapped among an array of crops that will respond to changes in soil management and weather conditions. Similarly, the SOILN module may also be interchanged with another N module. The 'manager' moduleis used to initialize the system and provide basic information about agronomic practices such as fertilization, irrigation and tillage, amongst others.

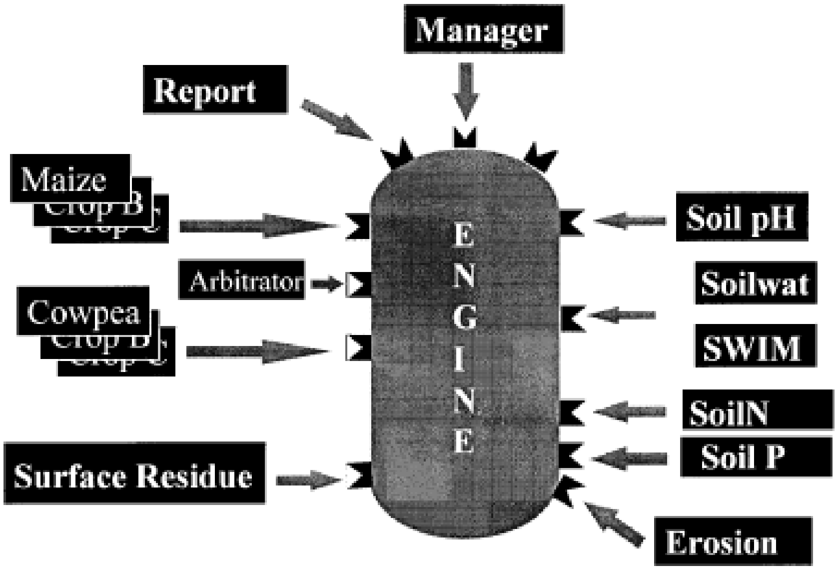


FIG. 1.2.1: Structural representation of the Agricultural Production Systems Simulator program. The model includes biological, environmental and management modules (Keating et al. 2003)

The description of the APSIM model that will follow is based on the work of Keating et al. (2003). The RESIDUE routine, adapted from PERFECT, caters for the incorporation of residue in soil and how it impacts runoff, evaporation, and, N dynamics. Decay of surface residues is regulated by climatic variables such as temperature, and any mineralized N that is not immobilized, is added to the soil surface layer. For the changes in below- and above-ground reactions to be reflected by the system, the RESIDUE module communicates with the SOILN and crop growth module. The SOILN module is at the heart of the simulation of N mineralization. The SOM is composed of three pools, the fresh residues pool (FOM) that decomposes to form the microbial biomass (BIOM) pool and finally, a more passive pool (HUM). This is a strength of APSIM because considering SOM as being multi-compartmented with fractions having individual turnover rates contributes to the simulation of more realistic rates of N mineralization (Nordmeyer and Richter 1985). The BIOM and HUM pools are thought to have C:N ratios that cause N immobilization, unless the amount of N resulting from the decomposition of the FOM pool is superior to the immobilization demand. In this case, the production of NH_4^+ would be initiated. An assumption of the model is that the three OM pools have similar and constant C:N ratios. However, an attempt by Mohanty et al. 2010 to predict N mineralization from farmyard manure gave a weak correlation, as substantiated by a root mean square error (RMSE) of 14.69, and a modelling efficiency (EF) of 0.05. This study highlighted the weakness of APSIM in attributing the same C:N ratio to all SOM fractions. Specifying the C:N ratio of each individual fraction improved the goodness of fit by decreasing the RMSE to 9.24 and increasing the EF to 0.62. Probert et al. (2005) also reported improved simulation of N mineralization patterns for manures by setting different C:N ratios for the three pools in APSIM. The authors stated that the assumptions used to predict of N mineralization from plant residues in APSIM may not be applicable to manures considering the complexity of their composition, unless the C:N ratio of the SOM fractions was specified.

1.9.2 Decision Support System for Agrotechnology Transfer (DSSAT)

In the background of the scientific enterprise for the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), the model DSSAT was developed (Uehara 1989, Tsuji 1998). Design of the simulator was triggered by the need to evaluate and compare the suitability of different agricultural management options, and to make informed decisions about the risks of implementing a given practice in regions with site-specific soil properties and climatic conditions (Gijsman et al. 2002). Examples of research areas where DSSAT crop models were used include precision agriculture (Seidl et al. 2001), fertilizer management (Hodges 1998), crop management (Salam et al. 2001), tillage management (Andales et al. 2000), and irrigation management (Steele et al. 2000). Compared to the APSIM model where the soil module is central, the DSSAT software places more emphasis on the simulation of crop growth module. In Figure 1.2.2, DSSAT is shown to be composed of four independent operating units. To define a crop system and a management option for simulation, parameters with the assistance of the support software are entered (Jones et al. 2003). Crop growth and yield can be predicted for a broad range of crops that will grow dynamically based on user-specified environmental and biological parameters. The application component of DSSAT allows the user to run simulations against independent sets of measured data, providing a statistical basis to test the confidence of the results and assess the need for further calibration (Bidogeza et al. 2012). DSSAT has proven to be sensitive enough to environmental variables to be used in the risk assessment of crop cultivation in regions affected by climate variability (Ferreyra et al. 2001). However, it exhibits a major weakness when it comes to predicting the effects of continuous cultivation of different crops on the same soil over a short or long period (McCown et al. 1996). This is because each crop routine is connected to a given soil routine. Therefore, on swapping to another crop module, the soil routine also changes, and needs to be re-initialized. To make up for this short-coming, Jones et al. (2003) has proposed the DSSAT crop system model (DSSAT-CSM) in which the different components are organized into modules to enable the ‘plug-in’ and ‘pull-out’of modules, and the crop models share the same code to allow the use of many crop modules with the same soil module.

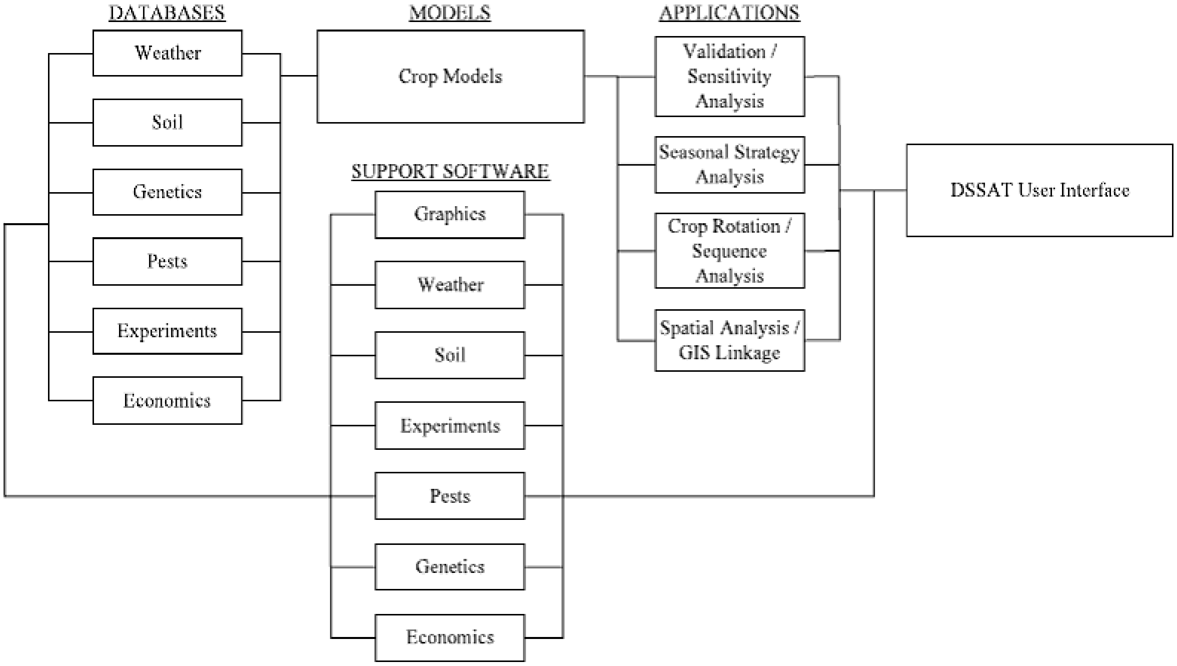


FIG. 1.2.2: Diagrammatic overview of the main components in the Decision Support System for Agrotechnology Transfer program (Jones et al. 2003)

The soil module of DSSAT caters for the investigationof SOM-residue dynamics in a sub-routine based on the PAPRAN model (Seligman and Van Keulen 1981). The developerscautioned that the PAPRAN model was calibrated for pasture production in semi-arid conditions, and that for this reason, extending the simulation of SOM and residue decay to other systems and under other environmental conditions could be challenging. Indeed, Gijsman et al. (2002) highlighted some limitations of the SOM-residue sub-routine to simulate N mechanisms in agricultural systems where organic materials were the main source of nutrients. The residue layer that is common in low-input systems, as when leguminous crops are left on the soil surface and represent a supply of N to the following crop (Palm and Sanchez 1991) is not taken into consideration by the module. In the same line of thinking, litter and SOM are assumed to consist of only one N and SOM pool respectively. The rates and magnitude of SOM and residue decomposition are calculated regardless of soil texture, but it has been shown that the soil texture had an incidence on microbial breakdown of OM (Conant et al. 2011). These limitations were later addressed by including the SOM-residue module of CENTURY in DSSAT, and also amending the crop module to consider N from senesced materials (Gijsman et al. 2002). The modified SOM-residue module developed proved to be effective for the simulation of N dynamics in sustainable agricultural systems with organic inputs, and was even integrated in the DSSAT-CSM.

1.9.3 Soil Water Balance (SWB-Sci)

The research version of the Soil Water Balance (SWB-Sci) model is a process-oriented, generic crop model initially developed for irrigation scheduling (Annandale et al. 1999). With time, the model has evolved into a predictive tool with broader applications for the study of crop response to irrigation with gypsiferous mine water (Annandale et al. 2001, Annandale et al. 2002), N dynamics in soils amended with organic materials (Tesfamariam et al. 2012) and the study of nutrient leaching losses in agricultural systems (Van Der Laan et al. 2010). It has also been shown to be a user-friendly model for the teaching of crop physiology (Jovanovic et al. 2000). Two versions of the software are currently in use, the first one being a basic program for irrigation scheduling and other simple applications such as yield and water estimates (SWB-Pro), and the second being more complex, and used for research work (SWB-Sci).

The inclusion of an N sub-routine into the SWB-Sci (research version) model is quite recent (Van Der Laan 2009) and was partly motivated by the need to simulate N dynamics in soils amended with biosolids and forecast any non-point source (NPS) pollution that could result from this practice and from the fertilization of agricultural lands in South Africa. The algorithms for the N subroutine were derived from Cropping Systems Simulation Model (CropSyst)(Stöckle et al. 2003). Before any simulation can be run, 11 soil layers need to be initialized. SWB-Sci considers surface residues from previous crop cycles as a source of nutrients and assumes that NH_4^+ ions resulting from SOM breakdown may become adsorbed on clay particles. Moreover, whilst DSSAT views SOM as being composed of a single pool, SWB-Sci provides a more realistic approach by dividing the SOM pool into four fractions with individual rates of decay. The rates and pattern of conversion of organic N into its inorganic forms rely on the C:N ratio of the decomposing pool and that acts as a sink for the OM resulting from decomposition (Van Der Laan 2009). In the event of N mineralization from a given pool, the immobilization demand is assumed to be zero. It may happen that the amount of N mineralized is negative and in this case, this amount is said to correspond to the amount that is being immobilized. This assessment is done for each SOM to obtain an overall immobilization demand. Ammonium-nitrogen (NH_4-N) is also assumed to be preferentially immobilized over the NO_3-N pool. Immobilization ofNO_3-N is thought to occur only if the NH_4-N is deficient. Insufficient amounts of NH_4-N and NO_3-N to meet the immobilization demand will cause the rate of SOM mineralization to decrease.

While testing the predictive capability of SWB-Sci with regards to N dynamics, it was found that the model gave an acceptable forecast of variables such as yield, top dry matter (TDM) and soil water content at different depths for a wheat (*Triticum aestivum*) crop (Van Der Laan 2009). The model's ability to forecast yield, TDM and leaf area index for dryland maize and irrigated maize-oat rotation was also ratified (Tesfamariam et al. 2012). However, inorganic N levels in soil were often overestimated. The study of Van Der Laan (2009) show that TDM and yield were well simulated as compared to the levels of inorganic N for which the simulated values are much higher than what has been measured in field (Figure 1.2.3). Immobilization following the application of fertilizer, and the span between sampling dates may have limited the detection of inorganic N in the measured data, thereby explaining the overestimation of SWB-Sci for this variable. In the model, C is uniformly distributed amongst the four OM pools and is given a constant value of 0.58. In a studyusing APSIM, accuracy at simulating N levels in soils amended with manures was improved by characterizing the OM pools in terms of both their C content and C:N ratios (Probert et al. 2005). So, this could represent a research avenue to improve the performance of SWB-Sci at simulation levels of inorganic N in soils.

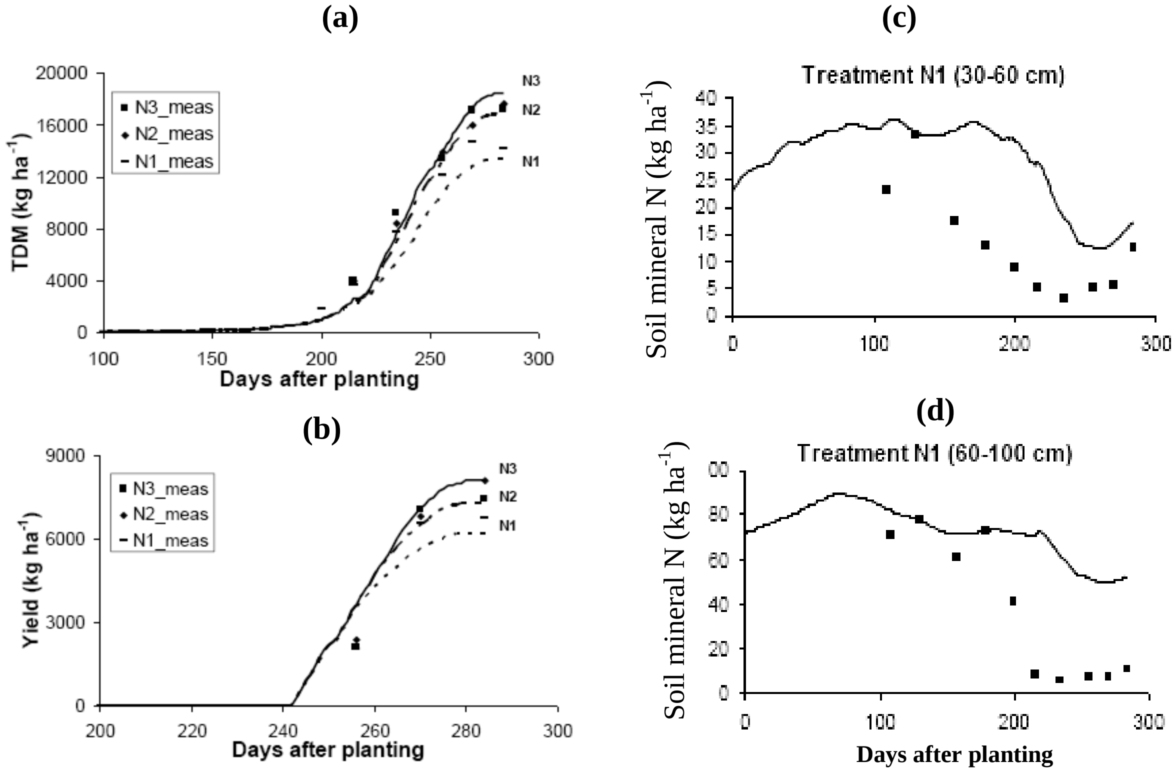


FIG. 1.2.3: On the left-hand side, graphs (a) and (b) show measured (dotted, broken and full lines) and simulated (point marker) above-ground dry matter and yield for wheat for three treatments, N1 to N3. On the right-hand side, graphs (c) and (d) show inorganic N recorded for treatment N1 compared to simulated data (Van Der Laan 2009)

Despite all the efforts to better understand the N mineralization from soil and organic amendments, and to mechanistically model these processes, research gaps remain. There is a need to further refine measurement and modeling techniques.

CHAPTER 2: INVESTIGATING MINERALIZATION FROM AGRICULTURAL COMPOSTS UNDER CONTROLLED CONDITIONS IN MAURITIAN SOILS

To make possible the integration of composts in sugarcane fertilization, the effects of exogenous organic products on nitrogen (N) bio-availability in soil needs to be studied. In natural ecosystems, N mineralization is a dynamic process that is a function of soil characteristics, environmental conditions and human alteration, all of which determine the amount, pattern and form of inorganic N mineralized or lost (Vitousek et al. 1997, Zech et al. 1997). In such an environment, it is difficult to measure the magnitude of each component of the ecosystem on net N mineralized. Therefore, to quantify the changes in N dynamics that occur upon application of compost to the five major soil groups of Mauritius, a laboratory incubation experiment under controlled conditions of soil moisture and room temperature was carried out. The sequence of the experiment is indicated in Figure 2.1.

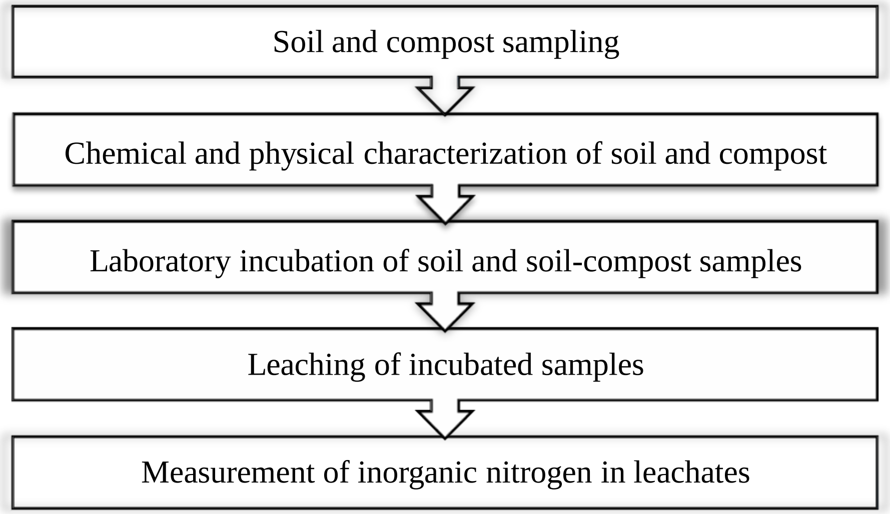


FIG. 2.1: Flow chart of the methodology used for the laboratory incubation

Hypothesis

(a) The amount of N that mineralizes from soil is strongly correlated to the carbon to nitrogen (C:N) ratio and organic matter (OM) content of soil.

(b) The influence of different agricultural composts on soil organic N mineralization will vary from one soil group to another according to the chemical and physical properties of both the agricultural compost and the soil group.

Major chapter objectives

(a) To determine the pattern and rate of ammonium (NH_4^+) and nitrate (NO_3^-) release of three different agricultural composts in five soil groups.

(b) To evaluate the impact of soil organic matter (SOM) levels, soil C:N ratio, and C:N ratio of organic materials on N mineralization potential in compost-amended soils.

2.1 Soil and compost sampling

For the incubation study, five soil groups under sugarcane cultivation were selected, and soil was sampled in each of the regions illustrated in Figure 2.1.1. From each of the three sugarcane fields sampled in each region, a composite sample was collected for laboratory analyses. It was ensured that the selected fields had not been fertilized during thesix months preceding sampling.Soil samplingwas done according to the technique described by the STASM (2003), whereby ten sub-samples werecollected each four hectare with an auger to a depth of 0.3 m. The sub-samples were then mixed and divided into quarters. One quarter of mixed soil was kept and quartered again until one kilogram was left. For the determination of inorganic N and moisture content, the samples were stored fresh at 4°C until analyzed. For the remaining tests, the composite sample was air-dried, sieved through a 2mm mesh and labeled.

Legend

▢ Tamarin: Low HumicLatosol (L)
🟩 Pierrefonds: Latosolic Reddish Prairie (P)
🟨 Belle Rive: Humic Ferruginous Latosol (F)
🟩 Union Park: Latosolic Brown Forest (B)
🟥 Riche en Eau: Humic Latosol (H)

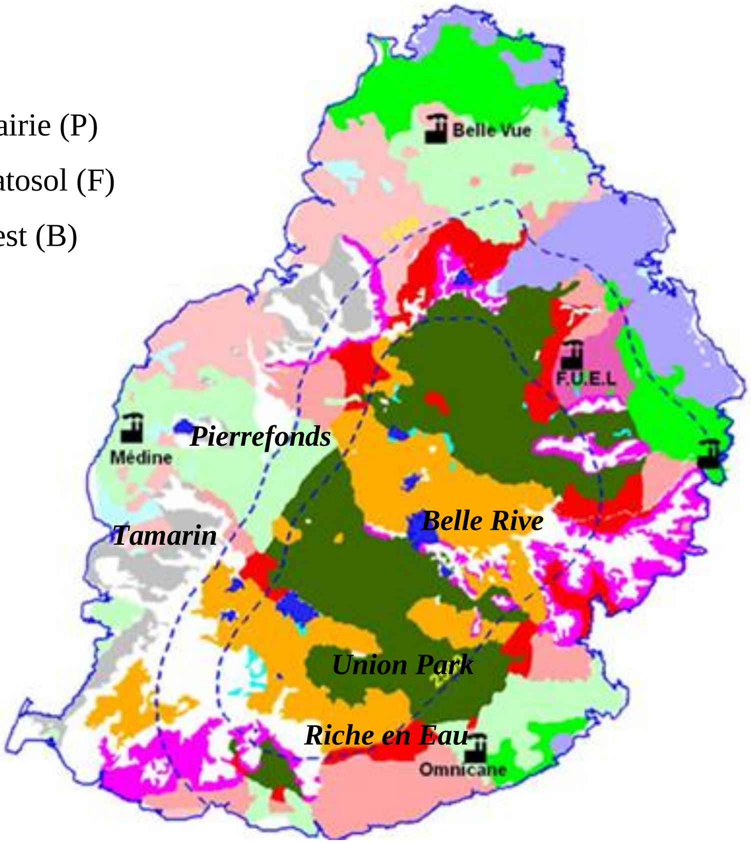


FIG. 2.1.1: Map of Mauritius showing the sampling sites (Pierrefonds, Tamarin, Belle Rive, Union Park and Riche en Eau) of the five major soil groups

For the laboratory experiment, three types of agricultural compost were selected, namely filtercake (FC), poultry manure with sugarcane trash (PM), and poultry litter compost (PL). The samples were collected at the composting site of Médine Ltd (20°25'42.28"S and 57°39'37.28"E). For each type of compost, five sub-samples were collected from individual heaps, and mixed to constitute a composite sample (Leege and Thompson 1997). Single windrows were usually 100 m long and consisted of two or more batches of organic material delivered at different time intervals. Compost maturity therefore varied along the windrow. To ensure that a representative sample of each type of compost was obtained for analysis purposes, compost was therefore collected along each FC, PM and PL windrow. A portion of the sample (500g) wasair-dried, then ground, sieved through a 2mm-mesh sieve, and stored until analyzed. Three composite samples per type of compost was collected, and characterized before experimentation.

2.2 Chemical characterization of soils and composts sampled

The methods used for the chemical characterization of soil and compost are summarized in Table 2.1.

2.2.1 Total nitrogen (N), phosphorus (P) and potassium (K)

For soil samples, total N was analyzed by the method of Bremner and Mulvaney (1982). The dried and sieved soil samples were digested in a hot mixture of concentrated sulphuric acid, salicylic acid and sodium thiosulphate. Digestion generates ammonium ions (NH_4^+). Steam distillation of the solution was then carried out in the presence of an alkali sodium hydroxide, and in the process, the NH_4^+ ions are converted into ammonia (NH_3), which is trapped in boric acid. To calculate total N, titration with 0.0025M sulphuric acid was done. For compost samples, the methodology of Tadessee et al. (1991) was followed to analyze total N.

Total P and K in soils were determined by boiling with concentrated perchloric acid (70%), as per the method of Tandon et al. (1968). During this process, OM is oxidized, and soil P and K are solubilized. While the P ions in solution were determined by colorimetry (spectrophotometer at 440 nm) after reaction with vanadate-molybdate reagent, the K ions were quantified by flame photometry.

The total P and K contents of compost were determined by ashing oven-dried material at 550°C in a muffle furnace, and boiling the ash with 10 ml 1:1 concentrated hydrochloric acid (Tadessee et al. 1991). For P quantification, a reagent composed of ammonium molybdate-sulphuric acid, antimony potassium tartrate solution, ascorbic acid and distilled water was added to the filtrate. Standard solutions containing 2.5, 5.0, 7.5, 10.0, and 12.5 µg P ml^{-1} and a control without P were also prepared. The absorbance of the samples was then read at 650 nm using a spectrophotometer. To determine the K concentration of compost, the filtrate was analyzed by flame photometry. For calibration purposes, standard K solutions containing 2, 4, 6, 8, and 10 µg K ml^{-1}, as well as a control were used.

2.2.2 Inorganic nitrogen

Inorganic N was extracted by mixing 60 ml of 2M potassium chloride with 12 g of sampled soil or compost (Keeney and Nelson 1982, MAFF 1985). The soil or compost suspension was agitated for one hour, centrifuged and filtered. A two-step distillation was then carried out with the filtrate to quantify the concentration of NH_4^+ and nitrate (NO_3^-) ions. For NH_4^+ions, reaction with magnesium oxide results in the formation of NH_3which is trapped in boric acid. Titration with 0.0025M sulphuric acid was done to determine the concentration of NH_4^+ions. The NO_3^- ions were then quantified by mixing the filtrate-magnesium oxide solution with Devarda's alloy (contains approximately 50% copper, 45% aluminium and 5% zinc). A reduction reaction converts NO_3^-into NH_3, which is trapped in boric acid. Titration with 0.0025M sulphuric acid then proceeds.

2.2.3 Extractable phosphorus and potassium

Available P and K in soil were both extracted by mixing 1 g of dried and sieved soil with 50 ml of 0.1M sulphuric acid (Cavalot et al. 1988; Murphy and Riley 1962; Anon 1986). Following one hour of agitation, the soil suspension was centrifuged and filtered. Extractable K was determined with a flame photometer that was initially calibrated with standard solutions containing 2, 4, 6, 8, and 10 µg K ml^{-1}, as well as a control (no K). Available P was determined by colorimetry at a wavelength of 650 nm. Standard solutions containing 2.5, 5.0, 7.5, 10.0, and 12.5 µg P ml^{-1} and a control without P were used to calibrate the spectrophotometer (SPECORD 40). For the quantification of available P and K, control soil samples were also used to ensure accuracy of the measurements.

TABLE 2.1: Laboratory methods for the chemical characterization of soils and composts sampled

Chemical tests	Method for soil	Method for compost
Organic carbon (C)	Oxidation with acidified potassium dichromate (Anderson and Ingram 1993)	Loss on ignition (Tadessee et al. 1991)
pH	Soil in water 1:2.5	Compost in water 1 : 5
Moisture content	Oven-drying	Same as for soil
Total Nitrogen (N)	Digestion with concentrated sulphuric acid and salicylic acid (Bremner and Mulvaney 1982)	Digestion with concentrated sulphuric acid and salicylic acid (Tadesse et al. 1991)
Ammonium (NH_4^+)	Extraction with 2M potassium chloride (Keeney and Nelson 1982, MAFF 1985)	Same as for soil
Nitrate (NO_3^-)	Extraction with 2M potassium chloride (Keeney and Nelson 1982, MAFF 1985)	Same as for soil
Total Phosphorus (P)	Treatment with perchloric acid (Tandon et al. 1968)	Extraction withconcentrated hydrochloric acid (Tadesse et al. 1991)
Total Potassium (K)	Treatment with perchloric acid (Tandon et al. 1968)	Extraction with concentrated hydrochloric acid Tadesse et al. (1991)
Available Potassium	Extraction with 0.1M sulphuric acid (Cavalot et al. 1988; Murphy and Riley 1962; Anon 1986)	-
Extractable Phosphorus	Extraction with 0.1M sulphuric acid (Cavalot et al. 1988; Murphy and Riley 1962; Anon 1986)	-

2.2.4 Organic carbon and organic matter

Organic carbon (C) in soil was analyzed as per Anderson and Ingram (1993) by mixing 10 ml of acidified potassium dichromate and 20 ml of concentrated sulphuric acid to 0.5g of soil in a beaker. Acidified potassium dichromate is an oxidizing agent which oxidizes soil organic C. During this process, potassium dichromate is reduced to Cr^{3+} ions. The concentration of Cr^{3+} ions formed indicates the quantity of organic C present in soil. Measurement of organic C was done using colorimetry at 600 nm (UV spectrophotometer, SPECORD 40). The spectrophotometer was calibrated with standard solutions containing zero to 25 mg C. The organic matter (OM) content of soil was then calculated according to the assumption that OM is composed of 58% C (Tadessee et al. 1991). For compost, the analysis of OM was based on the method described by Tadessee et al. (1991). The moisture content of 10 g of the compost sample was first determined by heating in an oven at 105°C for six hours. The difference in weight before and after heating represents the moisture content. An oven-dried compost sample (10g) was then weighed, placed in a dry crucible and heated in a muffle furnace at 550°C for eight hours. Following heating, the compost was cooled in a dessicator and weighed. The loss in weight on ignition represented the amount of OM, and based on the assumption that OM is composed of 58% C, the amount of C was calculated.

2.2.5 pH

Following drying and sieving, 20 g of soil was mixed with 50 ml of deionized water in a beaker using a glass rod (ratio 1:2.5). For compost, 10 g of material was mixed with 50 ml of deionized water. The soil- or compost-water suspension was kept under a constant temperature of 20°C during two hours with intermittent mixing every 15 minutes. The pH was measured using a glass electrode (Denver instrument). Before measurement, the pH meter was standardized with buffers of pH 4.0, 7.0 and 8.6. A control soil sample with known pH values was also used to confirm the accuracy of the analysis.

2.2.6 Moisture content

The moisture content was determined by the oven-drying method that involved weighing soil before and after drying in an oven during 24 hours, at a temperature of 105°C. Equation one was used to determine the moisture content:

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh mass} - \text{Dry mass}}{\text{Fresh mass}} \times 100 \qquad \textit{Equation 1}$$

Where,

Fresh mass refers to the mass of soil before oven-drying

Dry mass refers to the mass of soil after oven-drying

2.3 Physical characterization of soil

The methods used for the physical characterization of soil are summarized in Table 2.1.1.

TABLE 2.1.1: Methods for the physical characterization of soil

Physical tests	Method
Bulk density	Corer method
Particle size distribution	Hydrometer method (Gee and Bauder 1986)

2.3.1 Bulk density

Soil bulk density is the ratio of the mass of dried soil to the volume of soil particles and pores as it exists *in situ*. For soils with little or no stones, the core method is used. Using this technique, a metal sampler consisting of an inner and outer cylinder was inserted into the soil to a depth of 0.15 m and removed, as illustrated in Figure 2.1.2. The undisturbed soil from the inner cylinder was collected, and the same process was repeated to sample soil to a depth of 0.30 m. The collected soil was placed in an air-tight metal container and taken to the laboratory for drying. The weight of the soil and container was recorded before and after heating in an oven at 105°C. A wet sieving of the soil was then done to remove the stones, which were then weighed. Bulk density with and without gravels was then calculated using equation two.

$$\text{Soil bulk density (Kg m}^{-3}\text{)} = \frac{\text{Mass of dry soil (Kg)}}{\text{Total volume (m}^{3}\text{)}} \qquad \textit{Equation 2}$$

Where,

Mass of dry soil refers to the mass of sampled soil after oven-drying

Total volume refers to the volume of the cylinder used for sampling

In soils with a high degree of rockiness, the corer method cannot be used to measure the bulk density. As an alternative technique, the excavation method is used. A thin, flat metal plate is placed on the soil, and a soil core is excavated through the centre hole of the plate. The recovered soil is placed in an air-tight metal container that is weighed, and subsequently dried at 105°C. The volume of the excavation is then determined by filling the hole with sand of known density using a sand tower, as shown in Figure 2.1.2. The mass of sand needed to fill the hole is recorded. The soil bulk density is then calculated from the oven-dry mass of the recovered soil and the volume of the excavation.

FIG.2.1.2: The corer method for themeasurement of bulk density (A) and the sand tower method for the measurement of bulk density in rocky soils (B and C)

2.3.2 Particle size distribution

The relative proportions of sand, silt and clay was determined by the method of Gee and Bauder (1986) that involves the dispersion of soil particles in aqueous solution and subsequent separation of individual soil particles by sedimentation. For soil dispersion, OM, carbonates and soluble salts present in soil were first be removed. Chemical treatment of OM was carried out by heating 10g of air-dried soil (< 2mm) with 2g sodium metabisulphite in a beaker. When the content of the beaker was reduced to half of its original volume, 50ml of 10% hydrogen peroxide (H_2O_2) was added for the removal of carbonates and soluble salts by oxidation. This operation was repeated. The soil was then dispersed by shaking with sodium hexametaphosphate on a mechanical shaker for 16 hours at constant temperature of 20°C until sedimentation was complete. Silt was determined at constant temperature of 20°C by transferring the soil suspension to a 1L measuring cylinder and shaking the contents by repeated inversions for 30 seconds. After the required time needed for the silt particles to settle, a 20ml aliquot was pipetted to a depth of 0.10 m from the surface of the soil suspension. The suspension was left undisturbed for seven hours before proceeding to the pipetting of 20ml aliquot, 0.10 m from the surface of the suspension for clay determination. The remaining silt and clay fractions were siphoned, leaving the sand fraction which was evaporated to dryness at 105°C for one hour, cooled in a dessicator and weighed.

2.4 Aerobic laboratory incubation

To investigate the pattern of N mineralization in soils and blends of soil and compost, five soil groups were incubated with three types of compost in duplicates over a period of 30 weeks. The five soil types were also incubated in duplicates without any compost as control. In total, 40 samples were incubated. The four treatments incubated in the laboratory experiment were as follows:

Treatment 1	Composted FCwith soil to supply 140 kg N ha^{-1}
Treatment 2	Composted PM with soil to supply 140 kg N ha^{-1}
Treatment 3	Composted PL with soil to supply 140 kg N ha^{-1}
Treatment 4	Soil only (control)

2.4.1 Pre-incubation

The pre-incubation step aimed at establishing microbial flora in the dried samples, and was carried out at field capacity. To bring the soil to field capacity, 50g of sieved and dried soil was weighed and transferred to 80ml sintered Büchner funnels as illustrated by Figure 2.1.3. At this stage, no mixing of compost with soil was done. The soil samples were then saturated with distilled water and allowed to drain naturally for 24 hours to enable the redistribution of soil water (Cassel and Nielsen 1986). After drainage, the samples were assumed to be at field capacity, and were weighed to calculate the soil water content. The calculated soil water content was used as a reference point. Regularly, the soil was weighed, and soil water adjusted to its initial volume as carried out in a study of Kuo et al. (2000). Pre-incubation of soil samples at field capacity was done at roomtemperature for seven days. On the seventh day, the samples were leached with 150ml 0.01M $CaCl_2$ before the application of compost. The leachates were then analyzed for inorganic N, NH_4-N and NO_3-N.

FIG. 2.1.3: Soil incubated in sintered Büchner funnels

2.4.2 Aerobic incubation

Aerobic incubation started just after leaching onthe seventh day of the pre-incubation period. Initiation of aerobic incubation was said to have occurred on day zero, and involved the mixing of sieved and dried compost with soil according to the different treatments. Compost was added to soil to supply 140 kg N ha^{-1}, the recommended rate of inorganic N fertilizer in Mauritius for a sugarcane yield of 100 t ha^{-1}. The application rate of compost was based on the assumption that only 50% of the total N in compost would be available during the first crop season (Chabalier et al. 2006), therefore, 280 kg N ha^{-1} were effectively applied to soil via the compost in the laboratory experiment. The soil and compost mixing ratios were calculated according to measured bulk densities of each soil group, to a plough layer depth of 0.30 m (except for P soils for which the plough depth is 0.25 m), assuming that compost was broadcasted over one hectare or 10000 m^2. Each treatment was replicated two times. The Büchner funnels were covered with perforated parafilm to maintain aerobic conditions (Canali et al. 2011), and on a regular basis, the samples werecorrected for water loss by weighing the funnels and adding distilled water.A series of leaching episodes with 0.01M $CaCl_2$over 30 weeks was then carried out according to Stanford et al. (1974).

2.4.3 Data collection and analysis

Leaching episodes were carried out over 30 weeks at pre-determined days or week as depicted in Figure 2.1.4. For each episode, a total of 40 samples were leached, and the resulting leachate tested for inorganic N by the steam distillation method.

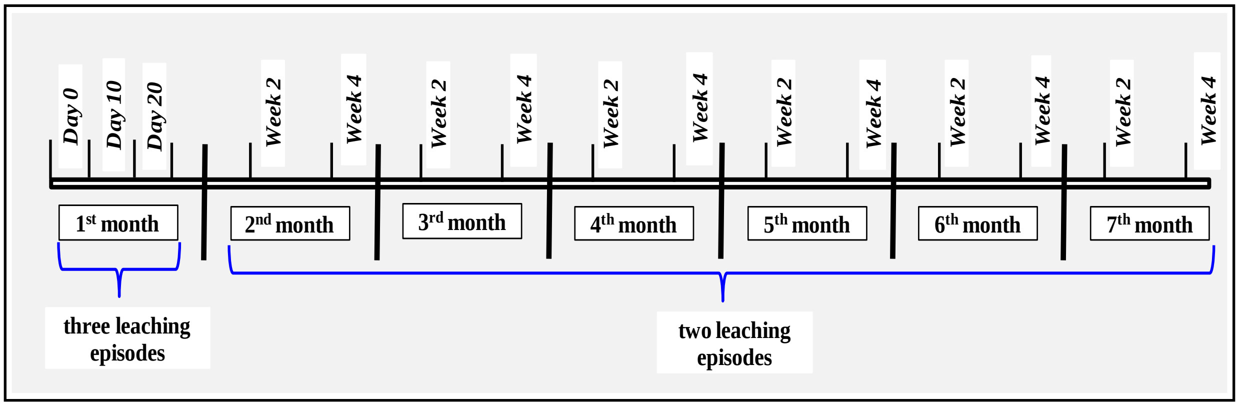


FIG. 2.1.4: Leaching frequency of the samples incubated in laboratory

To determine the significance of differences in net N mineralized between the treatments set, Analysis of variance (ANOVA), at a probability level of 0.05, was carried out using the software Genstat (14th edition). Whenever the treatment effects were found to be significant, the Tukey test was ran for the separation of means.To evaluate the correlation between selected soil properties and cumulative net N mineralized, a Spearman correlation test was carried out using the software Genstat (14th edition).

Net N mineralization from amended and un-amended soils, was calculated by subtracting the initial amounts of NH_4^+ and NO_3^- at day zero from amounts of inorganic N at each sampling time. At day zero (N_i), because soil of the different treatments were leached with 0.01M $CaCl_2$ before compost addition, the concentration of inorganic N left in soil when compost was added was considered to be zero. Organic N was calculated by subtracting inorganic N from total N. The equations used were as follows (Mbakwe et al. 2013, Chaves et al. 2014):

Net N mineralization from soil and compost mixture = $N_t - N_i$ *Equation 3*

Where, N_t refers to inorganic N (mg N kg^{-1} soil) measured at sampling date t

N_i refers to inorganic N (mg N kg^{-1} soil) measured at day zero before compost addition

Net N mineralization from compost = $[(N_{at} - N_{ai}) - (N_{ct} - N_{ci})]$ *Equation 4*

Where, N_{at} refers to inorganic N (mg N kg^{-1} soil) in amended samples at sampling date t

N_{ai} refers to inorganic N (mg N kg^{-1} soil) in amended samples at day 0

N_{ct} refers to inorganic N (mg N kg^{-1} soil) in control at sampling date t

N_{ci} refers to inorganic N (mg N kg^{-1} soil) in control at day 0

Percent of organic N mineralized from compost (%) = $[(N_{at} - N_{ai}) - (N_{ct} - N_{ci})]$ /organic N content of compost added at day zero *Equation 5*

To determine the soil N mineralization potential (N_0) at a rate constant *k* and a given period of incubation (*t*), the cumulative amount of inorganic N mineralized at each leaching episode was fitted into the regression model of Stanford and Smith (1972) that is based on first-order kinetics. The software Windows Regression 3.3 (WINREG) of Debord (2007) was used.

$N_t = N_o (1- e^{-kt})$ *Equation 6*

Where, N_t refers to theamount of N mineralized (mg N kg^{-1} soil) at time t

N_0refers to (potentially mineralizable N, mg N kg^{-1} soil)

t is the period of incubation (days)

k refers to thefirst-order rate constant (day^{-1})

The half-life t1/2 is given by (ln 2)/k

2.5 Results and discussion

2.5.1 Chemical and physical characterization of soil

The five soil groups sampled in different climatic zones of Mauritius have distinct chemical properties, as shown in Table 2.1.2.

TABLE 2.1.2: Chemical characteristics of the five soil groups incubated

Characteristic	**Latosolic Reddish Prairie (P)**	**Latosolic Brown Forest (B)**	**Low Humic Latosol (L)**	**Humic Latosol (H)**	**Humic Ferruginous Latosol (F)**
Zonal annual rainfall (mm)	**≤ 1000 - 2500**	**2000 - 4000**	**≤ 1000-2750**	**1500 - 3750**	**2000 - 5000**
Total Nitrogen, %	0.41 ± 0.07	0.36 ± 0.05	0.17 ± 0.03	0.19 ± 0.04	0.23 ± 0.04
Inorganic Nitrogen, %	0.0024 ± 0.0006	0.0020 ± 0.0005	0.0019 ± 0.0008	0.0018 ± 0.0003	0.0019 ± 0.0004
Extractable Phosphorus, %	0.028 ± 0.010	0.016 ± 0.006	0.008 ± 0.003	0.004 ± 0.001	0.007 ± 0.003
Available Potassium, milliequivalent %	1.06 ± 0.17	0.26 ± 0.10	0.82 ± 0.39	0.11 ± 0.03	0.24 ± 0.13
Organic Carbon, %	3.69 ± 0.56	3.55 ± 0.57	1.53 ± 0.24	2.00 ± 0.44	2.69 ± 0.58
Carbon : Nitrogen ratio	9.0 ± 0.2	9.8 ± 0.2	8.9 ± 0.7	10.5 ±0.6	11.9 ± 0.3
Organic matter, %	6.35 ± 0.96	6.11 ± 0.99	2.63 ±0.42	3.44 ± 0.76	4.63 ± 0.99
pH (H_2O) †	6.36 ± 0.12	5.30 ± 0.17	6.31 ±0.13	6.04 ±0.27	5.31 ± 0.21
Gravimetric soil water content, %	20.4 ± 4.5	32.1 ± 4.1	24.2 ± 0.3	29.5 ± 0.8	22.0 ± 2.9

†Soil in water 1:2.5

TABLE 2.1.3: Physical characteristic of the five soil groups incubated

Characteristic†	Latosolic Reddish Prairie (P)	Latosolic Brown Forest (B)	Low Humic Latosol (L)	Humic Latosol (H)	Humic Ferruginous Latosol (F)
Sand, %	56.5 ± 4.8	20.0 ± 5.5*	16.0 ± 2.3	23.3 ± 5.4*	33.6 ± 3.5*
Silt, %	19.8 ± 3.7	32.3	15.3 ± 3.8	14.7	28.9
Clay, %	23.7 ± 1.3	47.7 ± 6.6*	68.8 ± 6.0	62.0 ± 3.7*	37.5 ± 4.2*
Bulk density (0- 0.15 m), Mg dw m^{-3}	0.80*	0.85*	1.15 ± 0.22	1.16 ± 0.01	0.90*
Bulk density (0.15-0.30 m), Mg dw m^{-3}	0.75*	0.80*	0.78 ± 0.07	0.91 ± 0.09	1.05*

†dw, dry weight

* Particle size distribution results obtained from Ng Cheong (2007) andbulk density from Chan and Li Pi Shan (1975)

The SOM level, C:N ratio and pH are known to strongly influence N mineralization in natural ecosystems. In general, soils of Mauritius were slightly acidic to near neutral, with a pH (water) range of 5.30 to 6.36. Soil acidity and alkalinity is largely determined by the amount of annual rainfall recorded which determines the degree of weathering. While severe leaching of bases occurs in high rainfall zones, accumulation of cations tends to occur in drier regions (Van Breemen and Buurman 2002), explaining the trend in pH (water) observed in Table 2.1.2. The most acidic soils located in high rainfall regions are the B (pH 5.30) and F (pH 5.31) groups, and under these soil conditions, the activity of nitrifiers, *Nitrosomonas* and *Nitrobacter*, can be hindered, leading to a build-up of NH_4^+ (Roswall 1976). Nevertheless, compared to factors such as C:N ratio, soil pH has less impact on the degree of N mineralization (Er et al. 2004).

Some studies have shown that soils having an OM content higher than 4% had a correspondingly high N-supplying capacity (Meyer et al. 1983, Meyer et al. 1986). For the soils considered in this study, the OM content was between 2.63% and 6.35%, with the less weathered soils having a much more appreciable OM content than the mature soils (Table 2.1.2). Because SOM constitutes the main source of organic N in soil, the inherent N-supplying capacity of each soil group tends to be strongly influenced by the level of OM in soil and soil characteristics such as C:N ratio and texture (Conant et al. 2011).The integration of inorganic N in the organic pool occurs through the process of immobilization, which involves the assimilation of mineral N by microbes for their growth (Chowdary et al. 2004). Generally, the extent of immobilization is determined by the ratio of C and N in soil, the wider the C:N ratio, the stronger the driving force for immobilization (Alexander 1977). According to Table 2.1.2, the C:N ratios of the five soil groups under study varied from 8.9 to 11.9, and it was noted that soils located in the highest rainfall regions, namely the H, F and B soils, had the widest C:N ratios.This finding is concordant with past studies carried out by Ng Cheong (2007) who observed that C:N ratios in Mauritian soils do in fact vary according to the different agro-climatic zones. The C:N ratiosmay indicate that compared to other mature (L) and immature (P) soils in drier zones, F, H and B soils have a higher N-immobilizing power. Any inorganic N applied is therefore likely to be integrated in the organic N pool of soil through assimilation by microbes. With an OM content of 6.35% and low C:N ratio of 9.0, the P soil may potentially have an appreciable N-supplying capacity. On the other hand, with the lowest SOM content of the five soil groups, the L soil is expected to have relatively lower N-supplying capacities.

Parish and Feillafé (1965) claimed that Mauritian soils had a low inherent fertility and that the fertility gradient decreased with increasing rainfall and geologic age of the parent material. The N, P, K content of soils shown in Table 2.1.2 supports this statement. The total N content of the five soil groups ranged from 0.41% to 0.17% and was in the order of P > B > F > H > L. In terms of extractable P, between 0.028% and 0.004% was measured in the order of P > B > F > L > H. For available K, the range observed was between 1.06 m.e% and 0.11 m.e% in the order P > L > B > F> H. Compared to mature soils, the immature soil groups P and B had higher contents of total N and extractable P.

As shown by Table 2.1.3, the proportion of clay in Mauritian soils ranged from 23.7 % to 68.8%, and the sand content from 5.5% to 23.3%. In general, the soil texture varied from silty clay loam (P, B and F soils) to silty clay (L/H group) to clay (L/H group). Compared to other soil groups, the H group had a high bulk density (1.16 Mg dwm^{-3}) and clay content (62.0%), properties that may foster poor soil aeration. Similarly, the L soil was fine-textured, had a relatively high bulk density (1.15 Mg dwm^{-3}) and clay content (68.8%). Being negatively charged, clay minerals encourage the adsorption of organic molecules via cation exchange, hydrophobic bonding or polyvalent cation bridges depending on the charge of the organic molecule (Mortland 1986, Zech et al. 1997). Cations such as NH_4^+ that result from ammonification may also become adsorbed on clay particles (Neider et al. 2011). Although soil texture is considered as a minor parameter controlling N mineralization, finer soil textures have been shown to contribute to lower mineralization rates (González-Prieto et al. 1992).

Unlike the L and H soils, the P soil had a low clay content, thereby reducing the occurrence of NH_4^+ fixation. The P group is characterized by a set of chemical and physical properties that may enhance N mineralization. The N mineralization process which is carried out by microbes is powered by oxygen, and because of the low bulk density and coarse texture of the P soil, this biological process may be enhanced. The immature B group had bulk densities comparable to the P group, although the clay and silt proportions were higher. The F soil group had well-balanced proportions of sand, silt and clay, and a low bulk density that may ensure good soil aeration for the biological process of N mineralization. With an OM content of 4.63%, it would be expected that the F group would have an appreciable N-supplying capacity.

At a soil pH of 5.31, elements such as aluminium (Al) and iron (Fe) become more soluble in soil. The complexation of SOM with Al and Fe may constitute a physico-chemical barrier against degradation by micro-organisms, and lead to low rates of N mineralization (González-Prieto et al. 1992). Therefore, along with the soil texture, parameters such assoil C:N ratio, SOM, total N and pH which directly affect the microbial breakdown of organic N will be considered together to understand the impact of agricultural composts on N mineralization in soil.

2.5.2 Chemical characterization of compost

The chemical profiles of the three agricultural composts FC, PM and PL used for the laboratory incubation study are shown in Table 2.1.4. Five replicate samples were analyzed for each compost type. While FC and PM samples were homogeneous in terms of nutrient content, PL samples were quite heterogeneous, as shown by the high standard deviations. This can be explained by the variable maturity of the sampled PL along the windrow of the composting facility as single windrows may contain two or more batches of PL delivered at different time intervals.

TABLE 2.1.4: Chemical characteristics of three agricultural composts

Characteristic †	**Filtercake (FC)**	**Poultry manure-thrash (PM)**	**Poultry litter (PL)**
Total Nitrogen, %	1.65 ± 0.18	2.07 ± 0.14	3.66 ± 0.19
Inorganic Nitrogen, %	0.09 ± 0.01	0.05 ± 0.01	0.58 ± 0.02
Total Phosphorus, %	0.96 ± 0.08	1.16 ± 1.22	2.56 ± 1.46
Total Potassium, %	1.11 ± 0.07	5.46 ± 0.18	10.00 ± 4.29
Total Carbon, %	15.02 ± 4.76	12.71 ± 0.68	22.37 ± 13.56
Carbon : Nitrogen ratio	9.2 ± 3.1	6.2 ± 0.6	6.2 ± 3.9
Organic matter, %	28.89 ± 9.15	24.45 ± 1.30	43.02 ± 26.09
pH (H_2O)††	5.68 ± 1.70	9.46 ± 0.04	6.57 ± 0.02
Gravimetric water content, %	59.7 ± 1.6	26.8 ± 0.6	29.8 ± 0.7

† Percent nutrients expressed on a dry weight basis

††Saturated extract of compost in water ratio of 1:5

Amongst the three types of agricultural composts analyzed, PL contained the highest amounts of the main elements, N, P and K that are essential for plant nutrition. PL is composed of wood shavings and poultry excreta which contain uric acid and undigested protein, the main sources of N (Nahm 2004). The N components of PM are susceptible to losses by volatilization in the form of ammonia, and without the use of carbonaceous materials like wood shavings as bedding in poultry sheds, N losses can be considerable (Alexander 1977). Carbon-rich materials provide the necessary energy for microbial populations to develop, and by widening the C:N ratio of the manure, the carbonaceous product also promotes N immobilization, thereby conserving more N in PL. In comparison, the PM compost consists of poultry manure that originates from layers farms (chicken rearing for egg production) where no carbon-rich bedding is used. As a result, between the time of manure production and the mixing with sugarcane trash on the composting facility, much N has been lost by volatilization (Nahm 2004), resulting in an end-product that contains lower amounts of N than PL.

The nutrient content of the three composts was similar to that reported in the literature (Chabalier et al. 2006), as described in Table 1.1 of Chapter 1. The K content of both PL and PM was however, relatively higher due to the incorporation of vinasse during the composting process. The low ratio of inorganic N to total N measured for the three agricultural composts indicated that N was predominantly in the organic form. However, the calculated C:N ratios were all below 30, suggesting that the composts are likely to undergo mineralization rather than immobilization (Alexander 1977). The composts contained appreciable amounts of OM, but standard deviation values showed that the OM content of PL (43.02 ± 26.09) and FC (28.89 ± 9.15) may fluctuate while that of PM (24.45 ± 1.30) is quite stable. With regards to the pH (H_2O), PL was near neutral (pH 6.57), while FC was more acidic with a pH of 5.68 and PM highly alkaline with a pH of 9.46. The addition of phosphoric acid to sugarcane juice during clarification explains the relatively low pH of FC. Under acidic conditions, fungal dominate bacterial population, and this may eventually result in poor rates of N mineralization (Nahm 2004). On the other hand, PM compost, due to innate levels of calcium (1.24%) and magnesium (0.89%) is alkaline (Ano and Ubochi 2007), and may promote nitrification, a process regulated by the *Nitrosomonas* and *Nitrobacter* bacteria (Robinson 1963).

2.5.3 Biochemical characterization of compost

The fibre content analysis showed that the agricultural composts under study contained between 8.69 and 22.8 g of acid detergent lignin (ADL) per 100 g of compost (Table 2.1.5). In a study of Mubarak et al. (2010), a significant correlation ($R^2 = 0.74$, $P < 0.05$) was established between the total inorganic N mineralized in soils amended with manure and the lignin content of the manure. Crop residues with a lignin content as high as 21% are known to lower the rate of organic N breakdown (Muhammad et al. 2010). Neutral Detergent Fibre (NDF) which relates to structural parts of the cell wall such as hemicelluloses, cellulose and lignin (Rasby and Martin 2017) ranged between 2.13 to 32.36 g 100 g^{-1} of material analyzed. Cellulose and lignin which are the least digestible components are represented by the Acid Detergent Lignin (ADF) that varied from 19.33 to 46.91 g 100 g^{-1} of material. In terms of starch, the compost analyzed contained a range of 0.84 to 1.01 g 100 g^{-1} of organic product.

TABLE 2.1.5: Fibre content of filtercake, poultry manure-thrash and poultry litter

Characteristic (g 100 g^{-1}) †	**Filtercake (FC)**	**Poultry manure-thrash (PM)**	**Poultry litter (PL)**
Ash	56.03	65.18	33.19
Crude fibre	9.29	9.45	24.57
Neutral detergent fibre	2.13	9.07	32.36
Acid detergent fibre	30.17	19.33	46.91
Acid detergent lignin	22.56	8.69	22.8
Starch	1.01	0.93	0.84
Gravimetric moisture content	47.4	22.4	46.0

† Analysis was carried out by Nutrilab at the University of Pretoria

2.5.4 Cumulative net nitrogen mineralization

Cumulative net N mineralization in compost-amended and control soil samples, given as the difference between N measured at each sampling date and N present at day zero is shown in Figure 2.1.5. A lower cumulative net N mineralized in amended soils compared to control soils infers that the addition of agricultural compost causes N immobilization. Similarly, a higher cumulative net N mineralized in amended soils indicates increased N mineralization. In FC-amended soils, the cumulative net N mineralized ranged from 53 to 137 mg N kg^{-1} dry soil. In general, FC caused variable periods of N immobilization in all the amended soil groups when compared to the control soils. For the B and F soils, the immobilization period occurred during the first 68 days of incubation. The P and H soils only started to mineralize more N than the control soils after 95 days and 110 days respectively. As for the L soil group, the addition of FC considerably decreased the total amount of inorganic N mineralized during the 215-day incubation from 70 (control soil) to 53 (amended soil) mg N kg^{-1} dry soil. In contrast with PL and PM, FC had a lower initial total N, and therefore less organic N for microbial breakdown and subsequent inorganic N release. The L soil is also fine-textured, has the highest clay content of the five groups, and with this type of soil mineralogy, the phenomenon of NH_4^+ fixation is favoured (Neider et al. 2011).

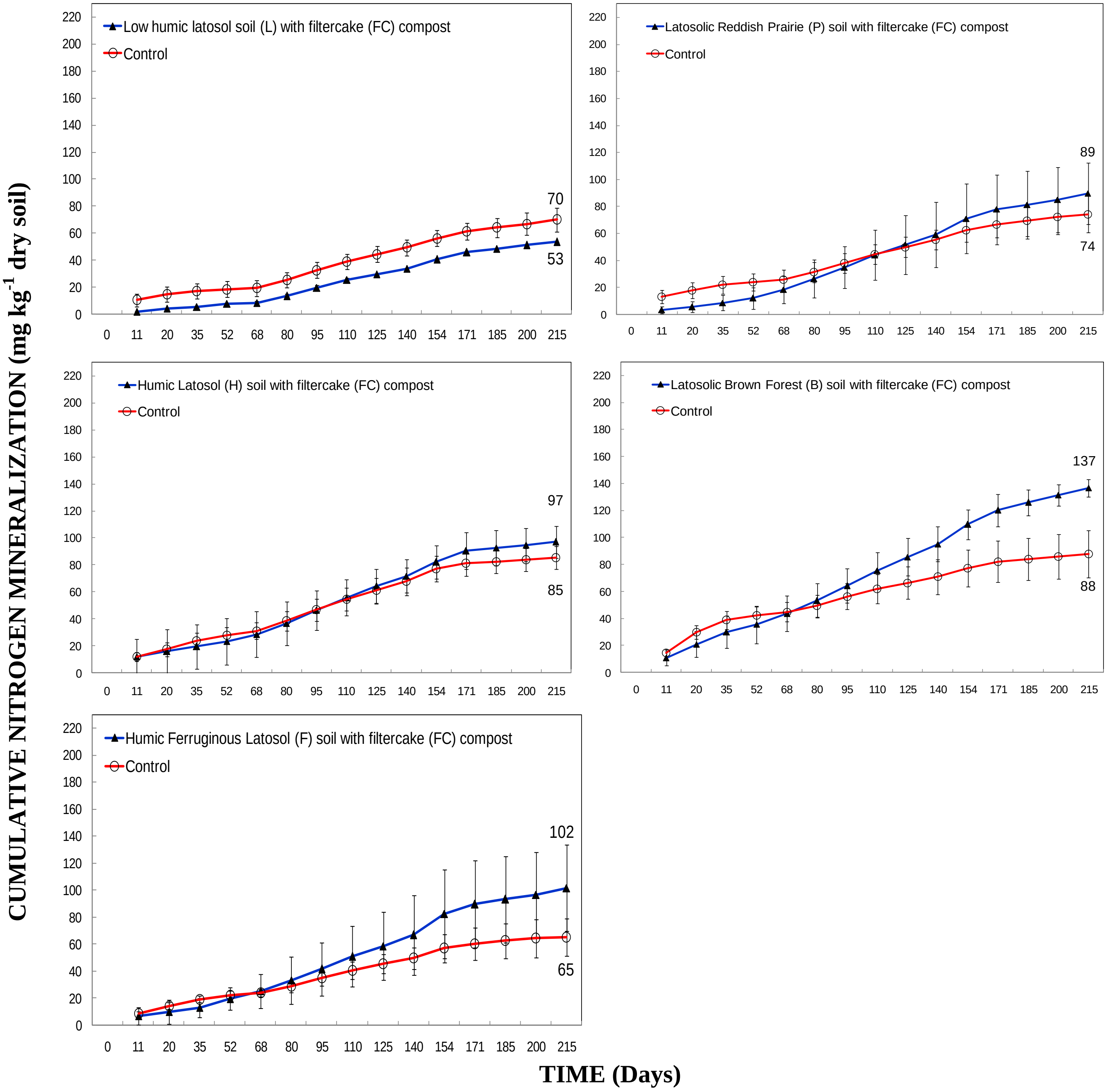


FIG. 2.1.5: Cumulative net nitrogen mineralization in five soil groups amended with filtercake (FC) compost during a laboratory incubation of 215 days

Upon addition of PM to the different soil groups (Figure 2.1.6), the net amount of N mineralized over 215 days ranged between 74 and 197 mg N kg^{-1} dry soil. In the mature soils, PM resulted into an important increment in the cumulative net N mineralized. While the net N mineralized increased from 85 (control soil) to 197 (amended soil) mg N kg^{-1} dry soil in the H soil, the net N mineralized in an F soil increased from 65 (control soil) to 121 mg N kg^{-1} dry soil. Unlike the detrimental effect of FC on N mineralization in the L soil, PM enhanced N mineralization despite an initial immobilization period of 52 days. At the end of the incubation period, 111 mg N kg^{-1} dry soil had been mineralized in the PM-amended L soil against 70 mg N kg^{-1} dry soil in the control soil. The biochemical composition of PM can possibly explain this observation. In fact, PM contains less lignin (86.9 g kg^{-1}), an indigestible compound, than FC (225.6 g kg^{-1}) and PL (228.0 g kg^{-1}). In a study of Mubarak et al. (2010), a significant correlation (R^2= 0.74, $P < 0.05$) was establishedbetween the total inorganic N mineralized in soils amended with manure and the lignin content of the manure. Indeed, crop residues such as cotton which have a lignin content as high as 21% were found to lower the rate of organic N breakdown (Muhammad et al. 2010).

The addition of PM to the immature soils P and B had a relatively mitigated effect on N mineralization. In the P soil, the cumulative net N mineralized was even lower than in the control soil, 67 mg N kg^{-1} dry soil against 74 mg N kg^{-1} dry soil. There are no clear reasons about the decrease in N mineralization in these soils upon addition of PM. The P soil is characterized by a set of chemical and physical properties that may enhance N mineralization. Poultry manure is alkaline in nature and it is known that alkalinity triggers the conversion of NH_4^+ into ammonia (NH_3), a reaction called volatilization (Brady 1999). Despite the fact that PM had been incorporated in all the soil groups, gaseous exchanges between soil and the atmosphere may have been more considerable in the immature soils which have lower bulk densities than the mature soils. This assumption could be further tested in laboratory experimentations by monitoring the emission of NH_3 in compost-amended soils.

Amending soils with PL resulted in net N amounts ranging from 75 to 198 mg N kg^{-1} dry soil (Figure 2.1.7). Nitrogen mineralization was improved in all soils, except in the L group. In fact, the inorganic N in amended L soil remained lower than the control soilduring 140 days. In the immature soils, P and B, PL resulted in the highest levels of mineralized N compared to the control soils. While this statement also applies to the mature F soil, the magnitude of N mineralization in H and L soil groups was greatest when PM was applied.

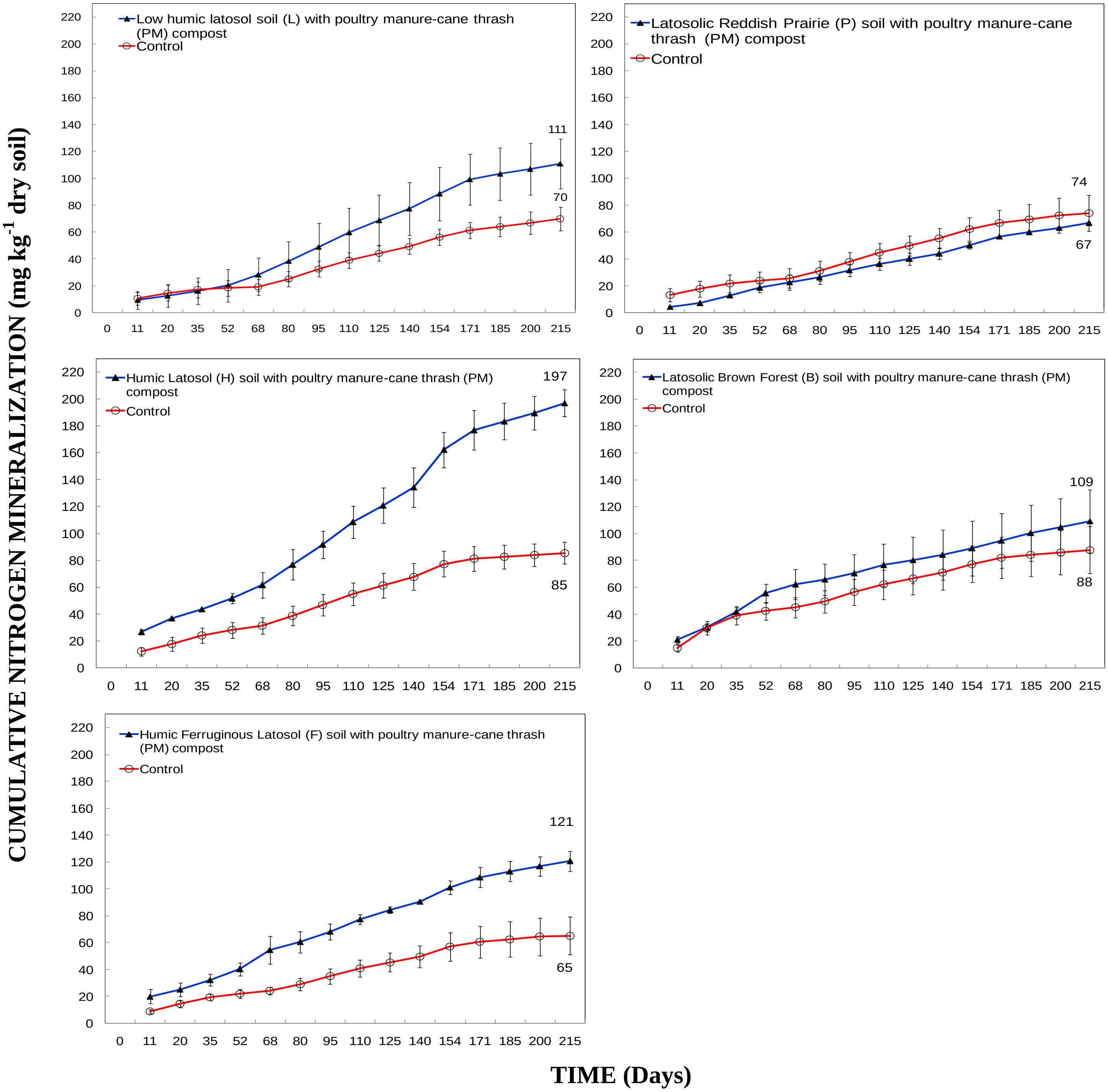


FIG. 2.1.6: Cumulative net nitrogen mineralization in five soil groups amended with poultry manure-cane thrash (PM) compost during a laboratory incubation of 215 days

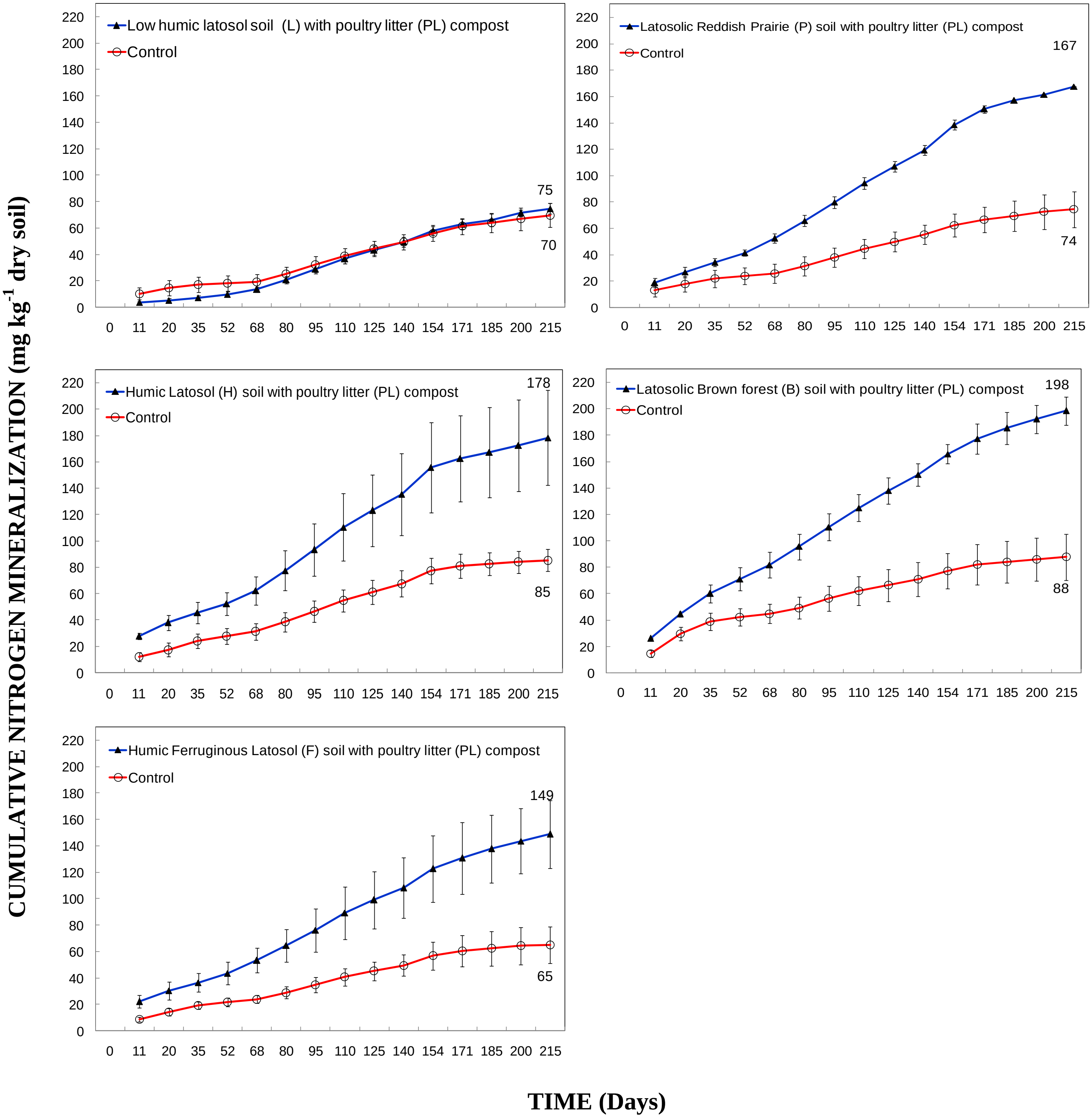


FIG. 2.1.7: Cumulative net nitrogen mineralization in five soil groups amended with poultry litter (PL) compost during a laboratory incubation of 215 days

2.5.5 The Spearman's correlation coefficient

The Spearman's correlation coefficients (Table 2.1.6) showed a positive correlation between inorganic N mineralized in control soils and SOM, implying that the amount of inorganic N mineralized would increase with increasing SOM levels (Appendix III). Since N mineralization is influenced by many soil factors besides SOM, high inorganic N levels may not always be proportional to high SOM. For instance, the P and F soil groups that had a higher OM content than the H group, had lower concentrations of mineralized N than the H group. The Spearman's correlation also established a negative correlation between soil C:N ratio and N mineralization. Therefore, the higher the C:N ratio, the lower the indigenous N mineralized from soil.In this context, the wide C:N ratio (11.9) of the F soil could have led to the rapid re-integration of newly mineralized N into the soil's organic pool because of the high microbial N demand. This could explain why relatively low levels of mineralized N were detected, when the high OM content of the F soil (4.63%) would suggest high N-supplying capacity (Meyer et al. 1983, Meyer et al. 1986). In Mauritius, it was reported that in high rainfall regions (> 3000 mm per year) where the F soil is located, biological immobilization was indeed marked, contributing to low levels of N leaching, less than 5% of the fertilizer N, ten months after application (Ng Kee Kwong 1986).

TABLE 2.1.6: Spearman correlation coefficient between cumulative inorganic nitrogen of control soils and a set of selected chemical and physical soil properties

	Cumulative inorganic nitrogen (control soils)	
Variable	**Correlation coefficient**	**Probability**
Organic matter	0.300	0.129
C:N ratio	-0.100	0.196
Total N	0.300	0.129
pH	-0.300	0.129
Clay content	0.100	0.196

The highest cumulative net N mineralized was observed in soils amended with either PL or PM, which contained higher initial concentrations of total N. In an incubation study on the N mineralization behavior of 47 crop residues, Trinsoutrot et al. (2000) identified total N as the most influential factor in N dynamics. This is further supported by the positive correlation

(0.300) between total N and cumulative inorganic N that highlights the tendency of inorganic N levels to increase with increasing total N content.

2.5.6 Cumulative net nitrogen mineralized in relation to soil bulk density

The cumulative net N mineralized measured during 215 days (Figures 2.1.5 to 2.1.7) was expressed in terms of N mineralized on a monthly basis per hectare according to the different bulk densities of the soils incubated. The results of this conversion are given in Table 2.1.7. Due to their rocky nature, immature soils have lower bulk densities than mature soils, and despite having higher amounts of N mineralized, the amount of mineralized N per hectare tends to be lower than mature soils with higher bulk densities. For instance, when converted to hectare basis, the net amount of N mineralized for latosol and latosolic soils ranged from 26.4 to 30.5 kg N ha^{-1} and from 26.7 to 36.8 kg N ha^{-1} respectively.

In an *in situ* incubation done in Mauritius, the amount of N mineralized varied from 0.1 to 10.1 kg N ha^{-1} month^{-1} in an unfertilized L soil and from 2.4 to 15.7 kg N ha^{-1} month^{-1} in an unfertilized B soil (Anthony 1998). The reported figures are much lower than those obtained during the laboratory incubation for the L and B control soils. As shown by Table 2.1.7, for an L soil, 28.3 kg N ha^{-1} month^{-1} was recorded, while for the B soil, the monthly amount of N mineralized was 30.5 kg N ha^{-1} month^{-1}. Under laboratory conditions, the microcosm created is protected from N losses which, under field conditions are caused by leaching, denitrification, and in which soil N levels fluctuate with plant uptake. Weinhold (2007) found that even when the laboratory N mineralization rates were corrected with field temperatures, the estimated N mineralized was still higher than the measured rates *in situ*- 292 kg N ha^{-1} in the laboratory against 139 kg N ha^{-1} for the field trials with corers. Therefore, compared to the magnitude of N mineralization that may occur in field, the results obtained in the laboratory incubation may be overestimated. Nevertheless, laboratory incubations under controlled conditions remain a prerequisite to determine the nitrogen mineralization potential of soils, and also generate datasets for the calibration of models.

TABLE 2.1.7: Net nitrogen mineralized in five soil groups amended with three types of agricultural compost

Treatment	Net N mineralized over 215 days (mg kg^{-1} dry soil)†	Net N mineralized over 215 days (kg ha^{-1})	NetN mineralized (kg ha^{-1} month^{-1})
P soil bulk density (0–25 cm) : 1.02 g dw†† cm^{-3}			
P soil	74.2 ± 13.4	189.2 ± 34.2	26.4
P soil + filtercake	89.4 ± 22.7	228.1 ± 57.8	31.8
P soil + poultry manure-thrash	66.5 ± 0.9	169.7 ± 2.3	23.6
P soil + poultry litter	167.4 ±0.3	426.9 ± 0.7	59.6
B soil bulk density (0-30 cm): 0.83 g dw cm^{-3}			
B soil	87.8 ±17.5	218.5 ± 43.6	30.5
B soil + filtercake	136.8 ± 6.4	340.6 ± 16.0	47.5
B soil + poultry manure-thrash	109.2 ± 23.6	271.9 ± 58.8	37.9
B soil + poultry litter	198.4 ± 10.5	494.0 ± 26.1	68.9
L soil bulk density (0-30 cm): 0.97 g dw cm^{-3}			
L soil	69.8 ± 8.9	203.1 ± 25.8	28.3
L soil + filtercake	53.3 ± 0.1	155.1 ± 0.2	21.6
L soil + poultry manure-thrash	110.7 ± 18.6	322.3 ± 54.1	45.0
L soil + poultry litter	74.8 ± 3.8	217.6 ± 11.2	30.4
H soil bulk density (0-30 cm): 1.04 g dw cm^{-3}			
H soil	85.4 ± 8.3	263.9 ± 25.6	36.8
H soil + filtercake	97.0 ± 11.8	299.7 ± 36.6	41.8
H soil + poultry manure-thrash	197.0 ± 10.1	608.7 ± 31.2	84.9
H soil + poultry litter	178.4 ± 36.1	551.2 ± 111.5	76.9
F soil bulk density (0-30 cm): 0.98 g dw cm^{-3}			
F soil	65.2 ± 13.9	191.6 ± 40.9	26.7
F soil + filtercake	101.6 ± 31.7	298.8 ± 93.3	41.7
F soil + poultry manure-thrash	120.6 ± 7.4	354.6 ± 21.8	49.5
F soil + poultry litter	149.0 ± 25.7	438.1 ± 75.5	61.1

†dw; dry weight

2.5.7 Tests of significance of cumulative nitrogen mineralized

In the un-amended control treatment, the cumulative net N mineralized over 215 days, although numerically different across the five soil groups, was not statistically significant (P = 0.498) (Appendix IV and Appendix V). As shown in Table 2.1.8, relative to the control, a significant difference in cumulative net N mineralized was noted in all soil groups, except in the F soil group (P = 0.058). The latter had the highest C:N ratio (11.9) of the soil groups. Consequently, in the F soil, only PL that had the highest initial total N (3.66%), and OM content (43.02%), and the lowest C:N ratio (6.2) of three types of compost resulted in a significant increase in net N mineralized in the F soil (149.0 mg N kg^{-1} soil), relative to the control in which 65.2 mg N kg^{-1} soil was measured (Table 2.1.8). In the L soil, which is characterized by a high clay content (68.8%) and low OM content (2.63%), only PM which had a lower lignin content (86.9 g kg^{-1}) than FC (225.6 g kg^{-1}) and PL (228.0 g kg^{-1}) triggered a significantly high cumulative net N mineralized (110.7 mg N kg^{-1} soil) compared to the control (69.8 mg N kg^{-1} soil). Both PM (197.0 mg N kg^{-1} soil) and PL (178.4 mg N kg^{-1} soil) produced significant amounts of mineralized N in the H soil, when compared to the un-amended treatment (85.4 mg N kg^{-1} soil). In the immature P soil, only PL increased the concentration of N mineralized to significantly higher levels (167.4 mg N kg^{-1} soil) than the control (74.2 mg N kg^{-1} soil). However, both FC (136.8 mg N kg^{-1} soil) and PL (198.4 mg N kg^{-1} soil) lead to a statistically meaningful increase in inorganic N mineralized in the B soil, relative to the control (87.8 mg N kg^{-1} soil).

TABLE 2.1.8: Test of significance, coefficient of variation (CV) and least significance difference (LSD) of the effect of three agricultural composts on the net cumulative nitrogen mineralized in each soil incubated during 215 days

	Mean net cumulative nitrogen mineralized (mg kg^{-1} soil) †				
Treatment	**Latosolic Reddish Prairie (P)**	**Latosolic Brown Forest (B)**	**Low Humic Latosol (L)**	**Humic Latosol (H)**	**Humic Ferruginous Latosol (F)**
Control	74.2 ± 13.4a	87.8 ±17.5a	69.8 ± 8.9a	85.4 ± 8.3a	65.2 ± 13.9a
Filtercake (FC)	89.4 ± 22.7a	136.8 ± 6.4b	53.3 ± 0.1a	97.0 ± 11.8ab	101.6 ± 31.7ab
Poultry manure-thrash (PM)	66.5 ± 0.9a	109.2 ± 23.6ab	110.7 ± 18.6b	197.0 ± 10.1c	120.6 ± 7.4ab
Poultry litter (PL)	167.4 ± 0.3b	198.4 ± 10.5c	74.8 ± 3.8ab	178.4 ± 36.1bc	149.0 ± 25.7b
ANOVA	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P = 0.058$
CV (%)	2.0	10.9	10.2	14.4	14.6
LSD (0.05)	47.87	24.22	25.50	55.77	54.95

† Treatments sharing the same letter are not significantly different

2.5.8 Fluctuation in net nitrogen mineralization at each sampling date

The fluctuation in the net amount of N mineralized in amended and control soils at room temperature and controlled moisture over 215 days is given in Figures 2.1.8 to 2.2. Lower amounts of net N mineralized in amended soils compared to control soils infers that the addition of agricultural compost causes N immobilization. Similarly, higher amounts of net N mineralized in amended soils indicate increased N mineralization upon addition of compost.From Figure 2.1.8, it can be seen that the addition of FC to soil caused a negative priming effect whereby the level of inorganic N in the amended soils, indistinctive of the soil group, was low compared to the control soils. It is generally accepted that incorporated materials with C:N ratios wider than 10 cause negative priming effects while those with smaller C:N ratios cause positive priming effect and enhanced N mineralization (Nicolardot et al. 1986). Therefore, the mean C:N ratio of 9.2 ± 3.1 of FC may have accounted for the observed initial N immobilization. The period of N immobilization ranged from 35 days to 215 days. In all the soil groups, except the L group, the sequestration period was distinct and was followed by N mineralization till the end of the incubation. In the amended L soil, the amount of inorganic N remained lower than the control soil most of the time. The initial, relatively low total N content and higher C:N ratio of FC, as well as the high NH_4^+ fixing capacity of the clayey L soil may account of this observation.

The N immobilization-mineralization sequence in PM-amended samples was not as defined as for FC-amended samples (Figure 2.1.9). The first leaching event 11 days after compost application showed that the priming effect was negative in the mature L soil and the immature P soil, and positive in the H, F and B soils. In the immature soils, the addition of PM resulted in periodic N immobilization during 215 days and irregular N mineralization. This implies that in these soil types, the use of PM may not ensure a regular N supply to crops during the growing phase. In the mature soils, the amount of inorganic N remained higher than in the control soils throughout the laboratory incubation, indicating that a regular supply of N can be ensured to crops. A short N immobilization period of 20 days was observed in the L soil, but in contrast to the negative impact of FC on soil N mineralization, PM enhanced N mineralization after 20 days. Organic residues have been broadly characterized in terms of their polysaccharide contents, cellulose being the least resistant to microbial breakdown and polyphenol the most resistant (Shukla and Singh 1984). Located in the cell wall of plants, these carbon compounds constitute a protective barrier between microbes and the intracellular nitrogenous materials. In this context, the higher degradability of PM due to a lower lignin content than FC may have contributed to the increased N-supplying capacity of the L soil.

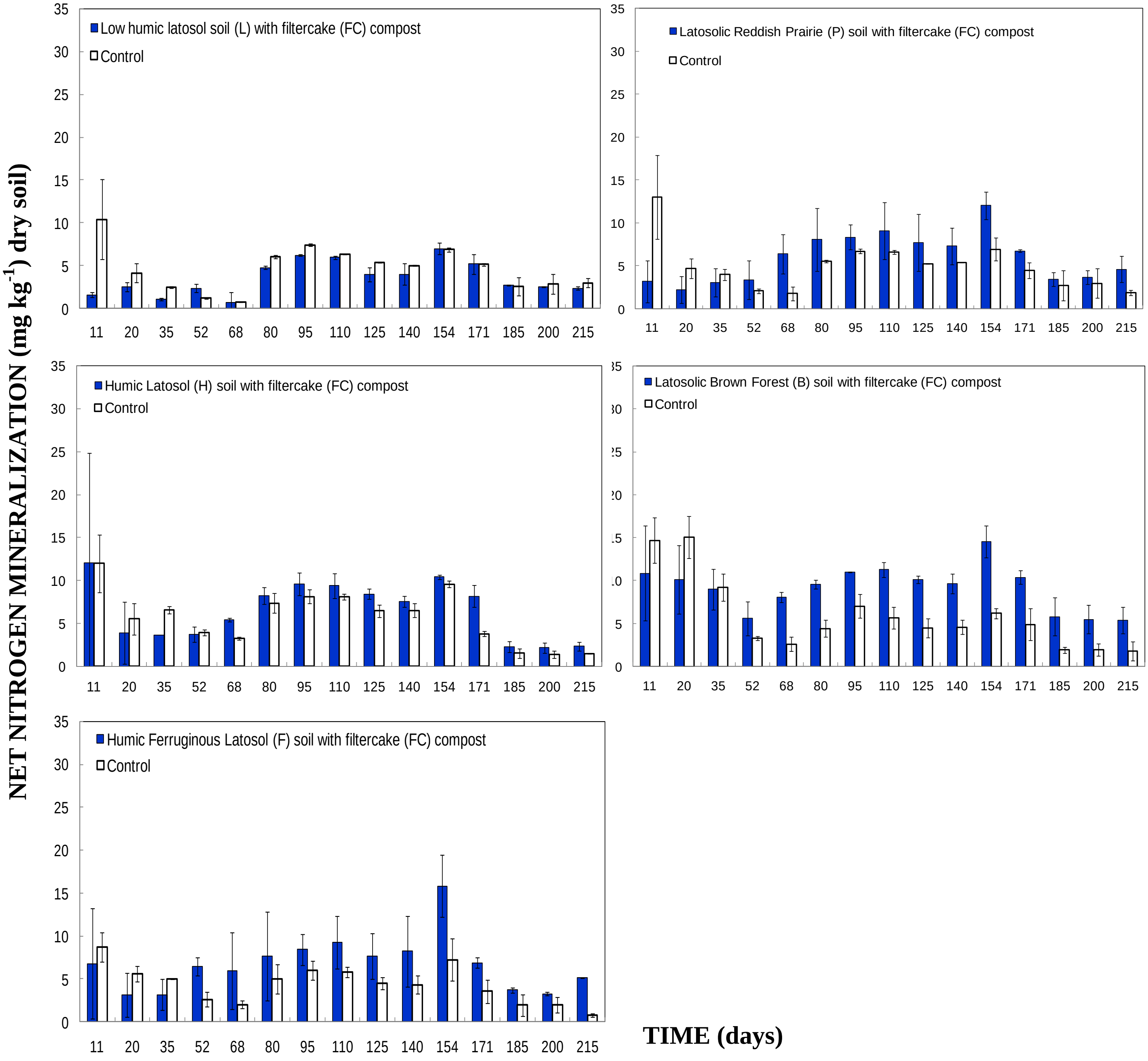


FIG. 2.1.8: Evolution of net nitrogen mineralized in soils amended with filtercake (FC) over 215 days

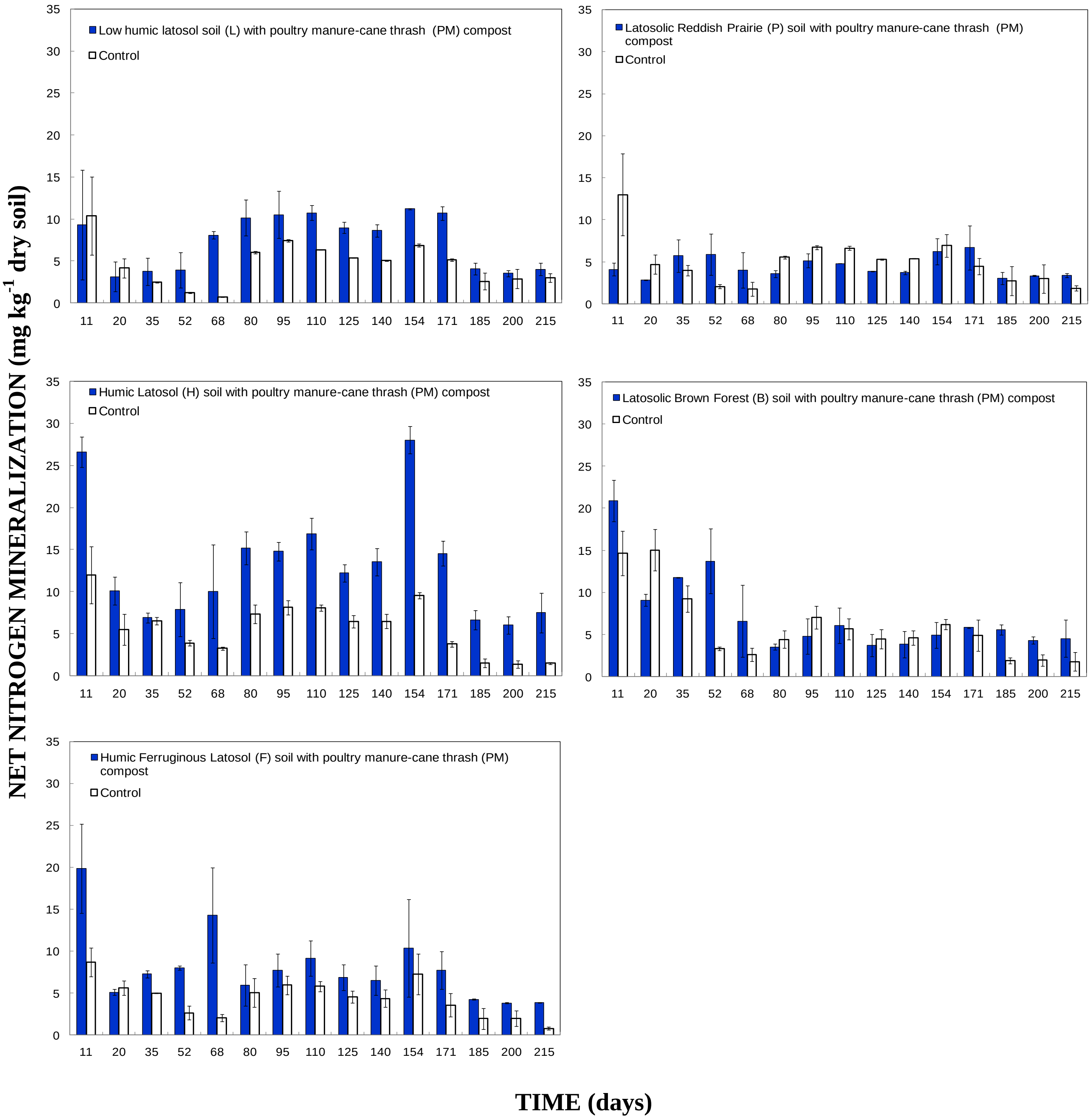


FIG. 2.1.9: Evolution of net nitrogen mineralized soils and soils amended with poultry manure-thrash (PM) over 215 days

A positive priming effect was noted in all the soils, except in the L group, amended with PL (Figure 2.2). During 215 days of incubation, inorganic N levels in amended soils were persistently higher than the control soils. While the continuous availability of N may be of interest for crop production, the potential risks of N losses to groundwater through leaching should be evaluated. In the past, lysimeter experiments have been initiated in Mauritius to study the effect of vinasse, bagasse ash and inorganic N fertilizers on the quality of groundwater (Ng Kee Kwong et al. 1986, Soobadar 2009). This technique could be used to study the risks of N leaching in compost-amended soils. It is an agreed fact that OM is a heterogeneous mix of faunal and floral residues that are biochemically differentiated, being composed of groups of organic substances that vary in their decomposition kinetics (Thuriès et al. 2002). Generally, it is assumed that OM consists of different pools that decompose and release N at varying points in time (Benbi and Richter 2002). These pools have been described in terms of their microbial turnover time as active, intermediate and passive (Sollins et al. 1996, Von Lützow et al. 2006). Therefore, high initial and persistent inorganic N release during the incubation in nearly all soils could be an indication that the OM pool in PL is mostly active in nature.

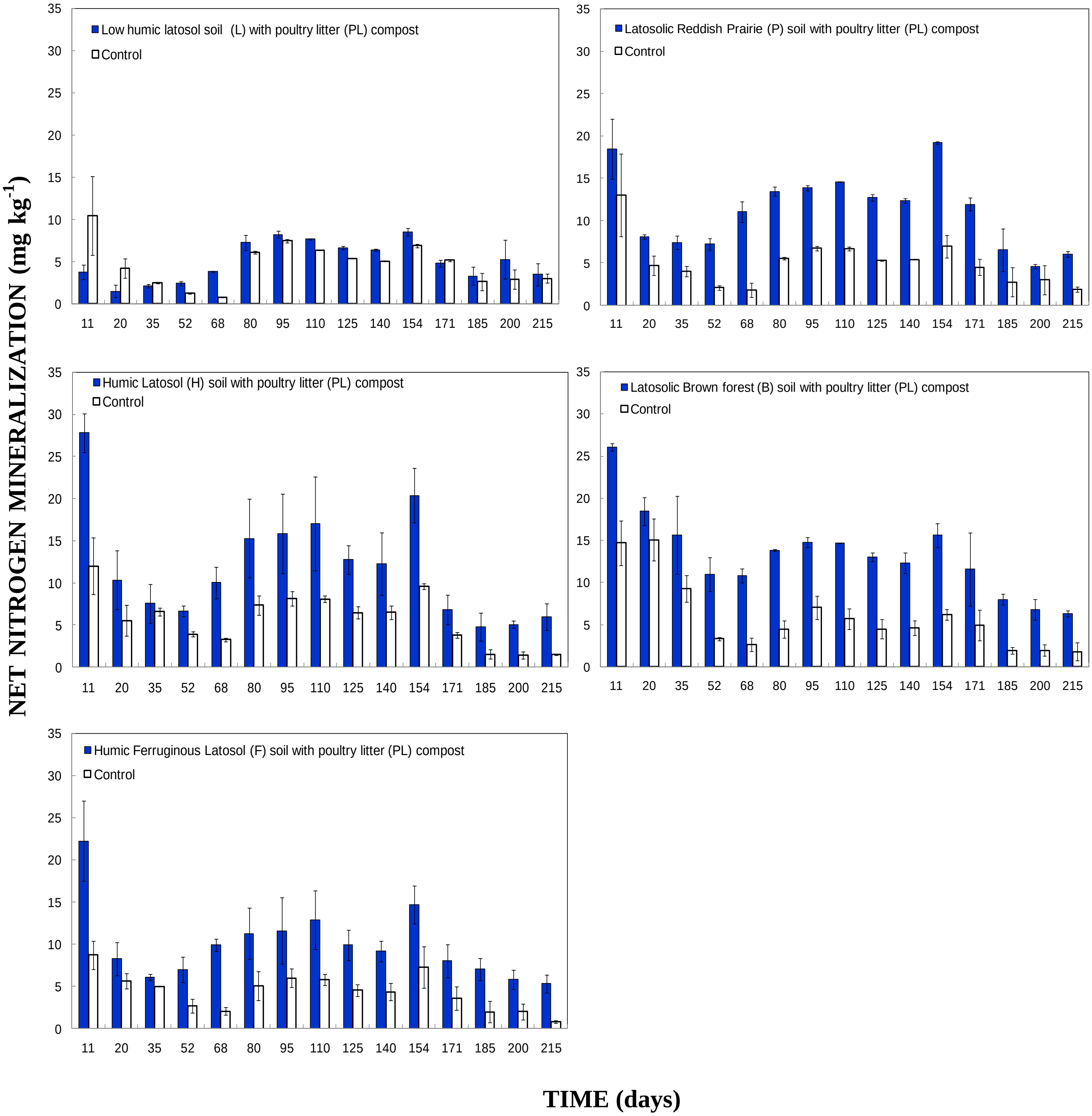


FIG. 2.2: Evolution of net nitrogen mineralized in soils amended with poultry litter (PL) over 215 days

2.5.8 Patterns of ammonification and nitrification in soils

The sequence of ammonification and nitrification in control soils and in soils amended with agricultural composts are depicted in Figures 2.2.1 to 2.2.4. In Figure 2.2.1, it can be seen that following an initial accumulation of NH_4^+ (day zero) that lasted over a maximum of 11 days, the amounts of NH_4^+ decreased drastically and the levels of NO_3^- increased simultaneously. The peaks in NO_3^- at day 11 and sudden drop in NH_4^+in the P soil (0.2 mg NH_4^+ kg^{-1} and 12.8 mg NO_3^- kg^{-1}) and L (0.3 mg NH_4^+ kg^{-1} and 10.1 mg NO_3^- kg^{-1}) indicate rapid rates of nitrification in these soils. However, in the H (6.7 mg NH_4^+ kg^{-1} and 5.3 mg NO_3^- kg^{-1}), B (8.4 mg NH_4^+ kg^{-1} and 6.3 mg NO_3^- kg^{-1}) and F (1.6 mg NH_4^+ kg^{-1} and 7.1 mg NO_3^- kg^{-1}) soils, appreciable levels of NH_4^+ could still be detected at day 11, and in the H soil up to day 20. It was observed that the accumulation of NH_4^+ occurred predominantly in soils that had a relatively low pH such as the H (6.04), the B (5.30), and F (5.31) soils. Similarly, in the P and L soils that had a near neutral pH of 6.36 and 6.31 respectively, the amounts of NH_4^+ ions receded quickly to NO_3^-. The trends in nitrification activities as a function of soil pH were also noted by Thangarajan et al. (2013). In a microbial count done on soils of varying pH, the authors found that acidic soils contained only 45 cells of nitriying bacteria g^{-1} dry soil, compared to 405 cells in neutral soils and 495 cells in alkaline soils. Therefore pH is an important parameter to consider in N mineralization studies.Across the five soil groups, the dominant form of N was nitrate (NO_3^-).

Across the five soil groups, $NO_3^-$was the main form of N liberated upon addition of FC (Figure 2.2.2). Because ammonification precedes nitrification, low levels NH_4^+ will be associated to a correspondingly high concentration of NO_3^-. The concentrations of NH_4^+ and NO_3^- in all FC-amended samples, except in the L group, were higher than in control soils. According to Thangarajan et al. 2013, the enhanced nitrification activity observed following the incorporation of an organic material in soil may be attributed to the intrinsic population of ammonia-oxidizing bacteria of the added material. In the L soil, the concentrations of the bioavailable forms of N dropped just after the addition of FC, and only started to increase after 68 days. However, the levels of both NH_4^+ and NO_3^- throughout the incubation remained lower than in the control soils, indicating microbial immobilization. A similar observation applied to the P soil whereby the levels of NH_4^+ and NO_3^- decreased upon input of FC and only started to increase after 52 days.As noted in the control soils H, B and F, accumulation of NH_4^+ also occurred in the same soils when amended with FC. The latter compost is acidic in nature (pH 5.68) and in low pH soils like the H, B and F soils, may have slowed down the oxidation of NH_4^+ to NO_3^-. Reduced activities of nitrifiers in acidic soils is consistent with the findings of Khalil et al. (2005).

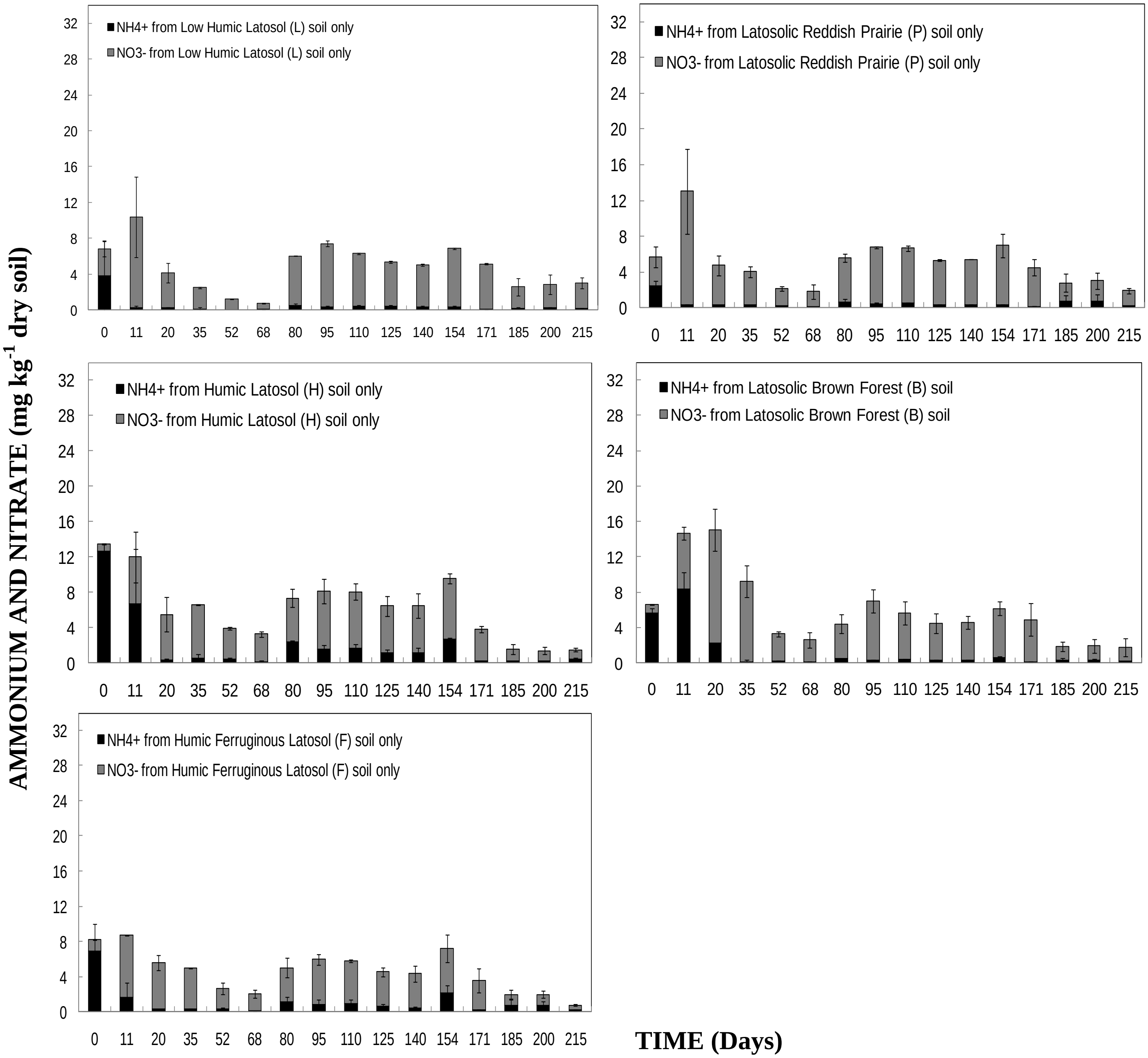


FIG. 2.2.1: Ammonification and nitrification in control soils of Low Humic Latosol (L), Latosolic Reddish Prairie (P), Humic Latosol (H), Latosolic Brown Forest (B), and Humic Ferruginous Latosol (F)

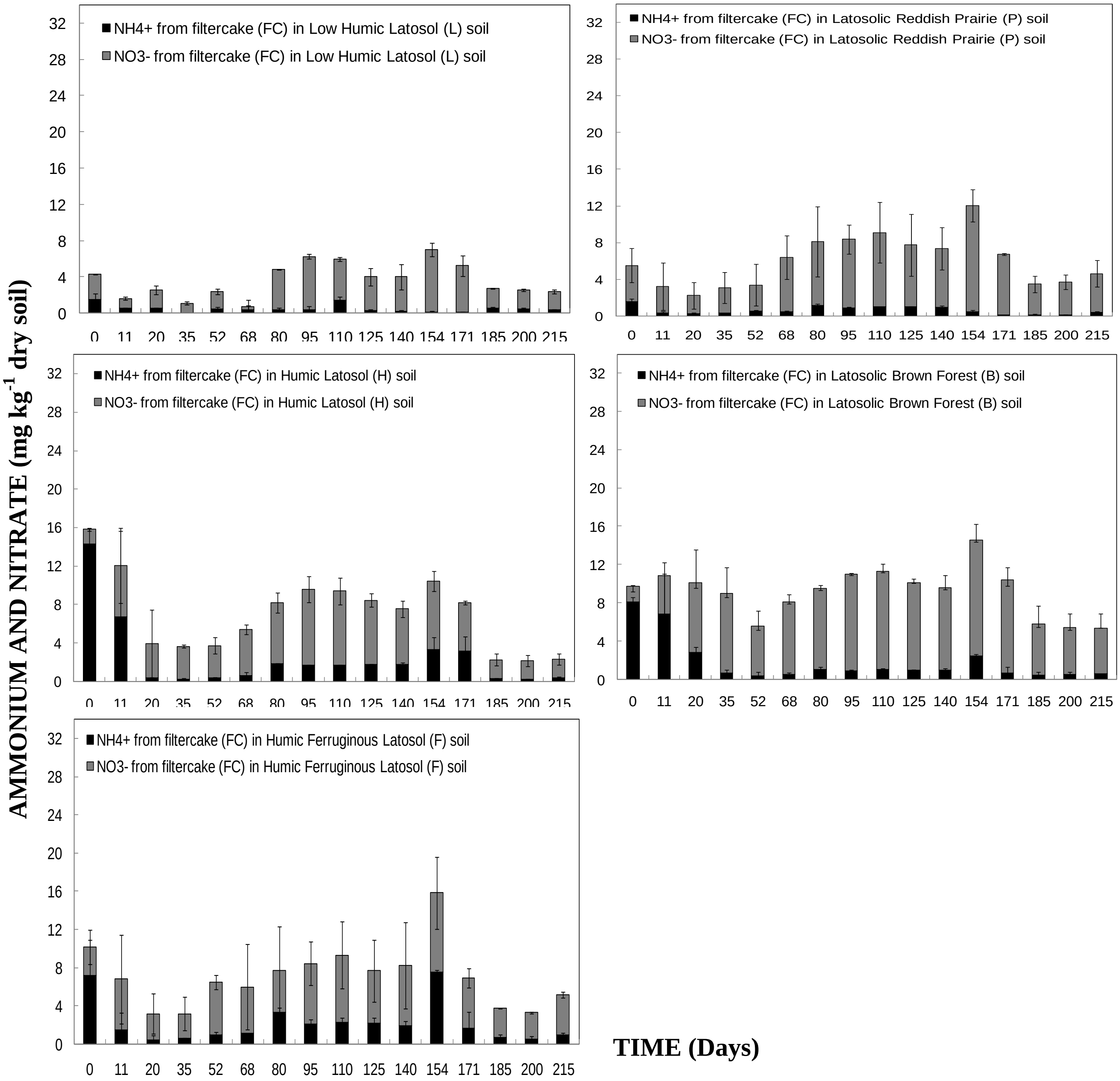


FIG. 2.2.2: Ammonification and nitrification in Low Humic Latosol (L), Latosolic Reddish Prairie (P), Humic Latosol (H), Latosolic Brown Forest (B), and Humic Ferruginous Latosol (F) amended with filtercake

According to Mubarak et al. (2010), high concentrations of NH_4^+ following the incorporation of compost in soils indicate fast break down of OM. Based on this statement, it was observed in Figure 2.2.3 that 11 days after the application of PM, the levels of NH_4^+ in the H and B soils were higher than in control soils and soils amended with FC. In the L and F soils, an initial peak was also noted, but in these two cases, N was present as NO_3^-. Whilst NO_3^- was dominant in the P soil, the concentrations remained lower than in the control and FC-amended samples.

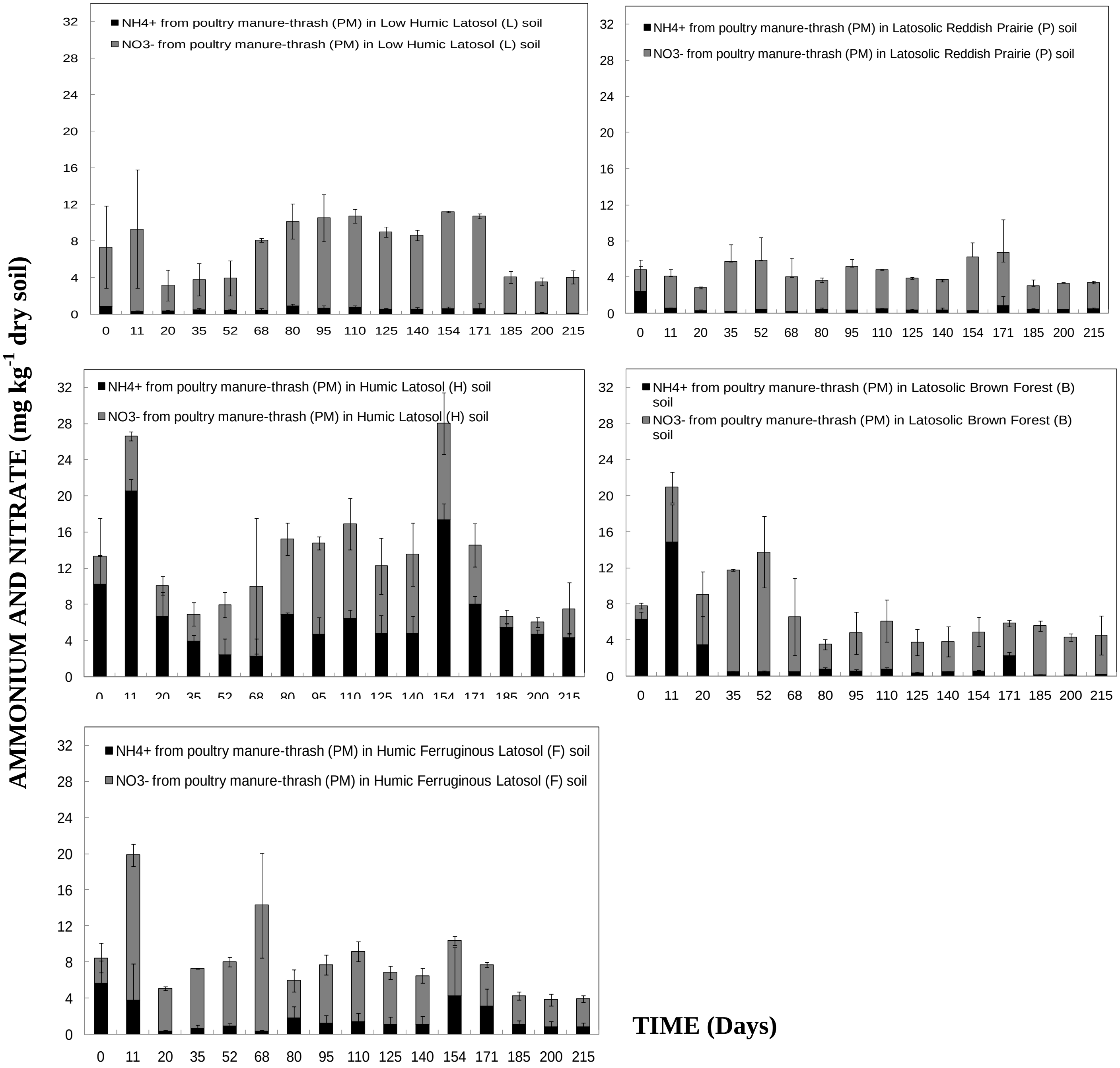


FIG. 2.2.3: Ammonification and nitrification inLow Humic Latosol (L), Latosolic Reddish Prairie (P), Humic Latosol (H), Latosolic Brown Forest (B), and Humic Ferruginous Latosol (F) amended with poultry manure-thrash

Ammonification did not follow a general pattern, the production of NH_4^+ being continuous during 215 days in the H soil, and remaining very low in the L and P soils throughout the incubation. In the B and F soils, after an initial peak in NH_4^+, ammonification dropped to a lagphase of 68 days before increasing again.

The addition of alkaline products to acidic soils has been reported to promote the actvity of nitrifying bacteria (Thangarajan et al. 2013). However, when PM which is alkaline in nature (pH of 9.46) was added to the acidic B soil, the concentration of NO_3^- produced was even less than in filtercake-amended samples. In another acidic soil F (pH 5.31), the levels of NO_3^- indeed increase following the incorporation of PM.These contrasting effects of PM on nitrification imply that that there are more important chemical parameters than pH that influence nitrification (Er et al. 2004).

The ammonification and nitrification data shown in Figure 2.2.3 are of agronomic and environmental significance as they indicate the periods and span of N availability. For instance, it is known that when applied at the surface, N-rich products are susceptible to N losses by volatilization. In the H soil, the NH_4^+ form dominates and ammonification is continuous over 215 days. Therefore, to maximize N retention, incorporation of PM would be recommended in the H soil. Moreover, if used as the main source of N, it would be best to apply PM several weeks after planting so that the crop benefits from the continuous N being mineralized. Compost application prior planting may increase the risks of N losses by leaching. In the L soil, the concentrations of both NH_4^+ and $NO_3^-$are relatively low between day 20 and day 52 of compost addition. Therefore, for crops with long cycles like sugarcane, application of compost at planting would be pertinent because the delayed release of NH_4^+ and NO_3^- would coincide with the period of maximum N uptake by the crop. In contrast, the application of PM could be delayed in both the B and F soils because of the appreciable levels of bioavailable N released after mixing with the soil. Poultry manure-thrash may not be a good source of N to crops when applied in the P soil because of the consistently low levels of NH_4^+ and NO_3^- measured.

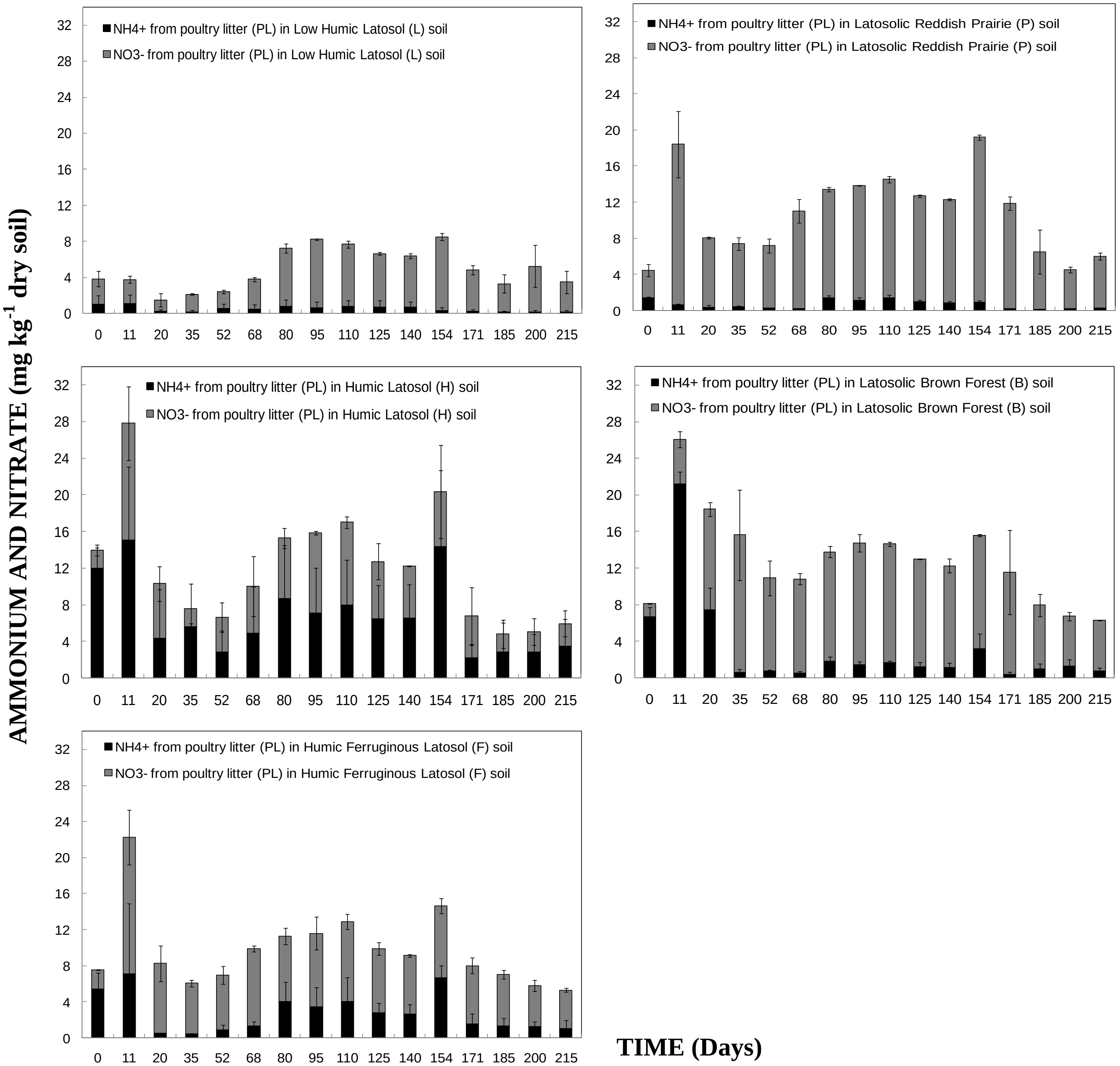


FIG. 2.2.4: Ammonification and nitrification in Low Humic Latosol (L), Latosolic Reddish Prairie (P), Humic Latosol (H), Latosolic Brown Forest (B), and Humic Ferruginous Latosol (F) amended with poultry litter

In PL-amended soils(Figure 2.2.4), a strong initial increase in the levels (mg kg^{-1} dry soil) of NH_4^+ and NO_3^- was recorded in soils such as P (0.7 NH_4^+ and 17.8 NO_3^-), H (15.1 NH_4^+ and 12.8 NO_3^-), B (21.2 NH_4^+ and 4.9 NO_3^-) and F (7.1 NH_4^+ and 15.1 NO_3^-), but not in the L soil

(1.0 NH_4^+ and 2.7 NO_3^-). In the P, H and F soils, the sudden increase in bioavailable N was followed by a decrease in the concentrations of NO_3^- and NH_4^+ that persisted up to day 52 before increasing again. In the B soil, the drop in NO_3^- and NH_4^+ observed was not sharp and during 171 days, the concentrations of ions remained consistently high before starting to decrease at day 185. In the L soil, the concentrations of ions dropped after the addition of agricultural compost and only started to rise again after a lag phase of 68 days. The slow initial ammonification observed in the L soil amended with PL is similar to that noted when FC was applied.

The main form of N was NO_3^- in all soils except in the H group where higher levels of N-NH_4^+ were observed. The persistent accumulation of NH_4^+ throughout the incubation indicates rapid decomposition of OM after the addition of PL, but also implies that the rate of ammonification is higher than the rate of nitrification in the H soil. The pattern and magnitude of ammonification and nitrification in soils amended with PL show that this compost may be a potential source of N for cops. Because, NH_4^+ levels tend to be high in soils amended with PL, it is highly recommended to incorporate PL instead of broadcasting on the soil surface to prevent heavy volatilization losses, particularly in alkaline soils.

2.5.9 Nitrogen mineralization potential

Potentially mineralizable N (N_0) is described by Stanford and Smith (1972) as the amount of soil organic N that may become plant-available over time at a given rate of mineralization (k) based on first-order kinetics. As pointed out by Tesfamariam et al. (2012), the use of the Stanford and Smith (1972) equation enables the expression of measured data during laboratory incubation in terms of the natural logarithm of N decay with time. In this study, the N_0 determined for the major soils under sugarcane cultivation amended with agricultural composts can in future works, be used to assess the robustness of chemical indices to predict N mineralization. According to Table 2.1.9, the N_0 of soils of Mauritius (un-amended) ranged from 93.6 to 137.8 mg N kg^{-1} dry soil while the rate of Nmineralization was between 0.004 and 0.013 day^{-1}. In soils amended with compost, the N_0 ranged from 113.5 to 606.1 mg N kg^{-1} dry soil and the k constant from 0.001 to 0.014 day^{-1}. The quantification of inorganic N susceptible to mineralization on a daily basis cannot be achieved by considering N_0 and k values individually. Therefore, the N_0 values were multiplied by the corresponding rate constants k to indicate N availability in the different treatments. The index of N availability, N_0k showed that in control soils, the daily N availability (mg N kg^{-1} soil day^{-1}) was in the order B (1.242) > H (0.975) > F (0.674) > P (0.637) > L (0.524). The relatively high N availability in the B soil may explain why sugarcane cultivated on this soil are lowly responsive to increments in N fertilizer (MSIRI 1986). Relative to the N_0k of control soils, FC reduced N availability (mg N kg^{-1} soil day^{-1}) in soils, in the order, B (0.933) > H (0.881) > F (0.674). The N_0k obtained for soils treated with PM recalls the relatively poor effect of this agricultural compost on the cumulative concentration of N mineralized in the P soil. In other soil groups, despite a reduced rate of N mineralization, the increases in N_0 lead to a higher daily N availability (mg N kg^{-1} soil day^{-1}) than the control soils, namely B (1.600) > H (1.327) > F (1.168) > L (0.667) > P (0.454). Similar observations were made for samples amended with PL, whereby the increased N_0 compensated the decreased k constants. In these samples, the magnitude of N availability was in the order B (1.748) > H (1.533) > F (1.130) > P (0.982).

It was observed earlier that the addition of FC and PL to the L group both resulted in a net amount of N mineralized lower than in the control soil. In these two treatments, and in the P soil amended with FC, the measured data did not fit the exponential equation of Stanford and Smith (1972) and the values of N_0 and k could not be determined. The unsuitability of the first-order exponential function for certain treatments is consistent with observations of Schomberg et al. (2009) in soils subjected to different tillage treatments. Similarly, in some Australian soils amended with chicken manure and biosolids, the measured data did not fit the model (Thangarajan et al. 2013). Interestingly, it was noted that the equation was unsuitable when FC and PL, composts containing 22.6% and 22.8% lignin respectively, were used in specific soil groups (L and P groups). On comparing the kinetic model proposed by Stanford et al. (1974) to a first order model with two mineralizable organic N pools, Seyfried and Rao (1988) obtained better fits with measured data. This finding is further supported by studies that highly recommend the consideration of at least two mineralizable N pools in the simulation equation (Molina et al. 1980, Diaz-Fierros et al. 1988). In fact, every living system is subject to instability, the source of instability being in the incubation experiment the input of agricultural composts, and when this occurs, the statistical model built by the functional approach can be inappropriate (Chertov and Komarov 2013).

TABLE 2.1.9: Estimates of nitrogen mineralization potential, rate constant and half-life for different treatments

Parameter	Latosolic Reddish Prairie (P)	Latosolic Brown Forest (B)	Low Humic Latosol (L)	Humic Latosol (H)	Humic Ferruginous Latosol (F)	Mean†
N_0 (potentially mineralizable N, mg N kg^{-1} soil)						
Control	115.8	96.7	137.8	121.8	93.6	113.1
Filtercake	-	310.9	-	172.7	511.7	331.8
Poultry manure-thrash	151.2	113.5	606.1	457.5	162.2	298.1
Poultry litter	545.4	277.5	-	283.8	256.7	340.9
Mean	270.8	199.7	372.0	259.0	256.1	
K (First-order rate constant, day^{-1})						
Control	0.005	0.013	0.004	0.008	0.007	0.007
Filtercake	-	0.003	-	0.005	0.001	0.003
Poultry manure-thrash	0.003	0.014	0.001	0.003	0.007	0.006
Poultry litter	0.002	0.006	-	0.005	0.004	0.004
Mean	0.003	0.009	0.002	0.005	0.005	
N_0 . k (mg N kg^{-1} soil day^{-1})						
Control	0.637	1.248	0.524	0.975	0.674	0.812
Filtercake	-	0.933	-	0.881	0.614	0.809
Poultry manure-thrash	0.454	1.600	0.667	1.327	1.168	1.043
Poultry litter	0.982	1.748	-	1.533	1.130	1.348
Mean	0.691	1.382	0.595	1.179	0.896	
Half-life (days)						
Control	126	53	182	87	96	109
Filtercake	-	231	-	136	578	315
Poultry manure-thrash	231	49	630	239	96	249
Poultry litter	385	110	-	128	157	195
Mean	247	111	406	147	232	

The half-life, time taken for half of the total amount of organic N to mineralize, has been calculated for the different treatments. For control soils, the half-lives ranged from 53 to 126 days. The estimated half-lives indicate that in un-fertilized, but disturbed Mauritian soils, organic N turnover tends to be fast. Whilst a plant cane might benefit from the rapid N turnover that occurs in an unfertilized soil at planting, the rapidly declining soil reserve of organic N will be detrimental to the crop in the following ratoon. Numerous studies have shown that there were no significant yield differences between an unfertilized and a fertilized field for a plant cane (Parish and Feillafé 1962). The yield difference only becomes apparent in the first ratoon. The short half-life of soil organic N further supports this observation. Except in B soils treated with PM, the half-life of organic N considerably increased when additional OM in the form of compost was incorporated in soil. With FC, the half-life observed was in the range of 136 to 578 days, while a range of 49 to 630 days was obtained with PM and 110 to 385 days with PL.

2.6 Percentage of organic nitrogen mineralization from compost

In Figure 2.2.5, the net N mineralized from compost and soil organic N has been expressed in terms of the total organic N in soil plus the added organic N from compost. In general, the percentage of N mineralization in control soils, varied from 2% to 4%, relative to the initial stock of soil organic N. Hartz et al. (2000) reported similar organic N mineralization values that varied from 1.9% to 2.5% for non-amended soils. It can be appreciated that the input of FC in soil promoted the mineralization of organic N from soil and compost, and may therefore enhance N availability to the crop. Between 2% and 5% of the organic N from soil and FC mineralized. However, in the clayey L soil, FC depressed N mineralization when compared to the non-amended control soil. Applied in the weathered soil groups (H, L and F), PM resulted in an appreciable increase in organic N mineralized that varied between 6% and 9%. However, compared to the effect of PM and PL on net N mineralization, PM had a relatively mitigated impact in the less weathered P and B soils. While net N immobilization was observed in the PM-amended P soil, the increase in N mineralized in the B soil was relatively low compared to the non-amended control soil. Across the soil groups amended with PL, from 4% to 8% of the total organic N mineralized. Only in the L soil did N immobilization occur when PL was applied.

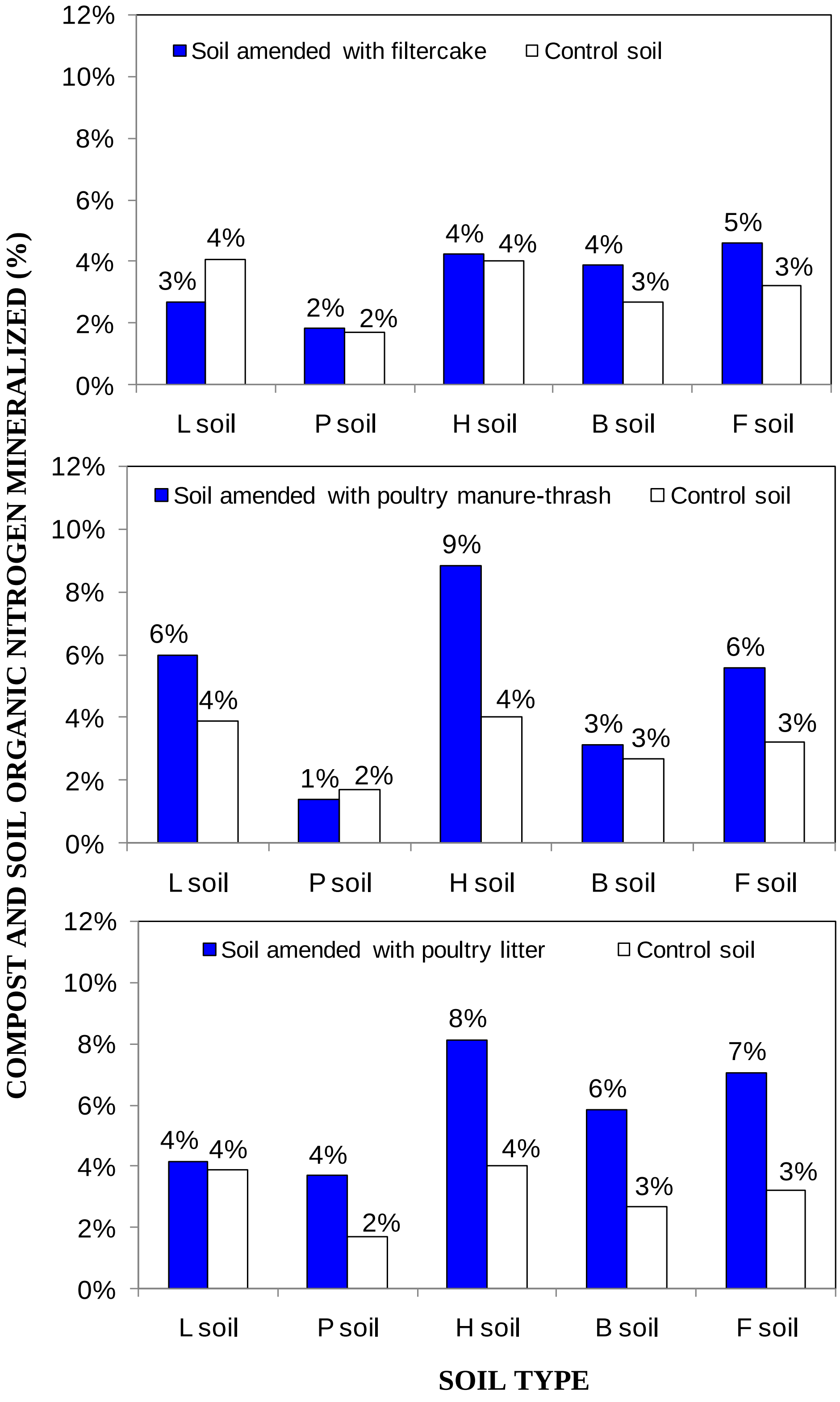


FIG. 2.2.5: Percentage of total organic nitrogen (soil and compost) mineralized in Low Humic Latosol (L), Latosolic Reddish Prairie (P), Humic Latosol (H), Latosolic Brown Forest (B), and Humic Ferruginous Latosol (F)

2.7 Conclusion

The laboratory incubation study initially aimed at determining the pattern and rate of NH_4^+ and NO_3^- release of three different agricultural composts in five major Mauritian soil groups under sugarcane cultivation, and characterizing the nature of the relationship existing between C:N ratio and OM and N mineralization. The quantification of inorganic N showed that over 215 days, the net amount of N mineralized in control soils ranged from 65.2 to 87.8 mg N kg^{-1} dry soil. The monthly N mineralization varied from 26.4 to 36.8 mg N kg^{-1} dry soil.There were no significant differences (at the 5% level) in the cumulative net N mineralized between the five main control soil groups.

The addition of compost to soils caused a significant increase ($P < 0.05$) in the magnitude of N mineralization in soils. The immature (latosolic) soils B and P mineralized greater amounts of N than the mature (latosols) soils, at the exception of the H soil. This observation is in agreement with a three-week incubation study of the MSIRI (1971) on the N mineralization profile of Mauritian soils, whereby mature soils were described as having arelatively low N mineralization power. Indeed, compared to the mature soils, the immature soils had a higher total N and OM content which may have contributed to the higher cumulative net N mineralized observed.

In general, the three agricultural composts studied influenced positively N mineralization in soils, and in most cases, the magnitude of N mineralization after 215 days of incubation wasgreater than in control soils. FC improved the net cumulative amount of N mineralized (in mg N kg^{-1} dry soil) of all soils except the L group in the order, B soil (136.8) > F (101.6) > H (97.0) > P (89.4) > L (53.3). Poultry manure-thrashalso increased the indigenous inorganic N mineralized from soil, the cumulative N mineralized observed (mg N kg^{-1} dry soil) being H (197.0) > F (120.6) > L (110.7) > B (109.2) > P (66.5). However, the effects of PM on N mineralization in the immature soil P wasrelatively mitigated, and may not ensure a regular N supply to crops during the growing phase. As for PL, positive effects on N mineralization (mg N kg^{-1} dry soil) were observed in all soils, except the L group, and was in the order, B (198.4) > H (178.4) > P (167.4) > F (149.0) > L (74.8). While the continuous availability of N may be of interest for crop production, the potential risks of N losses to groundwater through leaching, and to the atmosphere via volatilization should be evaluated. In each soil group, only specific types of agricultural composts resulted in a statistically significant ($P < 0.05$) increase in cumulative N mineralized, relative to the control: PM in the L group, PM and PL in the H group, PL in the F group, PL in the P group, and FC and PL in the B group.

The Spearman's correlation coefficients showed a negative correlation (-0.100) between C:N ratio and inorganic N mineralized in control soils. This implies thatthe higher the C:N ratio of soil, the lower the indigenous N mineralized from soil. The relatively low amount of net N mineralized in the high C:N ratio (11.9 ± 0.3) F soil supports this observation.The highest net N mineralized was observed in soils amended with either PL or PM, which contained higher initial concentrations of total N. The positive correlation (0.300) between total N of control soils and cumulative inorganic Nhighlights the tendency of inorganic N levels to increase with increasing total N content. Except in H soils amended with PM and PL in which NH_4+ was the dominant form of N, NO_3^- predominated in all the treatments. Because, NH_4^+ levels tend to be high in soils amended with PL compost, it is highly recommended to incorporate PL instead of broadcasting on the soil surface to prevent heavy volatilization losses.

The index of N availability, N_0k showed that in control soils, the daily N availability (mg N kg^{-1} soil day^{-1}) was in the order B (1.242) > H (0.975) > F (0.674) > P (0.637) > L (0.524). The relatively high N availability in the B soil may explain why sugarcane cultivated on this soil are lowly responsive to increments in N fertilizer (MSIRI 1986). Interestingly, it was noted that the first order exponential equation Stanford and Smith (1972) was unsuitable when FC and PL composts containing 22.6% and 22.8% lignin respectively, were used in specific soil groups (L and P groups). In other FC-amended samples, although N_0 was higher than for control soils, the rate of N mineralization was lower, resulting in reduced N availability. However, in soils treated with PL and PM, despite a reduced rate of N mineralization, the increases in N_0 lead to a higher daily N availability than the control soil.

The estimated half-lives for control soils ranged between 53 and 126 days, indicating that in un-fertilized, but disturbed Mauritian soils, organic N turnover tends to be fast. Whilst a plant cane might benefit from the rapid N turnover that occurs in an unfertilized soil at planting, the rapidly declining soil reserve of organic N will be detrimental to the crop in the following ratoon.Except in B soils treated with PM, the half-life of organic N considerably increased when additional OM in the form of compost was incorporated in soil. With FC, the half-life observed was in the range of 136 to 578 days, while a range of 49 to 630 days was obtained with PM and 110 to 385 days with PL.

Over 215 days, the percentage of organic N mineralization in control soils, varied from 2% to 4%. Between 2% and 5% of the total N from soil and compost mineralized in FC-amended soils. In the clayey L soil, FC depressed N mineralization relative to the non-amended control soil. Applied in the weathered soil groups (H, L and F), PM resulted in an appreciable increase in organic N mineralized that varied between 6% and 9%. However, in the immature soil, PM had a relatively mitigated effect, with 1% of total N mineralization in the amended P soil, and 3% in the B soil. Across the soil groups amended with PL, from 4% to 8% of the total organic N mineralized. Only in the L soil did N immobilization occur when PL was applied.

CHAPTER 3: COMPOST NITROGEN BIOAVAILABILITY UNDER FIELD CONDITIONS

During the last decade, the average yield of sugarcane in Mauritius has declined. This phenomenon has been partly attributed to the impoverishment of soils resulting from the shift from manual cultural practices that left the field's fertile topsoil undisturbed to mechanized operations and intensive tillage. Soil organic matter (SOM) is known to promote the soil's biological, physical, and chemical properties through the preservation of microbial biomass, soil structure and cation exchange capacity (CEC) (Huber and Schaub 2011). However, under disturbed soil conditions, organic matter (OM) undergoes faster oxidation, leading to a decline in soil biota, structure and fertility. The escalating dependence on inorganic nitrogenous fertilizers at the expense of organic materials has further exacerbated the effects of OM losses and nitrogen (N) mining on soil fertility. It is well-known that the systematic use of inorganic fertilizers acidifies agricultural soils in the long run (Meng et al. 2013), and may cause a drop in cane yield. To perpetuate sugarcane yields and the fertility of cultivated soils, it is important to ensure that management practices are sustainable to replenish the dwindling stocks of OM, and conserve the fertility of Mauritian soils in the long term. Bholah (2008) confirmed the poor residual value of fertilizer N in soil and the need to consider organic sources of N for sustainable sugarcane production. When compost is used to counteract soil impoverishment and supply crop nutrients, it is crucial to understand the dynamics of nitrogenous compounds to optimize N uptake. In the absence of a suitable predictive capability to forecast organic N mineralization, the application of compost to soils with different chemical properties may result in over- or under-fertilization. Whilst under-fertilization may lower crop yield, over-fertilization is linked to the contamination of aquifers and eutrophication.

In Mauritius, based on Blackburn's (1984) root system architecture, it was established that the density of sugarcane's superficial roots was greatest along a vertical soil profile of 0.15 to 0.20 m. At planting, it is common practice to apply nitrogenous fertilizers such as mono-ammonium phosphate, di-ammonium phosphate, urea, Calcium Ammonium Nitrate, or 14-20-20 (NPK blend) in the cane row at planting. However, applied at this stage, inorganic fertilizers supply high amounts of nutrients that exceed the crop's initial demands, and in the absence of a well-developed root system, the uptake of nutrients is minimal. There is therefore concern about mobile ions such as nitrate (NO_3^-) leaching from the root zone during heavy rainfall (Weitz et al. 2001). Leaching losses of NO_3^- would adversely affect the crop's N use efficiency and also have a negative environmental impact. To evaluate the concentrations of inorganic N in a soil profile of 0.20 m during the four months following planting, anion and cation exchange resins were therefore placed at the base of the Polyvinyl Chloride (PVC) corers, to a soil depth of 0.20 m. Because of the absence of a rooting system at planting, the concentrations of inorganic N trapped by the resins will also indicate potential N losses that may occur when inorganic, organic or combinations of inorganic and organic fertilizers are used.

Laboratory conditions are not always representative of those in the field, especially when soil is disturbed during sampling and sieving (Raison et al. 1987). Field trials were therefore laid out to determine the changes in soil inorganic N in three major soil groups under sugarcane cultivation in Mauritius amended with threetypes of agricultural composts (filtercake- FC, poultry manure with sugarcane trash- PM and poultry litter- PL). World-wide, numerous field experiments using a range of organic materials have strongly underlined the need to determine N release under site-specific conditions before a successful integrated fertilization programme can be devised and implemented (Zou et al. 1992, Weinhold 2007, Abera et al. 2012).

Hypothesis

(a) The combined use of inorganic fertilizer together with compost to meet the N requirements of sugarcane will produce equal cane and sucrose yields as when using inorganic fertilizers only.

(b) Leaching losses of $N\text{-}NO_3^-$ in soils are agronomically insignificant in soils under sugarcane cultivation.

Major chapter objectives

(a) To investigate the changes in soil inorganic N under field conditions when compost is applied as the single source of N or is used in combination with inorganic N fertilizers.

(b) To evaluate the influence of soil and compost chemical and physical properties on N mineralization in compost-amended soils.

(c) To determine the residual effect of compost N on sugarcane yield in first ratoon cane.

(d) Potential N losses out of the active root zones were also evaluated.

3.1 Treatment description

Three experimental sites on commercial farms were selected to investigate N bioavailability, and determine sugarcane yields in fields amended with composts and combinations of compost and inorganic fertilizers.The Humic Latosol (H), Low Humic Latosol (L) and Latosolic Reddish Prairie (P) soil groups, being the most common groups under sugarcane cultivation in Mauritius, were chosen. As indicated by Figure 3.1, fields with soil of the L and P groups were located on the western side of the island, at Chebel (20°12'33.14"S and 57°27'42.10"E) and Pierrefonds (20°17'13.88"S and 57°26'35.34"E) respectively, and were part of the property of Médine Ltd. In this sub-humid region, sugarcane is grown under irrigation. The selected H soil group was found in the south, at Britannia (20°27'27.85"S and 57°34'05.84"E), where rainfall is relatively high and sugarcane is cultivated under rainfed conditions.

Before the implementation of the trials, three composite soil samples from each of the three trial sites were collected to a depth of 0.30 m (except at Pierrefonds, for the P soil group, where the degree of rockiness restricted sampling to a depth of 0.25 m) and characterized chemically and physically according to the analyzes described in the Sections 2.2 and 2.3 (Chapter 2) respectively. In all treatments, the recommended rates of phosphorus (P) - and potassium (K) - based fertilizers were applied according to soil tests done before planting (Appendix VI). In sugarcane cultivation, P fertilizers are usually applied at planting only, while K is applied in plant cane and after harvest in ratoon cane. Phosphorus and K were extracted with 0.1M sulphuric acid (Cavalot et al. 1988; Murphy and Riley 1962; Anon 1986), and where the P content of soil exceeded 80 mg kg^{-1} soil, and the K levels were above 0.5 m.e %, as at

Pierrefonds, P and K fertilizers were not applied in the plant cane and first ratoon. At Chebel and Britannia, P fertilizer was applied at planting only at the rates corresponding to the P test value (Appendix VI). The K fertilizer was added in all treatments at rates corresponding to the K test value in the plant cane and successive ratoons. Soil pH (water) is corrected for values lower than 5.0, so at Britannia (H soil group), the soil pH was amended by applying lime to the plant crop at a rate of 4.8 t ha^{-1}.

Legend

🟥 ● Chebel: Low HumicLatosol (L)
🟩 ▲ Pierrefonds: Latosolic Reddish Prairie (P)
🟥 ■ Britannia: HumicLatosol (H)

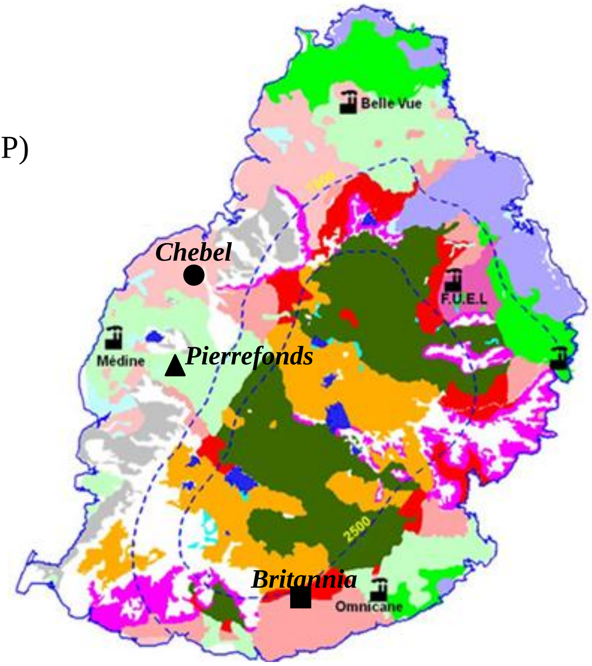


FIG. 3.1: Map of Mauritius showing the location of the three experimental sites within commercial fields at Chebel, Pierrefonds and Britannia

In Mauritius, the rate of N recommended for application in either plant cane or ratoon cane aims at ensuring maximum sugarcane yields at a cost of production that will remain profitable to the farmer. Depending on the costs of production (price of N fertilizer, harvest and transport costs) and yield response to applied N fertilizer, the recommended amount of N to apply is reviewed yearly, and may vary from 1.2 to 1.6 kg N per expected ton of millable cane. To standardize the experiment with regards to N across the three sites, 140 kg N ha^{-1} was applied in different forms according to the treatments to achieve maximum yield in both plant and ratoon canes. At each site, eight treatments were initiated and replicated three times. The treatments were as follows:

Treatment 1	Inorganic fertilization to supply 140 kg N ha^{-1}
Treatment 2	Inorganic fertilization to supply 105 kg N ha^{-1} and FC to supply 35 kg N ha^{-1}
Treatment 3	Inorganic fertilization to supply 105 kg N ha^{-1} and PM to supply 35 kg N ha^{-1}
Treatment 4	Inorganic fertilization to supply 105 kg N ha^{-1} and PL to supply 35 kg N ha^{-1}
Treatment 5	FC only to supply 140 kg N ha^{-1}
Treatment 6	PM only to supply 140 kg N ha^{-1}
Treatment 7	PL only to supply 140 kg N ha^{-1}
Treatment 8	Zero inorganic N fertilizer or compost (control)

The rates of compost used were based on the total N content determined during chemical characterization and the assumption that 50% of this will become plant-available in the short-term (Chabalier et al. 2006). Therefore, for the treatments twoand three, the rates of compost were calculated to supply 70 kg N ha^{-1}. The ratio of inorganic and organic fertilizers in treatments twoandthree was based on the study of Soomro et al. (2013) whereby sugarcane yields were maximized with organic fertilizers combined with 75% the recommended rates of inorganic NPK fertilizers.The application of the organic materials at planting and in successive ratoons was done manually in cane rows only, as illustrated in Figure 3.1.1. The assumption of 50% of total N availability was also referred to, to calculate the rates of compost of treatments five to six, whereby 280 kg N ha^{-1}were supplied.

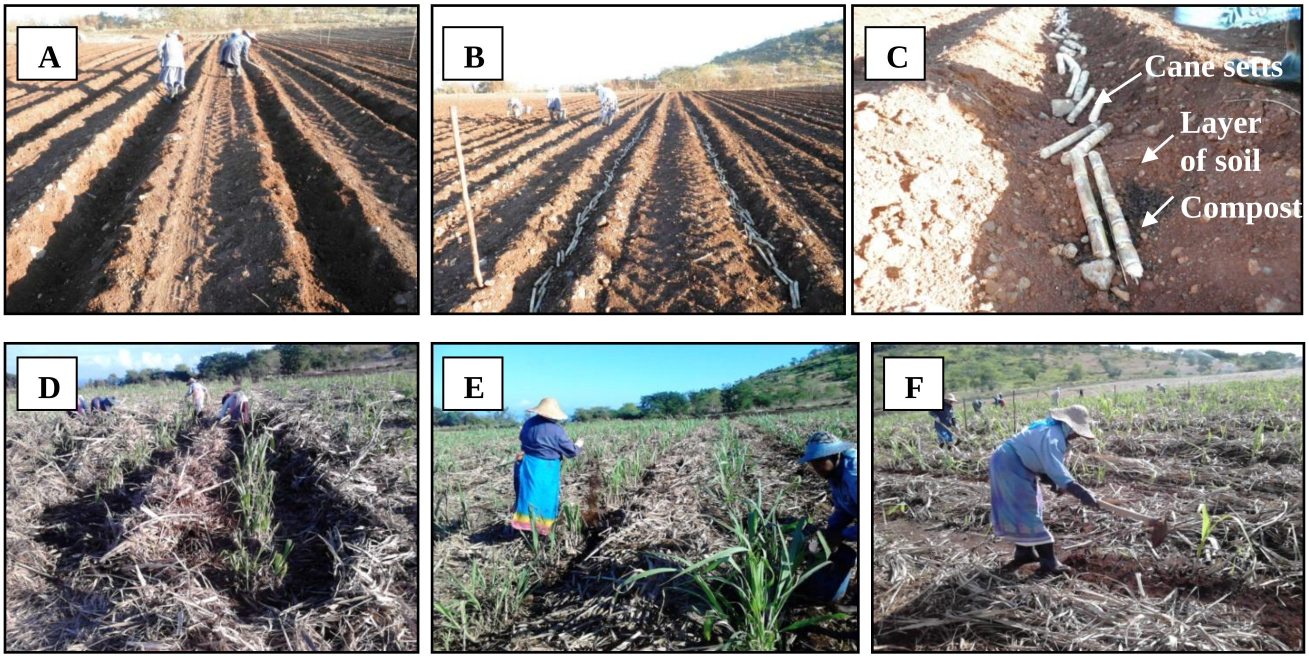


FIG. 3.1.1: Application of inorganic fertilizers and compost at planting (A to C) and fertilization of ratoon cane involving thrashing of the cane rows and earthing up (D to F)

3.1.1 Agronomic practices

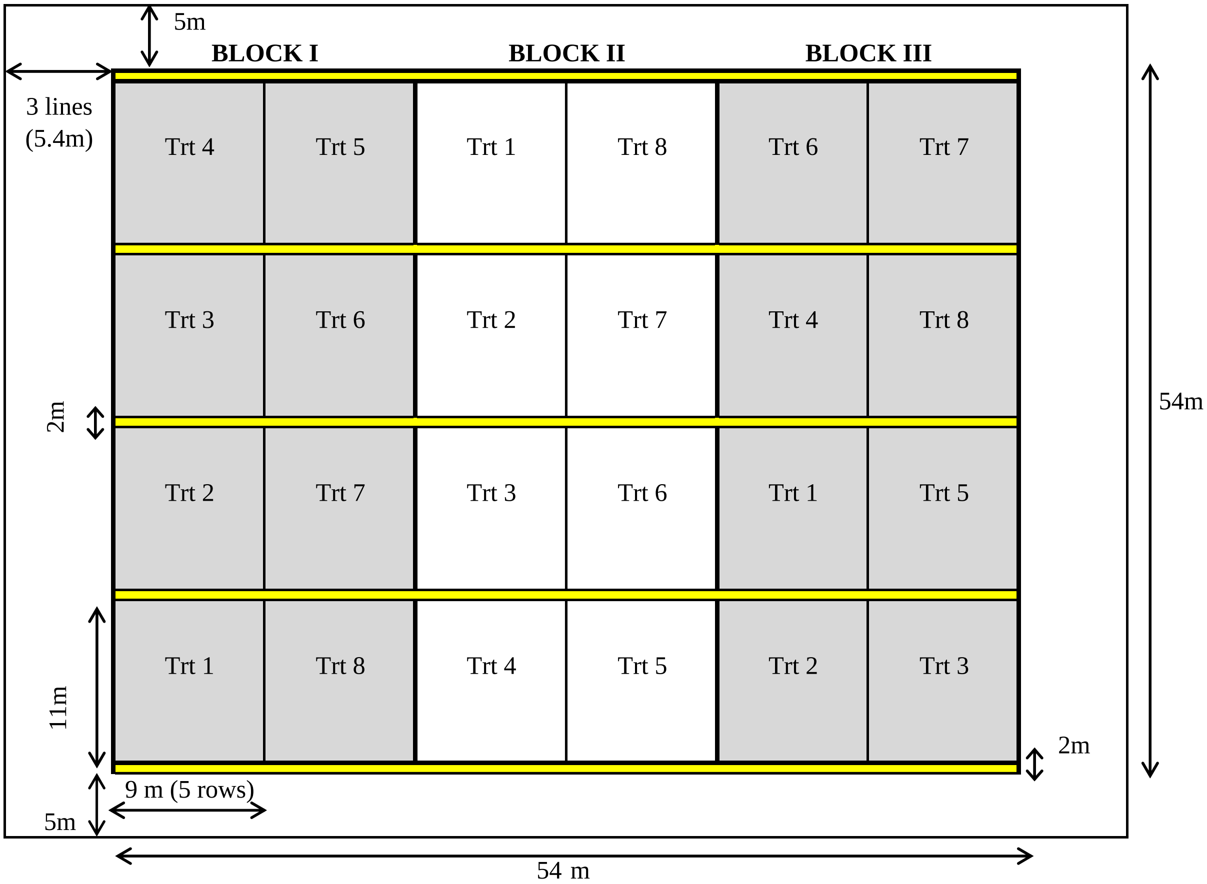
Prior to planting, the land was ploughed to a depth of 0.3 m with a disc, leveled and furrowed at a distance of 1.8m at Pierrefonds (P group), and 1.6m at Britannia (H group). At Chebel (L group), the site selected for the trial was part of a bigger field that was rocky and the process of land preparation was lengthy involving rock rippers, stone crushers, a disc plough and leveling equipment. Due to delays in soil preparation at Chebel, the trial field was only planted in December 2014 instead of December 2013 as at Britannia and Pierrefonds. At the three experimental sites, the 24 plots were earmarked with wooden stakes according to the layout shown in Figure 3.1.2, and irrigated lightly with an overhead sprinkler system before planting. At Pierrefonds, 86 mm was applied at intervals of 30 days involving a sprinkler standing time of 12 hours that involved two moves per day. Irrigation for this site was sometimes withheld due to repairs of irrigation pipes. On the other hand, irrigation was more regular at Chebel, with an application of 70mm at intervals of 10 days. Being located in a relatively high rainfall region, the trial site of Britannia was not irrigated.

On the day of planting, compost and/or inorganic fertilizers were applied in the cane rows according to the treatments described in Section 3.1, and covered with a thin layer of soil. The inorganic fertilizers applied to supply N, P, and K were urea, 14-20-20, mono ammonium phosphate (MAP), triple superphosphate (TSP) and muriate of potash (MOP). For ratoon cane, only N and K were applied in the forms of urea, 19-0-19 and MOP. Setts of the sugarcane variety M1400/86 at Pierrefonds and Chebel, and R573 at Britannia were treated with the fungicide methyl thiophanate against the pineapple disease which is caused by the fungus *Ceratocystis paradoxa*, and placed in the cane row. At a later stage, an herbicide mix containing the active ingredientsoxyfluorfen and diuron was applied for the pre-emergent control of weeds. Planting was carried out in single rows at the three sites.

Sugarcane harvest was done manually after 11 to 12 months and within one month of harvest, N and K (where applicable) fertilization was done. In ratoon cane, this operation required thrashing of the cane rows and earthing up of soil on the sides of the furrow to cover the applied fertilizers.

3.2 Field experimental layout and monitoring

For each experimental site, the treatments were arranged in a Randomized Block Design (RBD) with three blocks, as shown in Figure 3.1.2. By grouping the treatments in blocks, variation between plots of the same block was minimized. Possible sources of variation identified were a *Eucalyptus* windbreak at Pierrefonds, a fertility gradient at Britannia and a sloping land at Chebelwith possibilities of localized water accumulation or where the slope was sharper, rapid water flow during rainfall events. Each experimental field included a total of 24 plots. Each treatment was allocated three plots of 100 m^2, and comprised five rows, out of which two rows were considered as the plot borders; accordingly, there were three experimental rows per sugarcane plot. The treatments were separated by a 2 m wide spacing every 11 m to facilitate harvest and data collection, and each trial site covered an area of 3000 m^2.



BLOCK I		BLOCK II		BLOCK III	
Trt 4	Trt 5	Trt 1	Trt 8	Trt 6	Trt 7
Trt 3	Trt 6	Trt 2	Trt 7	Trt 4	Trt 8
Trt 2	Trt 7	Trt 3	Trt 6	Trt 1	Trt 5
Trt 1	Trt 8	Trt 4	Trt 5	Trt 2	Trt 3

FIG. 3.1.2: Field trial layout at the three experimental sites

Changes in soil inorganic N levels were investigated using the *in situ* method described by Weinhold (2007). At planting, five PVC pipes (termed corers for the purpose of this study) with a diameter of 0.05 m were inserted to a depth of 0.20 m in each of the 24 plots; in each plot, two corerswere placed in the rows two and three, and one corerin row four. The position of the PVC corers in the cane rows may be viewed in Figure 3.1.3 and in Appendix VII. After insertion, the corers were removed from the soil, and a nylon pouch of 25 cm^2 containing a mixture of hydrogen (H^+)-saturated cation (Dowex 50WX8 50-100; Manufacturer) and chloride (Cl^-)-saturated anion resins (Dowex 1X8 50-100) was placed at the bottom of the corer. Each nylon pouch contained 2g of cation resin and 2g ofanion resins. The main steps of the *in situ* incubation of PVC corers fitted with resins are outlined in Figure 3.1.4. The resin pouches were limited to the corers of blocks one and three only due to the high cost of the resins. In the following ratoons, the PVC corers were not left to incubate in the field, being devoid of resins.Instead, soil was sampled by inserting a PVC corer to a depth of 0.20m, removing the corer and collecting the soil in a tightly closed plastic bag to monitor the evolution of inorganic N in soil.

In the plant cane, the edges of the incubated corers were kept 0.05m above ground level to avoid surface runoff from entering the corers (Sistani et al. 2007), and manual weeding of the corers was also done on a weekly basis to prevent nutrient uptake by weeds. The soil corersof the three blocks, with and without resin bags were left uncapped to obtain a realistic estimate of soil inorganic N after losses via leaching and gaseous N losses. Because all the corers were left uncapped, this method cannot be used to derive an N balance equation, but will instead outline the trend in soil inorganic N levels at different points in time and where resins are used, indicate possible N losses by leaching during heavy rainfall and irrigation for different treatments.

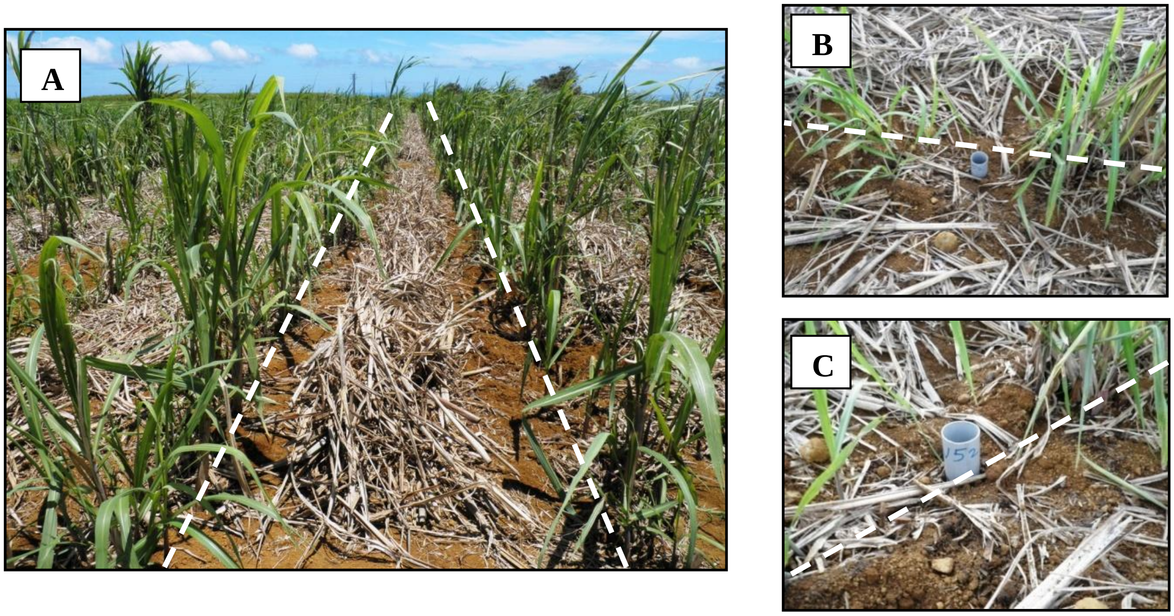
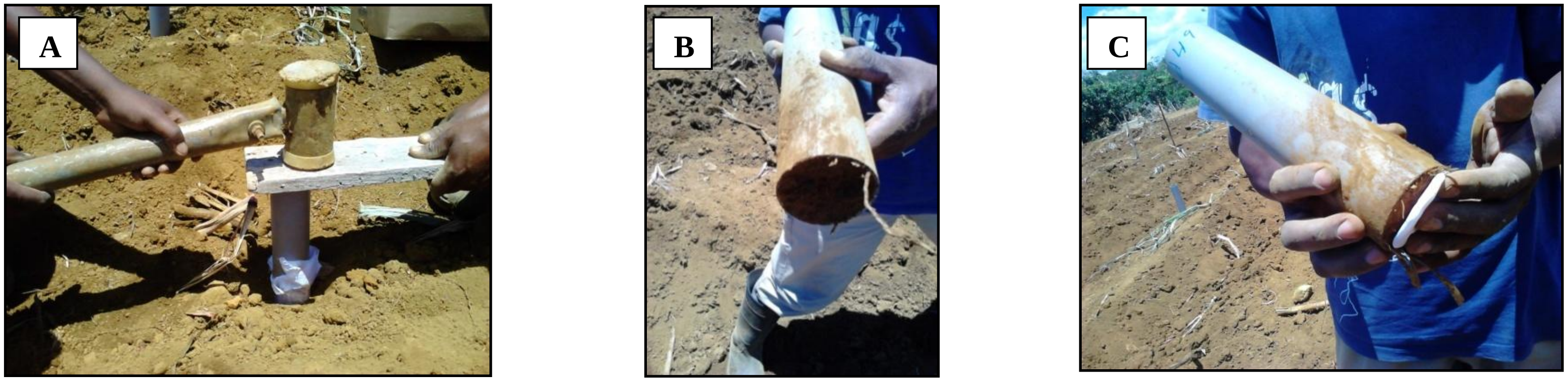


FIG. 3.1.3: Sugarcane rows at Britannia (Humic Latosol soil group) in ratoon cane indicated by white dashed lines (A) and PVC corers inserted in the cane rows after application of compost and/or inorganic fertilizers (B and C)



Insertion of Polyvinyl Chloride corer 0.20 m into soil

Removal of intact soil core

Insertion of nylon bag containing resin at the bottom of corer

Covering bottom of corer with nylon cloth

Insertion of corer with resin 0.20 m in soil

Incubation of corer until sampling

FIG. 3.1.4: Steps in the *in situ* soil corer incubation technique to monitor changes in soil nitrogen levels

3.3 Soil sampling and data collection

To determine the initial inorganic N content of soil, five soil samples were collected on the day of planting (before fertilization) in the cane rows to a depth of 0.02 m. Subsequent soil sampling was then carried out five and 20 days after planting and fertilization which were done on the same day. After 20 days, soil sampling was carried out monthly until harvest. A set of 24 soil corers (all three blocks) and 12 resin pouches (two blocks out of three) were collected from the cane rows, and per treatment, three soil samples were therefore collected. The amount of inorganic N trapped by resins was monitored over 125 days, and after this period, only soil samples were collected from the fields. Following unearthing of the PVC corers, the soil and the resin bags were analyzed separately for $NH_4^+$and NO_3^- using the steam distillation method described in Section 2.2.1 of Chapter 2. Soil collection is depicted in Figure 3.1.5.In the subsequent ratoon crops, resin bags were not used, and PVC corers were used to collect soils at regular intervals.

Sugarcane at the three experimental sites was harvested manually after 11 to 12 months, and the weight of fresh cane stalks for each plot recorded with a weighing balance. One week before harvest, the cane juice of stalks from each of the 24 plots was collected to determine the Industrial Recoverable Sucrose (IRSC). These tests were carried out by the Control Board of Médine Ltd. The weight of the stalks collected to test juice quality was recorded and added to the final amount of cane weighed per plot at harvest.Sucrose recovery was calculated using equation 1:

$$\text{Industrial Recoverable Sucrose (IRSC)} = (100 - \text{Fibre \%}) * \text{Pol \%} * 0.85 \qquad \textit{Equation 1}$$

In plots where gaps (spaces $\geq$ 0.6 m) were observed in the cane row, the gaps were measured, and the amount of cane that would have been obtained in a gapless situation calculated; the total amount of cane harvested was divided by the length of the rows harvested and the cane tonnage per metre was multiplied by the length of gaps. The final yield was adjusted accordingly. A calendar of field operations at the three trial sites can be viewed in Appendix VIII.

Identification of corer label for sampling

Removal of intact soil core

Removal of nylon cloth

Collection of nylon bag containing resins

Transportation of resins in bottles to the laboratory

Carrying soil in plastic bag to the laboratory

FIG. 3.1.5: Steps in the collection of soil corers fitted with resins in experimental fields

3.4 Statistical analysis

To investigate the response of sugarcane yield to the different N treatments, the approach of Meyer et al. (1986) was adopted, whereby the yield obtained with no fertilizer was subtracted from that achieved with the fertilizer amendments. The difference in yield was then expressed as a percentage of the zero-fertilizer yield. The same method was used to evaluate the response of IRSC to the N treatments set in the three field trials.

Using the computer program Genstat (14^{th} edition), one-way analysis of variance (ANOVA)was carried out to determine the level of significance of the differences in cane yield and IRSC between treatments of the same site. To determine if cane and sugar yield differences were significant across treatments of the three sites, a two-way ANOVA based on soil type and experimental treatments as main factors was carried out. Where the differences between means were significant, a Tukey test was done for the separation of means.The Least Significant

Differences (LSD) between treatments of the same site was calculated using the same software and the coefficient of variation (CV) recorded as a measure of the magnitude of in-field variation and the extent to which the experimental design minimized these variations.

3.5 Results and Discussion

3.5.1 Chemical and physical characterization of soil

The main chemical and physical properties of soil collected at the three trial fields are summarized in Table 3.1. The chemical characterization of the three soil groups under study indicated that in terms of pH, the P group was slightly alkaline (7.50) and the H group slightly acidic (4.72) compared to the L group (6.38).A similar characterization carried out on soils used in the laboratory incubation experiment highlights potential differences in acidity and alkalinity of soils of the same group, and cultivation practices to which soils are subjected are important clues to understand those differences. The soil used in the incubation study also originated from locations different from those in the field experiment.The H soil group which is located in high rainfall regions is generally acidic in nature, as shown in Table 3.1. The relatively higher pH (6.04) obtained for the H soil sampled at Riche-en Eau and used for the laboratory incubation study was most probably the result of liming with cement in year 2011 at the site of collection.

The P soil sampled for the field trial was more alkaline (pH 7.50) than that collected for the laboratory incubation (pH 6.36). Having been in a fallow state for a number of years, the field selected for the *in situ* experiment was a dumping site for vinasse from a distillery. Despite the acidity of vinasse (pH in the range of 4.10 to 4.90) and the initial decrease in pH that follows vinasse application (Soobadar 2009), it has been reported that the by-product may accelerate the oxidation of OM by triggering microbial activity (Vadivel et al. 2014). The H^+ ions from vinasse ultimately act as electron acceptors, causing in the long term an increase in soil pH. This explains why the pH was higher in the field trial soil, and also potentially, why the P group had a lower OM content than the H and L soil groups. When benchmarked against the reported OM ranges for Mauritian soils (Parish and Feillafé 1965), the measured OM levels recorded for the P soil are also much lower (3.28% against a range of 6.0 to 7.7%) while those for the H and L soil groups are both within the reported range.

TABLE 3.1: Chemical and physical characteristics of soil at the three trial sites

Characteristic†	Latosolic Reddish Prairie (P group of Pierrefonds)	Humic Latosol (H group of Britannia)	Low Humic Latosol (L group of Chebel)
Total Nitrogen, %	0.20 ± 0.02	0.24 ± 0.01	0.22 ± 0.03
Available Phosphorus, parts per million	370.4 ± 178.8	58.0††	37.2 ± 14.3
Available K, milliequivalent %	2.71 ± 0.38	0.18††	0.95 ± 0.20
Total Carbon, %	1.90± 0.29	2.38 ± 0.17	2.01 ± 0.32
Carbon : Nitrogenratio	9.6 ± 1.0	10.1 ± 0.7	9.0 ± 0.5
Organic matter, %	3.28 ± 0.49	4.09± 0.30	3.46 ± 0.56
pH (H_2O)	7.50± 0.17	4.72 ± 0.10	6.38 ± 0.10
Sand, %	36.3 ± 6.5	23.8 ± 0.8	8.7 ± 1.0
Silt, %	32.0 ± 4.3	28.8 ± 0.4	15.9 ± 1.1
Clay, %	31.7 ± 4.8	47.3 ± 0.8	75.3 ± 2.1
Gravimetric moisture content, %	12.1 ± 1.8	16.6 ± 2.3	11.2 ± 1.9
Bulk density (0- 0.15 m), Mg dw m^{-3}†††	1.04 ± 0.05	1.38 ± 0.09	0.99 ± 0.06
Bulk density (0.15- 0.30 m), Mg dw m^{-3}	1.00 ± 0.19 ††††	1.28 ± 0.20	0.82 ± 0.16

† The data shown are mean ± standard deviation

†† Tests carried out by the Mauritius Sugar Industry Research Institute (MSIRI) upon request of the Estate before planting

††† dw, dry weight

†††† At Pierrefonds bulk density was measured to a depth of 0.25 m only due to rockiness

In general OM is estimated to be composed of 58% C (Tadessee et al. 1991), and based on this assumption, was calculated from measured C. The observed trend in OM content was in the order H (4.09%) > L (3.46%) > P (3.28%). Since the N mineralization capacity of soils is strongly correlated with SOM content (Meyer et al. 1983), a higher concentration of inorganic N may therefore be expected in the H soil compared to the L and P soil groups. The measured total C content of soil was in the same order as the OM levels, with H (2.38%) > L (2.01%) > P

(1.90%). The total N content of the three soil groups also followed a similar trend, and was highest in the H group (0.24%) and lowest in the P group (0.20%).

The C:N ratio of the soils under study varied from 10.1 in the H soil, to 9.6 in the P soil and 9.0 in the L soil.Generally, the extent of N immobilization and mineralization is determined by the ratio of C and N in soil, the wider the C:N ratio, the stronger the immobilization (Alexander 1977). However, because the magnitude of N mineralization depends a on a set soil parameters and processes, it is difficult to predict differences in N mineralization across soils based on C:N ratio only. For instance, although the H soil had the widest C:N ratio of the three soil groups, this soil also had the highest SOM and relatively lower clay content than the L group.

According to Table 3.1, the clay content of the three soil groups under study was between 31.7% and 75.3%, being lowest in the P soil and highest in the L soil. Being negatively charged, clay minerals encourage the adsorption of organic molecules via cation exchange, hydrophobic bonding or polyvalent cation bridges depending on the charge of the organic molecule (Mortland 1986, Zech et al. 1997). Cations such as NH_4^+ that result from ammonification may also become fixed by clay particles (Neider et al. 2011). Therefore, in soils such as the L group which have a relatively high clay content, N mineralization may be less marked than in other soil groups, despite a C:N ratio of 9.0. As observed during the laboratory incubation experiment, the P soil also had relatively higher sand content (36.3%) than the H (23.8%) and the L (8.7%) soils. Soil texture is known to influence other physical soil properties such the infiltration rate that can in turn have an impact on losses of N by leaching. Amongst the three soils under study, the P soil has the highest infiltration rate (> 30 mm h^{-1}) (STASM 2003). As indicated in Table 3.1, the immature P soil group was also comparatively shallow due to a high degree of rockiness. Consequently, this soil group could be prone to losses of N via leaching.

Across the three soil groups, bulk density was highest in the upper 0.15 mof soil and decreased down the plough layer of 0.30 m. In the upper portion (0- 0.15 m), bulk density ranged from 0.99 to 1.38 Mg dwm^{-3} and in the lower portion (0.15- 0.30 m), varied from 0.82 to 1.28 Mg dw m^{-3}.The degree of soil compaction is strongly linked to soil aeration. *Nitrosomonas* and *Nitrobacter* that regulate nitrification and the production of NO_3^- are autotrophic aerobic bacteria, and under conditions of low oxygen availability, as during waterlogging, low concentrations of NO_3^- have been observed. With the highest soil bulk density of the three groups and being located in a high rainfall region, the H soil may foster ideal conditions for waterlogging, limiting the oxidation of NH_4^+ to NO_3^- (Chowdary et al. 2004).Extended or frequent rainfall events that fill the pore spaces (0.6 water filled pore space) following fertilization have also been linked to increased emissions of nitrous oxide (N_2O) that reflect the reduction or denitrification of NO_3^- to gaseous N in the absence of oxygen (Weitz et al. 2001). In Mauritius, it has been found that gaseous N emissions could be as high as 300 g N ha^{-1} day^{-1} whenever more that 80% of the soil pore space was filled with water (Ng Kee Kwong et al. 1999).

3.6 Changes in soil inorganic nitrogen content

3.6.1 Evolution of inorganic nitrogen in Latosolic Reddish Prairie (P) soil at Pierrefonds

In the plant cane of Pierrefonds, a total of 12 soil samples per treatment were collected to a depth of 0.20 m, showing spikes in the levels of soil inorganic N immediately after fertilization. According to Figure 3.1.6, the unfertilized (N) control P soil contained 20 mg N kg^{-1} soil at day six of the experiment, while the inorganic N levels in soils amended with reduced rates of inorganic N fertilizer peaked to 36 mg N kg^{-1} (PM blend) to 55 mg N kg^{-1} (PL blend) and 57 mg N kg^{-1} (FC blend). Unlike the 800 mg N kg^{-1} soil to a depth of 0.45 m reported by Ng Kee Kwong et al. (2005) one day after fertilization with inorganic fertilizer at a rate of 145 kg N ha^{-1}, the concentration of N five days after incorporation of inorganic fertilizer only resulted in a relatively low peak of 49 mg N kg^{-1} soil before declining to levels of 5 to 46 mg N kg^{-1}soil during the months preceding harvest. This decline is concordant with the observed range of 20 to 50 mg N kg^{-1} soil in dry regions of Mauritius (Ng Kee Kwong et al. 2005). In December 2013, the average soil temperature at Pierrefonds to a depth of 0.05 m reached up to 37.2 °C ± 2.8 and up to 33.2 ± 0.8 (Appendix IX) to a depth of 0.10 m in the afternoon. These temperatures were higher than those recorded in the trial site of Britannia during the same period (30.2 ± 2.9 at 5 cm and 29.7 ± 1.7) (Appendix IX). Since N was applied in the form of urea fertilizer at Pierrefonds, the high temperatures recorded may have decreased the solubility of ammonia gas in the soil solution (Meisinger and Jokela 2000), the rocky soil promoting gaseous losses despite the immediate irrigation event after planting. Inorganic N levels were only measured in soil to a depth of 0.2 m, in contrast to a depth of 0.45 m in the study of Ng Kee Kwong (2005), and it is therefore possible that N ions have moved into horizons below 0.20 m. In this study, PVC corers were incubated *in situ*. Being physically isolated from the remaining field, the soil core may have been subjected to a disruption of the natural soil pore network and a lowered hydraulic conductivity. Consequently, gaseous N losses may have been promoted by poor drainage conditions in the PVC corer, possibly accounting for the low initial inorganic N concentration. The present technique used could be improved by the drilling of holes around the tube to allow the lateral flow of water, as suggested by Hatch et al. (1998).

The addition of inorganic N fertilizer to compost is expected to trigger the mineralization of N by lowering compost C:N ratio (Nguyen et al. 2015). The dual use of inorganic N fertilizers with the three types of agricultural composts resulted in a positive priming effect five days after fertilization, and where PL and FC were used, the amount of N released by mineralization was even greater than with inorganic fertilizer in the plant cane. Hartz et al. (2000) showed that in compost-amended soils, an initial period of immobilization preceded N release. In the absence of an initial immobilization period (Figure 3.1.6), the present field experiment therefore suggests that increased N can be achieved by using compost jointly with inorganic N fertilizer.

During the yearly crop cycle of sugarcane, there is a boom stage whereby the crop's N, water and sunshine requirements are at a maximum, and vegetative growth is at a peak (Fillols and Chabalier 2007). The boom stage occurs between three and nine months (90 to 270 days). Consequently, the period of limited N availability observed between 94 and 246 days may reflect active N uptake by sugarcane. At day 307, the last sampling day in the plant cane, there were no marked differences in the soil inorganic N content between the different treatments which had reached basal levels of 12 to 15 mg N kg^{-1} soil. To understand sugarcane's use efficiency of reduced rates of inorganic fertilizer with compost, it would be interesting to monitor N accumulation in the above-ground parts throughout the yearly cycle.

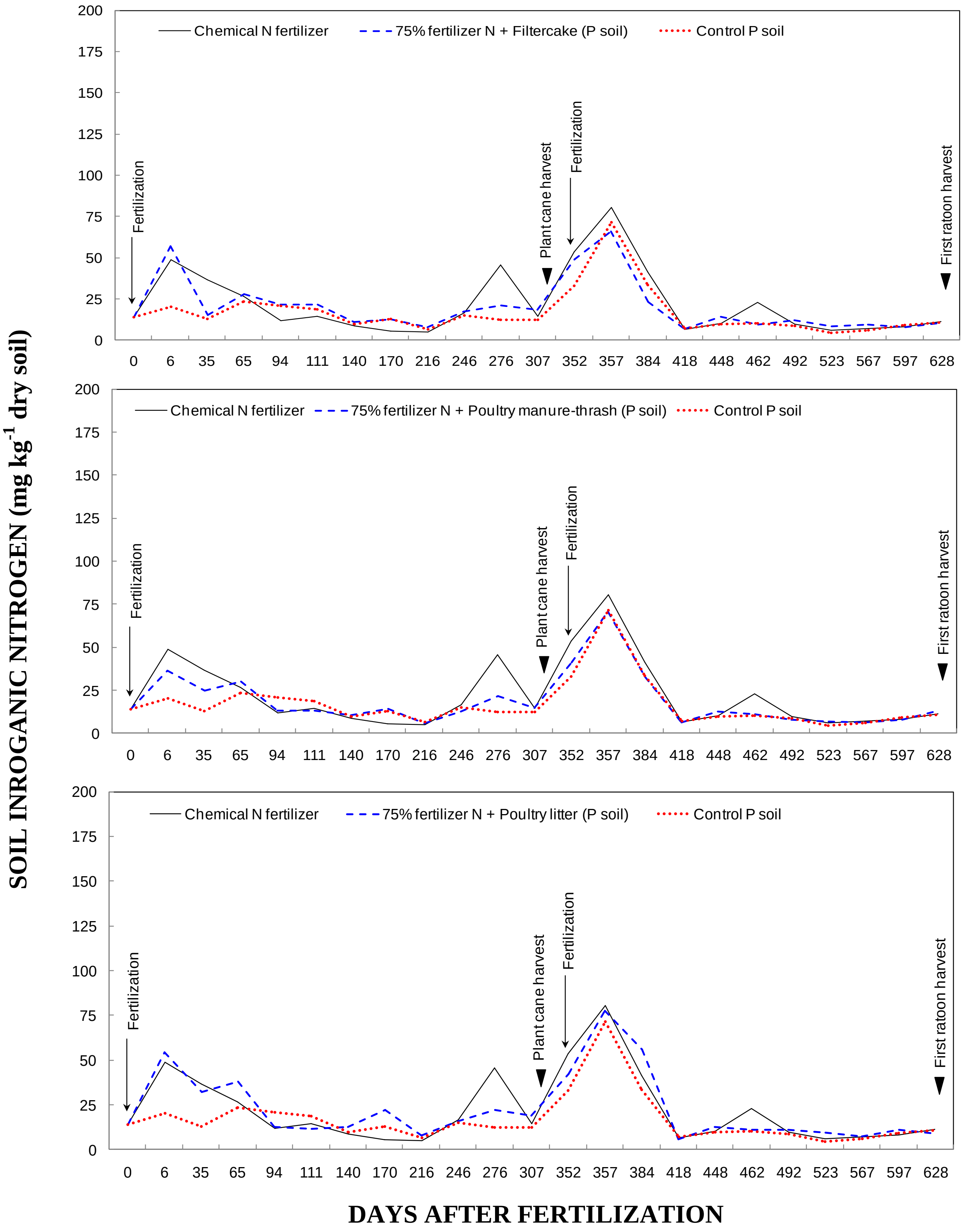


FIG. 3.1.6: Changes in inorganic nitrogen in a Latosolic Reddish Prairie soil (P) of Pierrefonds upon fertilization with combinations of inorganic fertilizers and agricultural composts

Soil samples collected at day 352, just after harvest of the plant cane, but before fertilization, showed that there was an increase in inorganic N in all plots, irrespective of the treatments (Figure 3.4). For instance, inorganic N increased from 19 to 49 mg N kg^{-1}soil just after harvest in plots previously fertilized with the FC blend. In the control soil, where no N fertilizer was applied, the concentration of inorganic N also increased to 71 mg N kg^{-1} soil 50 days after harvest (day 357). After harvest, the crop residues left in field form a blanket over the soil (Figure 3.1.7). Ng Kee Kwong et al. (1987) reported that thrash immobilized native soil N, and supported this statement with a reduced recovery of soil N in the above-ground parts of sugarcane in the presence of thrash at the end of an 18-months study. This in contradiction with the observed increase in soil available N that indicates mineralization following the deposit of thrash after harvest of the plant cane. Because the residues consist of cane tops, leaves and stem that differ in their biochemical composition and turnover rate, it is plausible that at the time of sampling (day 352), 45 days after plant cane harvest, easily-decomposable parts with cellulose and free amino acids (Vitti et al. 2010) have contributed to the temporary peak in N noted in the unfertilized plots, in the first ratoon. A study of Muhammad et al. (2010), also reported that despite an initial immobilization of the soil indigenous inorganic N pool in the presence of thrash during 28 days, the N levels started to increase again after 42 and 84 days. This coincides with the period at which sampling was done in the control soil of Pierrefonds.

FIG. 3.1.7: Surface crop residues (thrash) after plant cane harvest at Pierrefonds

In the first ratoon, the measured inorganic N levels at day 357, five days after fertilization were higher than in the plant cane, in the order of inorganic N fertilizer (81 mg N kg^{-1}soil) >PL blend (78 mg N kg^{-1}soil) > control soil (71mg N kg^{-1}soil) > PM blend (71 mg N kg^{-1}soil) > FC blend (66 mg N kg^{-1}soil). The quantitative inorganic N pattern observed for the different treatments in the first ratoon differed in some cases from the general trends noted in the plant cane. While the FC blend produced the highest amount of inorganic N in the plant cane, the soil N declined below that of the control soil five days after application and only produced quantities varying from 8 to 23 mg N kg^{-1}soil till harvest. Instead of the positive priming effect triggered by the PM blend in plant cane, the soil N levels were similar to those of the control soil up to day 384. The substantial amount of surface crop residuesin the first ratoon may explain these differences. With a high C:N ration of 142.1 (Muhammad et al. 2010), sugarcane thrash constitutes a readily available source of energy for microbes, which in the presence of N-rich materials such as PM and inorganic N fertilizer may have actively assimilated N for their growth (Chowdary et al. 2004), causing a decrease in the inorganic N pool of amended soils relative to the control soil.

Agricultural composts were applied as the only source of N in cane rows at planting, and to evaluate the residual effect of compost N on cane yield, compost application was discontinued in the first ratoon. In the plant cane (Figure 3.1.8), compost resulted in an increase in inorganic N that varied from 47 mg N kg^{-1} soil (PL) to 35 mg N kg^{-1} soil (FC) to 34 mg N kg^{-1} soil (PM) relative to the control soil at day five of the experiment. Only PL which had the highest percentage of OM (43.02%) and total N (3.66%) of three types of compost released sufficiently high amounts of inorganic N to match the quantity of N hydrolyzed from inorganic N fertilizer. However, as from day 94, inorganic N levels in PL-amended plots remained persistently higher, this trend lasting till day 246. Despite the chemical and biochemical differences existing between FC and PM, they both followed similar patterns of N mineralization. Broadly, N mineralization from FC and PM can be described in three main phases: firstly, the priming phase (day 5 to 65) whereby the N mineralized exceeded the indigenous N levels. Secondly the decline phase (day 94 to 216) whereby the inorganic N levels were either below or only slightly higher than the control soil. During this phase, inorganic N concentrations reached basal levels of 13 mg N kg^{-1} soil for FC and 24 mg N kg^{-1} soil for PM. The third and last phase which preceded harvest coincides with the end of the boom stage and a decrease in sugarcane N uptake.

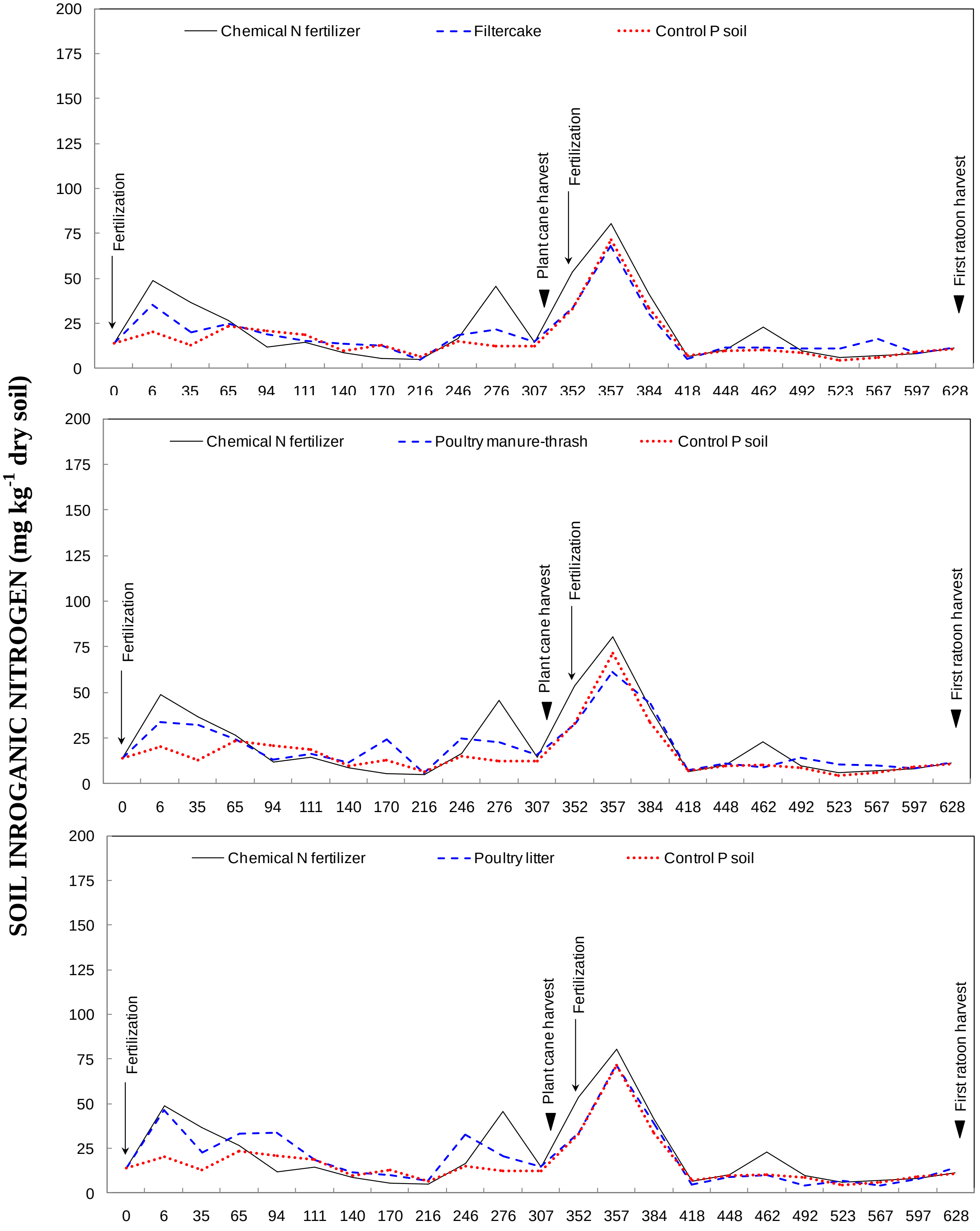


FIG. 3.1.8: Changes in inorganic nitrogen in a Latosolic Reddish Prairie soil (P) of Pierrefonds upon fertilization with agricultural composts

Although compost application was discontinued in the first ratoon for the treatments shown in Figure 3.1.8, an appreciable amount of soil inorganic N was measured at day 357, 50 days after harvest. The difference between inorganic N levels in plots previously amended with compost and the inorganic fertilizer treatment was quite small, varying from nine to 20 mg N kg^{-1} soil. Still, compared to the control soil, the amount of bioavailable N from compost was relatively lower except for PL, being in the order of PL (72 mg N kg^{-1} soil) > control soil (71 mg N kg^{-1} soil) > FC (68 mg N kg^{-1} soil) > PM (61 mg N kg^{-1} soil) at day 357. In the Pierrefonds field experiment, it can be concluded that the use of PL only at a rate of 13 t ha^{-1}, in the cane rows at planting resulted in soil inorganic N levels that were comparable to plots fertilized with inorganic N fertilizer only. The application of FC and PM at rates of 36 t ha^{-1} and 22 t ha^{-1} respectively lead to a similar changes in soil inorganic N that were described in three distinct phases.

3.6.2 Inorganic nitrogen in resins in Latosolic ReddishPrairie (P soil group) of Pierrefonds

Figure 3.1.9 shows the concentrations of inorganic N in soil and resins measured in a P soil. Sampling of the incubated PVC corers was done during summer months, starting on the 23 December 2013, five days after fertilization (DAF), and ending on the 21st April 2014 (125 DAF). For the first sampling, it was noted that the concentration of inorganic N in resins was higher for the inorganic N fertilizer treatment (6.3 mg N kg^{-1} soil), compared to 3.6 to 3.9 mg N kg^{-1} soil in plots fertilized with blends of inorganic N fertilizer and compost. This implies that within the five days that followed fertilization, the movement of N ions down the soil profile was more pronounced in plots fertilized with chemical N fertilizer only. On the 9 January 2014, 214 mm of cumulative rainfall and irrigation water had been recorded. Under these conditions, the inorganic N levels captured by the resins in plots fertilized with FC and PM blends were lower than with inorganic N fertilizer alone, most of the inorganic N being located in the upper 0.20 m of the soil core. However, where PL blends were applied, the quantity of inorganic N in the resins exceeded that in plots fertilized with inorganic N fertilizer.

Because the five PVC corers were all incubated at the same time, it would have been expected that the amount of inorganic N in the resins would increase linearly over time to indicate the cumulative inorganic N leached down into the resins at each sampling date.

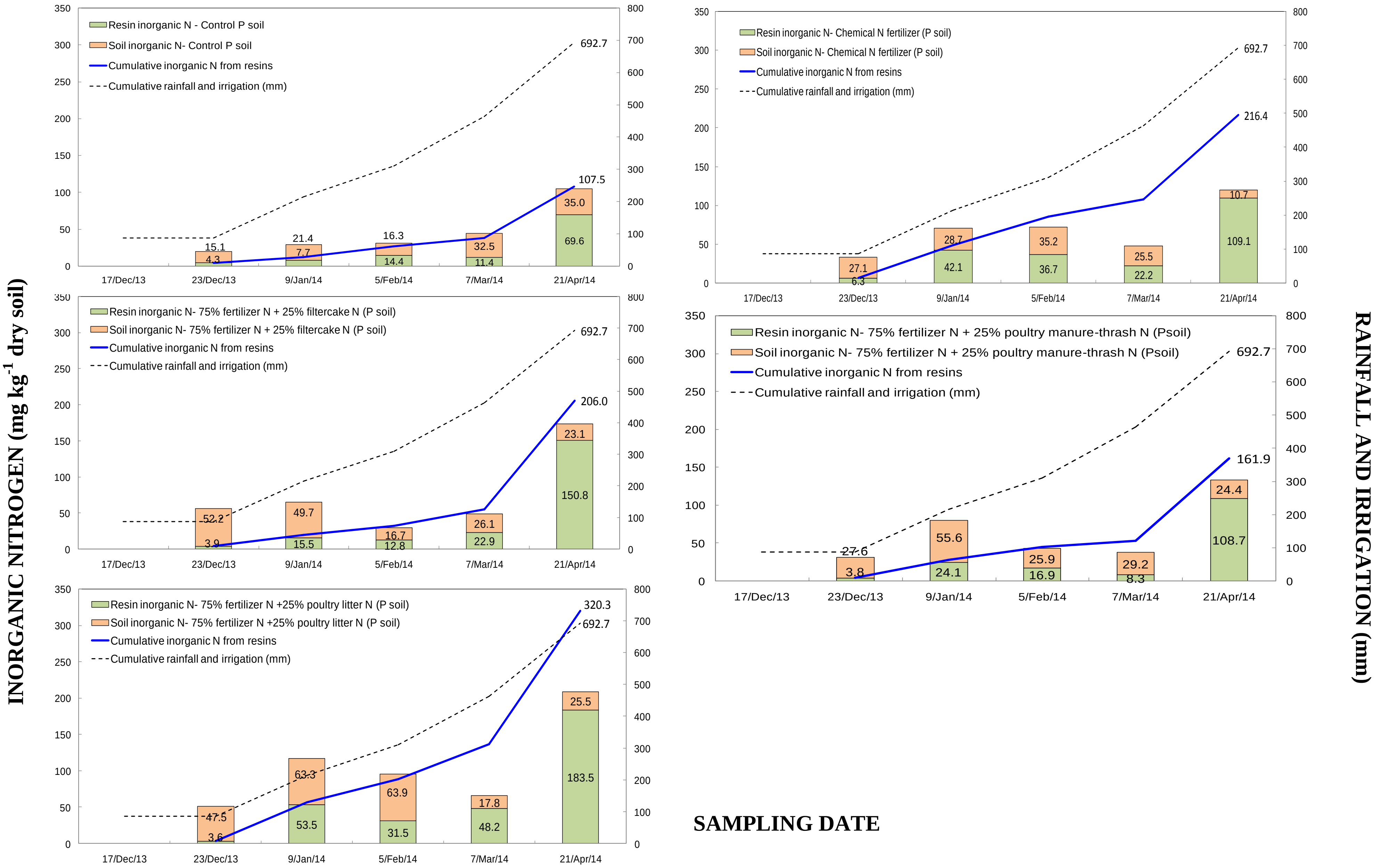


FIG. 3.1.9: Inorganic nitrogen in Latosolic Reddish Prairie soil (P) and resins of corers of Pierrefonds amended with inorganic nitrogenous fertilizers and compost

However, as illustrated by Figure 3.1.9, the inorganic N values in the resins do not show a constant increase. Weinhold (2007) stated that in the occurrence of resin saturation, N could be lost from the corer, a phenomenon known as by-pass flow. However, if resin saturation had occurred, the inorganic N concentrations would have reached a plateau, and would not have increased again on the final sampling date, on the 21st April 2014. The rockiness of the P soil under study may explain the fluctuating N levels observed; some the PVC cores used slit-opened upon insertion in the rocky soil and therefore, during rainfall/irrigation events inorganic N ions may have moved out of the core through the cracks and were therefore not trapped by the resins. Metal cores, although relatively expensive, instead of PVC ones may be more appropriate to study N mineralization *in situ* (Weinhold 2007, Moberg et al. 2013) in rocky soils of Mauritius.

By the 21 April 2014, the site received 434 mm of rainfall and 259 mm of irrigation water, amounting to a total of 692 mm of water. With this volume of water, the cumulative concentration of N captured by the resins after four months differed distinctively between treatments. In the unfertilized control plot, only 107.5 mg N kg^{-1} soil was captured by the resins to a depth of 0.20 m. To evaluate potential risks of N losses by leaching and determine whether the N losses are of agronomic importance, the cumulative inorganic N trapped by resins were benchmarked against the unfertilized plot. In all plots, the levels of inorganic N in the resins were higher than in the control soil, being in the order of inorganic PL blend (320.3 mg N kg^{-1} soil) > inorganic N (216.4 mg N kg^{-1} soil) > FC blend (206.0mg N kg^{-1} soil) >PM blend (161.9 mg N kg^{-1} soil). Relative to the control soil, it is clear that exogenous sources of N applied promoted the downward movement of N ions. Among the combinations of compost and inorganic N fertilizer localized in the cane row, only the PL blend amplified inorganic N in resins to levels greater than inorganic N fertilizer. Therefore, with this particular treatment, there can be risks of N losses from the root zone, particularly if the root system of sugarcane is not well developed at the time of fertilization, or when an extended period of dryness is followed by precipitation or irrigation (Wu and Brookes 2005, Jarvis et al. 2007). Lysimeter studies are recommended to further evaluate and quantify the movement of N ions in soils under simulated rainfall events. The blended treatments resulted in lower concentrations of inorganic N ions in the resins than inorganic N fertilizer to a depth of 0.20 m.

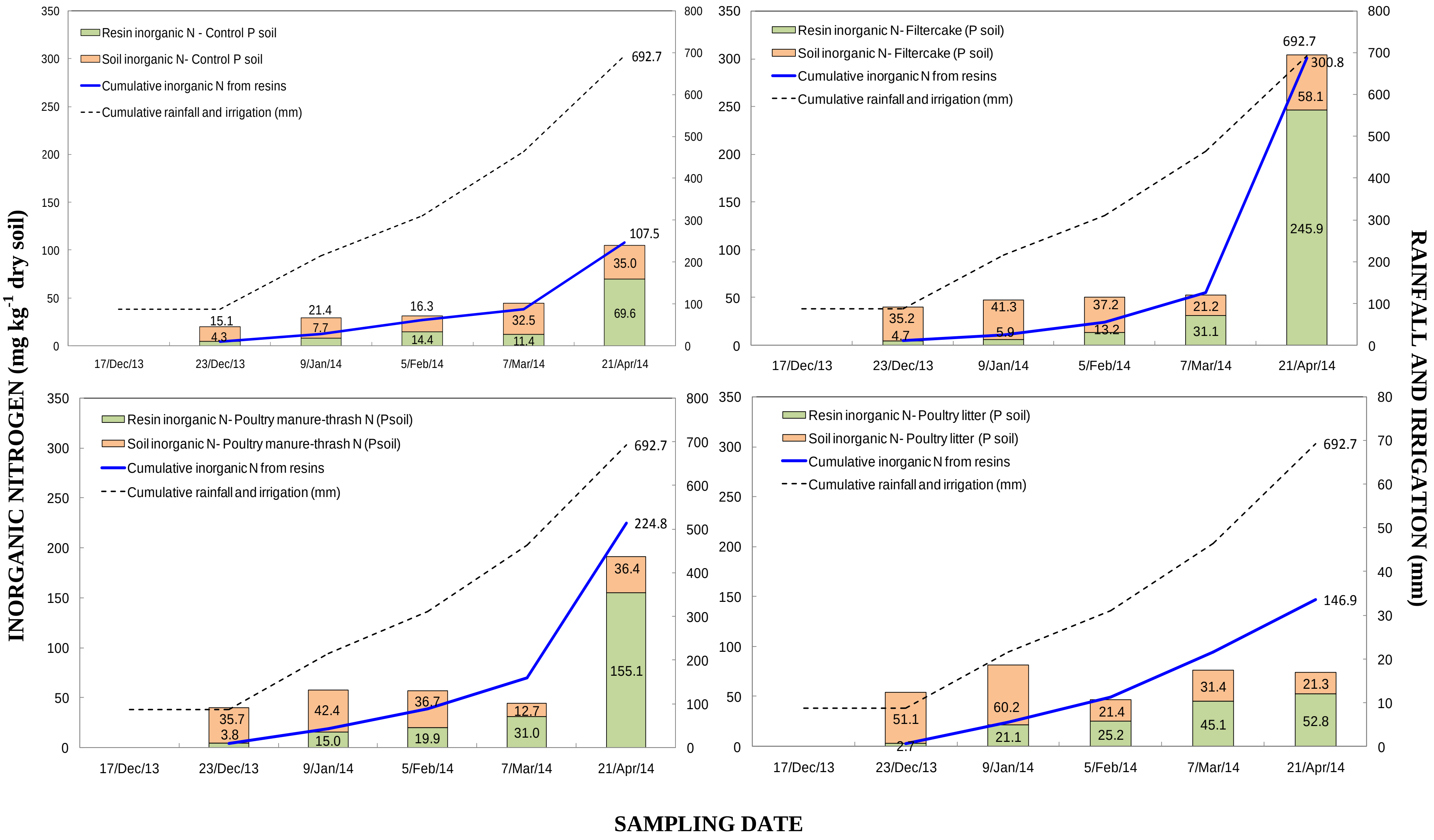


FIG. 3.2: Inorganic nitrogen in resins and Latosolic Reddish Prairie soil (P) of Pierrefonds amended with compost

When compost was applied in the cane rows, the amounts of inorganic N in the upper 0.20 m of the soil core and in the resins did not fluctuate substantially between the 9 February 2014 and the 7 March 2014 even if during this period, 464 mm water had been received (Figure 3.2). However, on the last sampling date, when the volume of rainfall and irrigation reached 693 mm, the concentration of N ions adsorbed by the resins peaked in FC- and PM- amended plots, leaving only a relatively small amount of inorganic N in the upper soil profile. In resins, the cumulative amount of inorganic N was in the order of FC (300.8 mg N kg^{-1} soil) > PM (224.8 mg N kg^{-1} soil) > PL (146.9 mg N kg^{-1} soil). Considering that PL had an initially higher total N content than FC and PM, it was interesting to note that the cumulative N ions in the resins during the last sampling date was not only smaller than the resins in FC and PM amended plots, but also smaller than the unfertilized control.

3.6.3 Evolution of inorganic nitrogen in the Humic Latosol (H group) at Britannia

The laboratory incubation done in the context of this study showed that the daily N availability in H soils (0.975mg N kg^{-1} soil day^{-1}) was higher than in the P soil (0.637 mg N kg^{-1} soil day^{-1}). The quantitative data collected under field conditions were consistent with these observations (Figure 3.2.1). In the plant cane, whilst the inorganic soil N levels in the H soil ranged from 17 to 38 mg N kg^{-1} soil, inorganic Nat Pierrefonds varied between seven and 24 mg N kg^{-1} soil from day zero to 307. Nevertheless, as demonstrated by many authors, without an extraneous source of N, the presence of thrash in the first ratoon immobilizes temporarily native soil N (Ng Kee Kwong et al. 1987, Muhammad et al. 2010). Since the C:N ratio of the H soil (10.1) was innately higher than the P soil (9.6), the phenomenon of N immobilization may have been more pronounced in the H soil than in the P soil in the first ratoon, the inorganic N levels ranging from six to 66 mg N kg^{-1} soil and from four to 71 mg N kg^{-1} soil respectively. Depending on the type of agricultural compost applied in combination with inorganic N fertilizer, the initial spike in inorganic N concentrations was different, varying from 215 mg N kg^{-1}soil for the FC blend, to 287 mg N kg^{-1} soil for the PM blend and 579 mg N kg^{-1} soil for the PL blend (Figure 3.2.1).

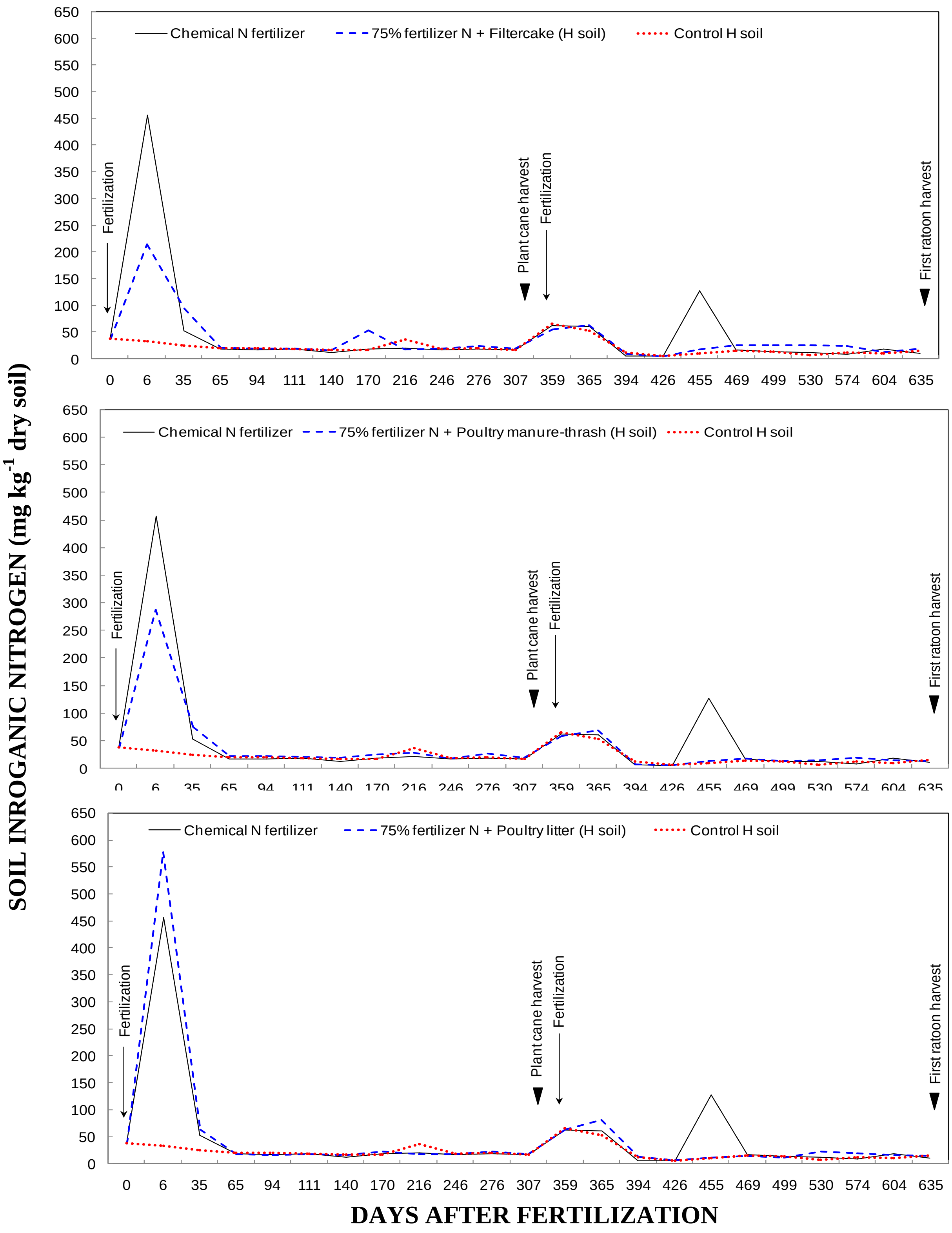


FIG. 3.2.1: Changes in inorganic nitrogen in a Humic Latosol soil (H) of Britannia upon fertilization with combinations of inorganic fertilizers and agricultural composts

Although a positive priming effect was achieved with all composts, only PL resulted in inorganic N levels greater than inorganic N fertilizer (457 mg N kg^{-1} soil) six days after application. Owing to the relatively high inorganic N peak upon incorporation of PL-blends at Britannia, the timing of application becomes particularly important; to optimize the absorption of such a considerable quantity of inorganic N, the grower should ensure that the crop's root system is sufficiently developed at the time of application. A sharp decrease in the bioavailable N content of soils treated with both PL blends and inorganic N fertilizer only was observed at day 35, and as from then onwards, the inorganic N levels remained low relative to the control treatment. A similar drop was also noted with PM and FC blends, and the trend repeated itself in the first ratoon. From day 35 to day 307 in the plant cane, the inorganic N levels were in the range of 15 to 63 mg N kg^{-1} soil for PL blends, 18 to 75 mg N kg^{-1} soil for PM blends and 18 to 94 mg N kg^{-1} soil for FC blends. These figures may be benchmarked against soils fertilized with inorganic N only (13 to 53 mg Nkg^{-1} soil) and to the unfertilized plot (17 to 36 mg N kg^{-1} soil).

In plots amended with FC at a rate of 36 t ha^{-1}, apart from a slightly higher inorganic N concentration relative to the control soil up to day 35, inorganic N remained most of the time lower than the native soil N in the plant cane (Figure 3.2.2). Thisobservation reflects the decreased index of N availability (N_0k) in the H soil from 0.975 mg N kg^{-1} soil day^{-1} to 0.881mg N kg^{-1} soil day^{-1}upon addition of FC during the laboratory incubation. With a higher C:N ratio (9.2)than PL (6.2) and PM (6.2), FC may have promoted N assimilation by microbes instead of N mineralization. The presence of lignin (22.6%) in FC may also have lowered the rate of organic N breakdown, as shown in an experiment of Muhammad et al. (2010) with cotton residues having a lignin content of 21%.A beneficial effect commonly attributed to enhanced SOM is improved soil water-holding capacity and microbial flora (Hongwei et al. 2012). Located at Britannia where the zonal annual rainfall ranges from 1500 to 3750 mm, the H soil amended with FC may have fostered a low-oxygen environment in the cane row by extending the period during which pore spaces are filled with water. Such conditions inhibit the activity of *Nitrosomonas* and *Nitrobacter* that regulate nitrification and the production of NO_3^-(Canali et al. 2011), and have been linked to increased emissions of nitrous oxide (Weitz et al. 2001).

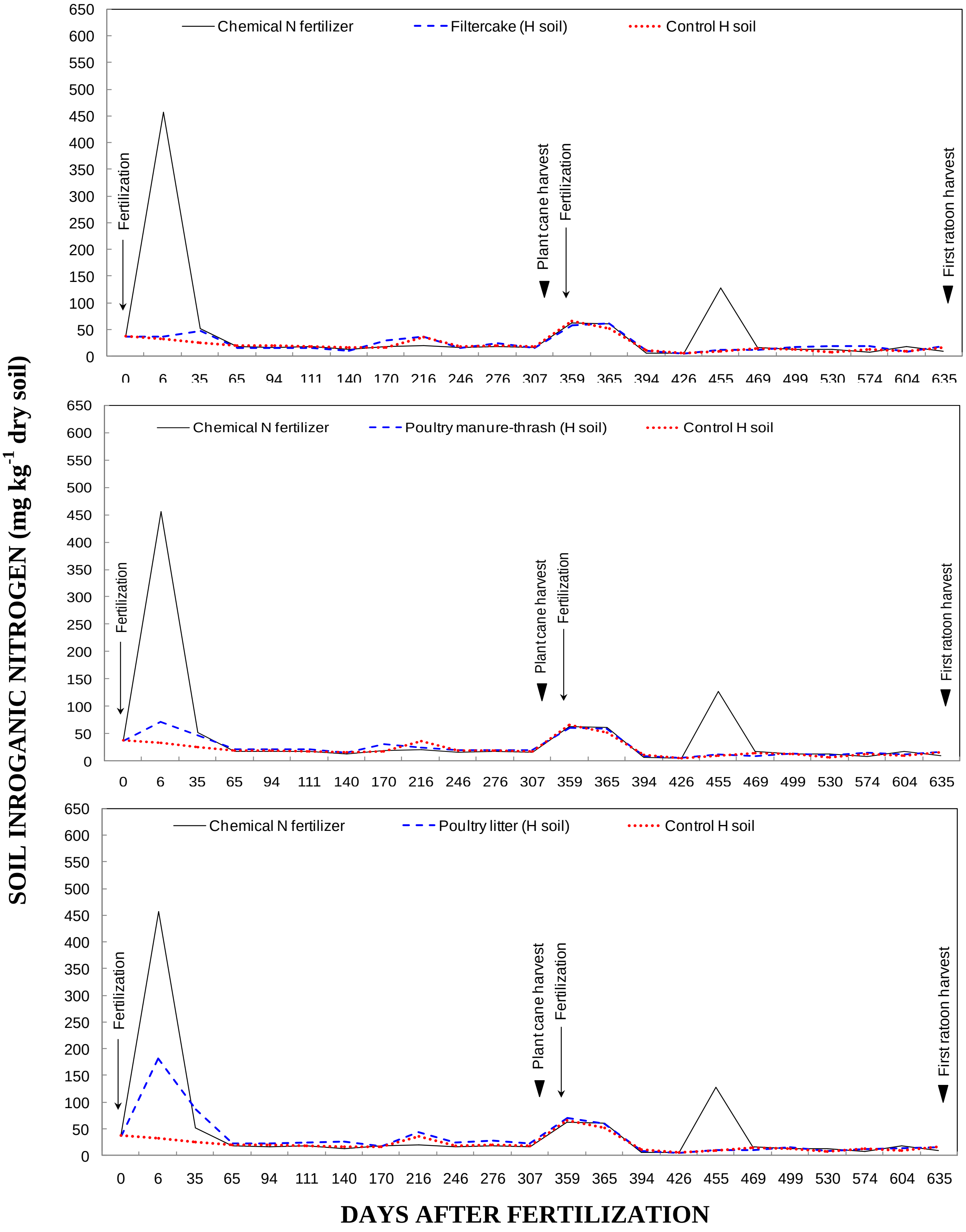


FIG. 3.2.2: Changes in inorganic nitrogen in a Humic Latosol soil (H) of Britannia upon fertilization with agricultural composts

In the first ratoon, FC application was discontinued to determine the residual N value of FC. The soil N values 58 days after harvest (day 365) were higher than the control soil and suggest the mineralization of N from the organic pool. Thereafter, the N levels remained low till harvest.

At an application rate of 22 t ha^{-1}, PM resulted in a positive priming effect upon application in the cane row at planting. Accordingly, from day 5 to 111, the inorganic N levels ranged from 22 to 72 mg N kg^{-1} soil in PM-amended plots, and from 18 to 33 mg N kg^{-1} soil in control plots. This observation is consistent with the improved availability of N in soils treated with PM during the laboratory incubation, increasing from 0.975mg N kg^{-1} soil day^{-1} to 1.327mg N kg^{-1} soil day^{-1}. Nevertheless, during the first 35 days of application, PM did not match the high spike of inorganic N from inorganic fertilizer application. In the first ratoon, when PM application was discontinued, the soil N levels were in general very close to the native N levels of the control.

Amongst the three types of agricultural compost applied at Britannia, PL had the most marked positive effect N mineralization as in the laboratory incubation experiment whereby the mixing of PL with soil increased N_0k from 0.975mg N kg^{-1} soil day^{-1} to 1.533mg N kg^{-1} soil day^{-1} over 215 days. In an incubation study on the N mineralization behavior of 47 crop residues, Trinsoutrot et al. (2000) identified total N as the most influential factor in N dynamics. Indeed, compared to other types of compost, PL had the highest N content. Applied at a rate of 13 t ha^{-1} (fresh weight basis), PLwhich contained on average 3.66% of total N and 43.02% of OM resulted in inorganic N levels that were persistently higher than the control soil throughout the field trial. As from day 35 till harvest, the measured concentrations of inorganic N in PL-amended soil (18 to 87 mg N kg^{-1} soil) were also higher than soils fertilized with inorganic N (13 to 53 mg N kg^{-1} soil). Generally, OM is described as being composed of pools that decompose at varying rates to release inorganic N (Benbi and Richter 2002), and depending on the microbial turnover time, the pools may be either active, intermediate or passive (Sollins et al. 1996, Von Lützow et al. 2006). The constantly higher N supply of PL relative to the control and inorganic N fertilizer plots even during the period of maximum crop uptake may indicate that the OM pool of PL is mostly active in nature.

3.6.4 Inorganic nitrogen in resins in Humic Latosol (H soil group) of Britannia

As shown by the graphs in Figure 3.2.3, despite the fact that the Britannia field experiment was done under non-irrigated conditions, the cumulative amount of rainfall recorded till 17 April 2014, the last sampling date, was approximately two times higher than the volume of water (rainfall plus irrigation) at Pierrefonds. As a result of the greater N-supplying capacity of the H soil compared to the P soil, and under high rainfall conditions, the resins placed to a depth of 0.20 m in the control treatment of Britannia trapped a greater concentration of N ions, 130.6 mg N kg^{-1} soil at Britannia against 107.5 mg N kg^{-1} soil at Pierrefonds.

By the end of the incubation period, 1499 mm of rainfall had been recorded at Britannia. Analysis of the amount of inorganic N adsorbed by the resins showed that the movement of N ions down the soil profile was highest in plots fertilized with inorganic N fertilizer, reaching 547.9 mg N kg^{-1} soil. This was over three times higher than observed for the control treatment (130.6 mg N kg^{-1} soil).

In plots fertilized with blends of inorganic N fertilizer and compost, the presence of inorganic N in the resins was lower than in plots fertilized with only inorganic fertilizer. The concentration of inorganic N in the resins was in the order inorganic N fertilizer (547.9 mg N kg^{-1}soil)> PM blend (369.9 mg N kg^{-1} soil) > PL blend (322.3 mg N kg^{-1} soil) > FC blend (188.1 mg N kg^{-1} soil).The results presented in Figure 3.2.3 therefore indicate that the blending of compost with inorganic N fertilizers can reduce the movement of inorganic ions downwards, potentially minimizing the risks of N leaching.

In Figure 3.2.4, the inorganic N captured by resins in soils treated with FC (179.6mg N kg^{-1} soil), PM (382.6 mg N kg^{-1} soil) and PL (200.1mg N kg^{-1} soil) show that the amount of inorganic N was lower than with inorganic fertilizer.

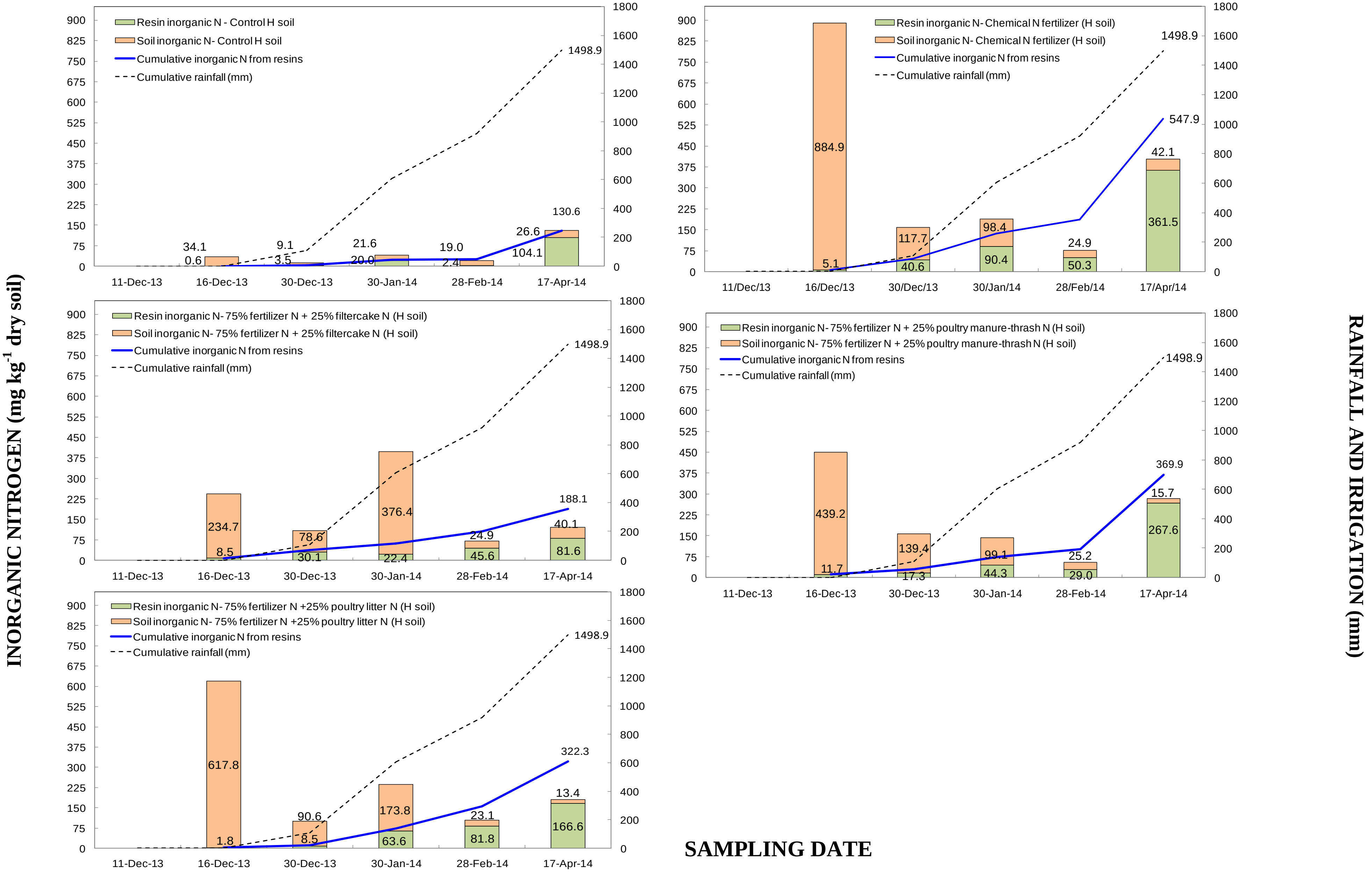


FIG. 3.2.3: Inorganic nitrogen in resins and Humic Latosol soil (H) of Britannia amended with combinations of chemical nitrogenous fertilizer and compost

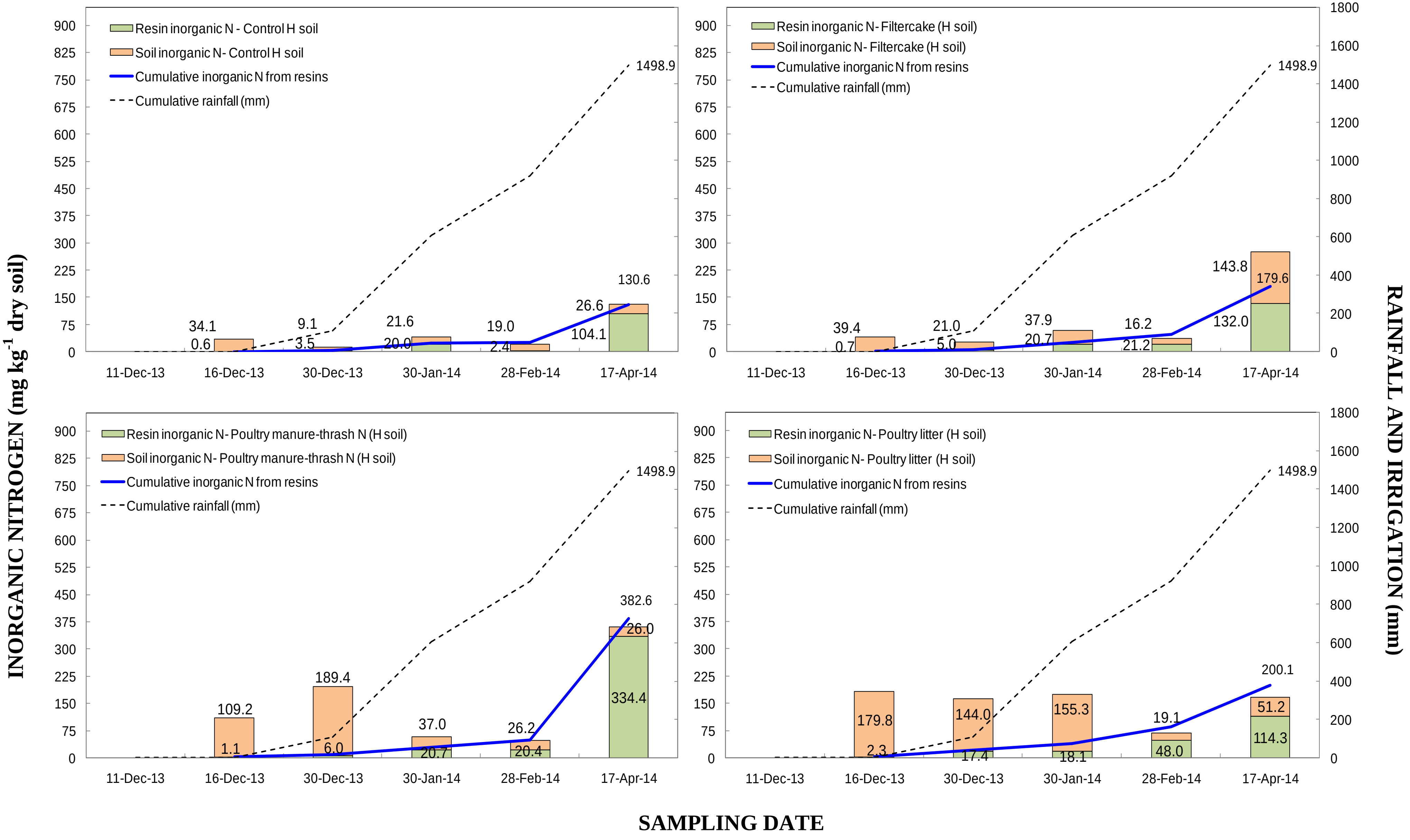


FIG. 3.2.4: Inorganic nitrogen in resins and Humic Latosol soil (H) of Britannia amended with agricultural composts

3.6.5 Evolution of inorganic nitrogen in a Low Humic Latosol soil (L group) at Chebel

The trial plot of Chebel had not been under sugarcane cultivation in the past, and required heavy de-rocking for mechanical operations such as planting, harvest or weed control to be feasible. The intensive soil preparation at Chebel delayed the implementation of the field trial, which was consequently laid down one year after those of Pierrefonds and Britannia. Accordingly, changes in inorganic N in plots subjected to different fertilization regimes were only monitored during one year (plant cane) in the L soil group instead of two years as in the P and H soil groups.

As presented by Figure 3.2.5, six days after the start of the experiment, 59 mg N kg^{-1} soil was measured in the control soil of Chebel. Despite the fact that such a high initial inorganic N concentration was neither detected at Britannia nor at Pierrefonds, the soil N levels at these two sites were still higher than at Chebel throughout the trial. The quantitative analysis of inorganic N in soil of the three sites reflected the trend in N availability (N_0k) observed in the laboratory incubation whereby the daily N availability (mg N kg^{-1} soil day^{-1}) was in the order H (0.975) > P (0.631) > L (0.524).

Unlike in the H and P soil groups where a peak in inorganic N was measured six days after fertilization, a flush in N was only noted after 20 days at Chebel for the fertilization regimes shown in Figure 3.2.5, and varied from 243 mg N kg^{-1} soil (PL blends) to 239 mg N kg^{-1} soil (inorganic N fertilizer), to 151 mg N kg^{-1} soil (PM blends) and 93 mg N kg^{-1} soil (FC blends). Because the inorganic N concentrations in fertilized plots were comparable to native soil N immediately after fertilization, it is suspected that soil mineralogy had an incidence on the release of N ions in the soil solution. Of the three soil groups, the L soil had the highest clay content (75.3%). Clay minerals are negatively charged and not only encourage the adsorption of organic molecules (Mortland 1986, Zech et al. 1997) on the charged surfaces, but also of NH_4^+ ions that have a high affinity for clay particles (Aulakh and Singh 1997). The likelihood of NH_4^+ fixation increases from coarse-textured soil to medium-textured and is highest in fine-textured soil (Neider et al. 2011). This could explain why the N spike occurred immediately after fertilization in soils of Pierrefonds (31.7% clay) and Britannia (47.3% clay) which had a lower clay content, and was delayed at Chebel.Indeed N mineralization tends to be higher in coarser-textured soils due to a lower adsorption of organic molecules (Canali et al. 2011).

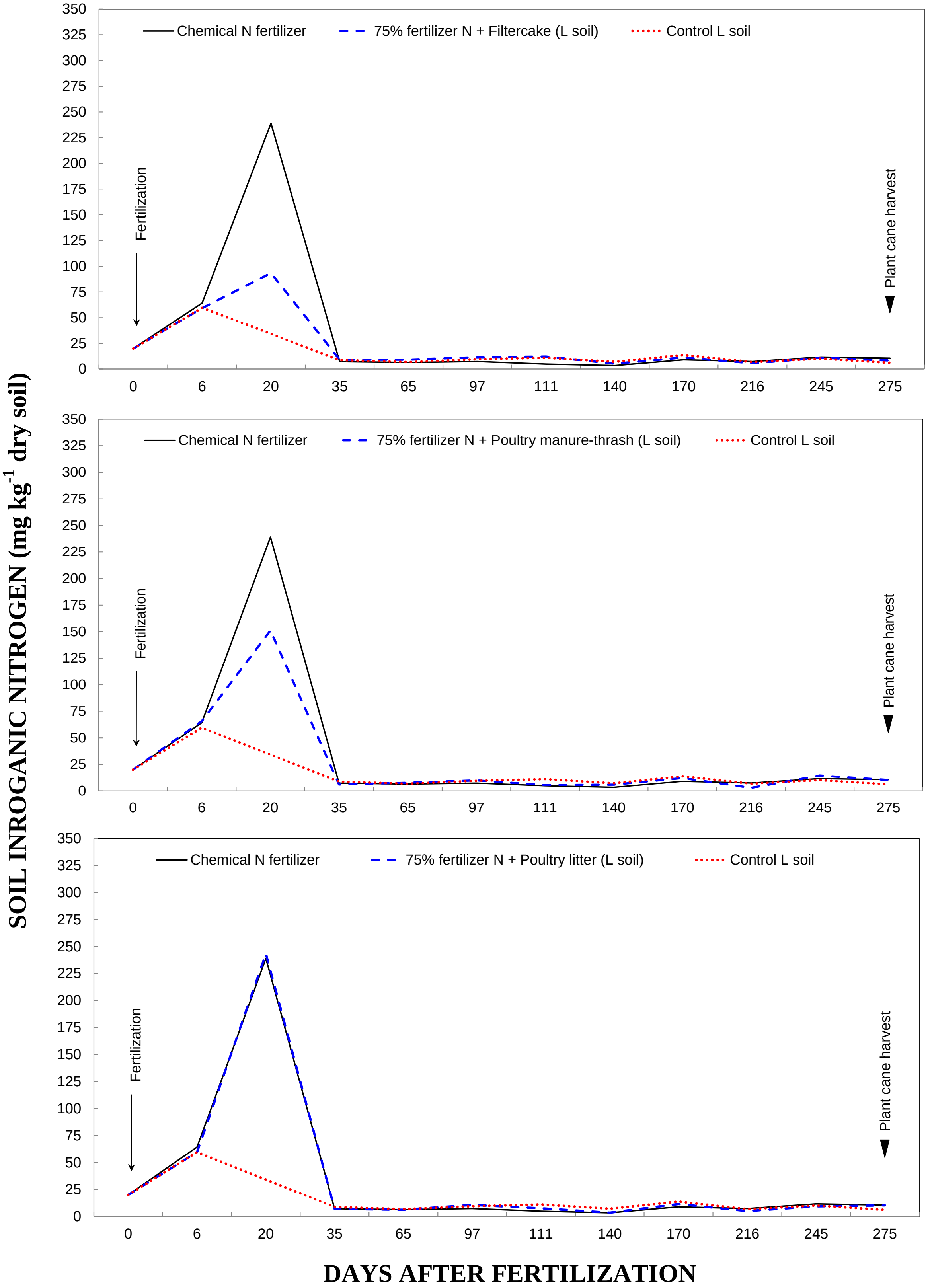


FIG. 3.2.5: Changes in inorganic nitrogen in a Low Humic Latosol soil (L) of Chebel upon fertilization with combinations of inorganic fertilizers and agricultural composts

Within 35 days of fertilization, there was a drastic drop in inorganic N to basal levels not exceeding 12 mg N kg^{-1} soil for inorganic N fertilizer, FC and PL blends and14 mg N kg^{-1} soil for PL blends. From then onwards, only a negligible difference was detected between native soil N and inorganic N in fertilized soils till harvest. The frequent and intense rainfall events during the first month of planting could also have contributed to the drop in inorganic N observed by promoting leaching, dentrification or even run-off losses as the trial plot was quite sloppy. Where water accumulation was persistent, cane growth was very poor and required recruiting. Considering the fact that PL blends resulted in quantities of bioavailable N comparable to those obtained with inorganic fertilizer only, this blend could not only constitute an interesting source of N to sugarcane, but also OM to conserve and promote soil fertility in the long term.

The application of agricultural composts as the only N source lead to the different inorganic N profiles shown in Figure 3.2.6. In general, the peak in inorganic N concentrations occurred 20 days after soil amendment, but the quantities measured were lower than when blended with inorganic fertilizer. At day 20, the levels of soil N varied from 26 mg N kg^{-1} soil (FC) to 86 mg N kg^{-1} soil (PM) and 119 mg N kg^{-1} soil (PL). With a greater total N content than FC, both PM and PL had a positive bearing on inorganic N concentrations in soil relative to the control soil 20 days after fertilization. Nevertheless, the increase in inorganic N did not match that obtained with inorganic N fertilizer. When FC was localized in cane rows at planting, the soil N levels remained inferior to the indigenous soil N up to day 97, following which inorganic N became more available. This observation is consistent with the initial, temporary N immobilization reported by Chabalier et al. (2006) when FC is localized in cane rows. Considering the innately low N content and higher C:N ratio of FC compared to other composts, it was expected that FC would indeed lead to immobilization instead of mineralization. Because of the extended immobilization period of approximately three months, there is a risk that FC might not provide a sufficient amount of N for the initial development of cane. The trend in inorganic N *in situ* also mirror the relatively lower amount of net N mineralized in the laboratory incubation experiment when FC was added to the L soil. The temporary initial N immobilization observed in the field trials with compost is also consistent with the findings of Nguyen et al. (2015). However, the immobilization periods were longer than the 10-day period reported when biosolids compost was used.

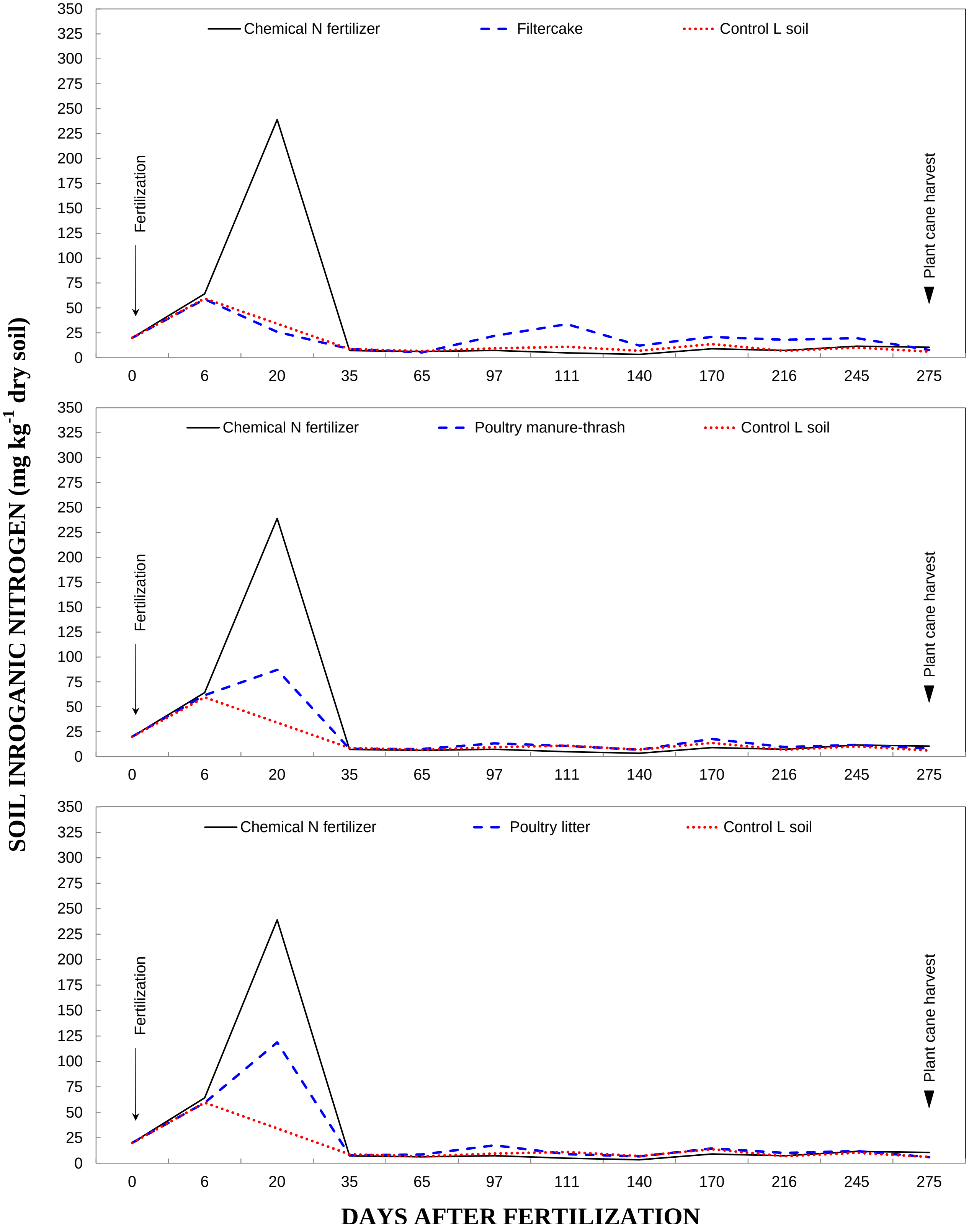


FIG. 3.2.6: Changes in inorganic nitrogen in a Low Humic Latosol soil (L) of Chebel upon fertilization with agricultural composts

3.6.6 Inorganic nitrogen in resins in Low Humic Latosol (L soil group) of Chebel

The chemical and physical analyses done on the L soil ofChebel at the start of the field experiment characterized this soil as fine-textured with a clay content of 75.3% and an OM content of 3.46%. During the laboratory incubation, the Spearman's correlation coefficients showed a positive correlation between inorganic N mineralized and OM in control soils, and as a soil that had the lowest OM content of the five soil groups under study, the L soil also had the lowest N mineralization capacity (0.524 mg N kg^{-1} soil day^{-1}).Figure 3.2.7 show that by the end of the *in situ* incubation at Chebel, on 13 April 2015, 688 mm of rainfall and 172 mm of irrigation had been received. Under these field conditions, 96.6 mg N kg^{-1}soil were detected in the resins of control plots, the N concentrations being lower than at Pierrefonds and Britannia. This trend could be explained by the innately low N mineralization capacity of the L soil, and also potentially by clay-fixation of NH_4^+ ions resulting from ammonification (Neider et al. 2011).

From Figures 3.2.7 and 3.2.8, it can be seen that soils amended partly or fully with compost resulted in the least concentrations of N ions in the resins. The descending order of inorganic N concentration support this statement, being inorganic fertilizer (338.5 mg N kg^{-1} soil) > PL blend (304.6 mg N kg^{-1} soil) > FC blend (247.3 mg N kg^{-1} soil) > PM blend (203.4 mg N kg^{-1} soil) > FC (171.6 mg N kg^{-1} soil) > PM (123.2 mg N kg^{-1} soil) > PL (101.8 mg N kg^{-1} soil) > control (96.6 mg N kg^{-1} soil). These results indicate that the dual use of agricultural composts with reduced rates of inorganic N fertilizer, or compost as the only source of N, can potentially decrease the risks of N losses by leaching.

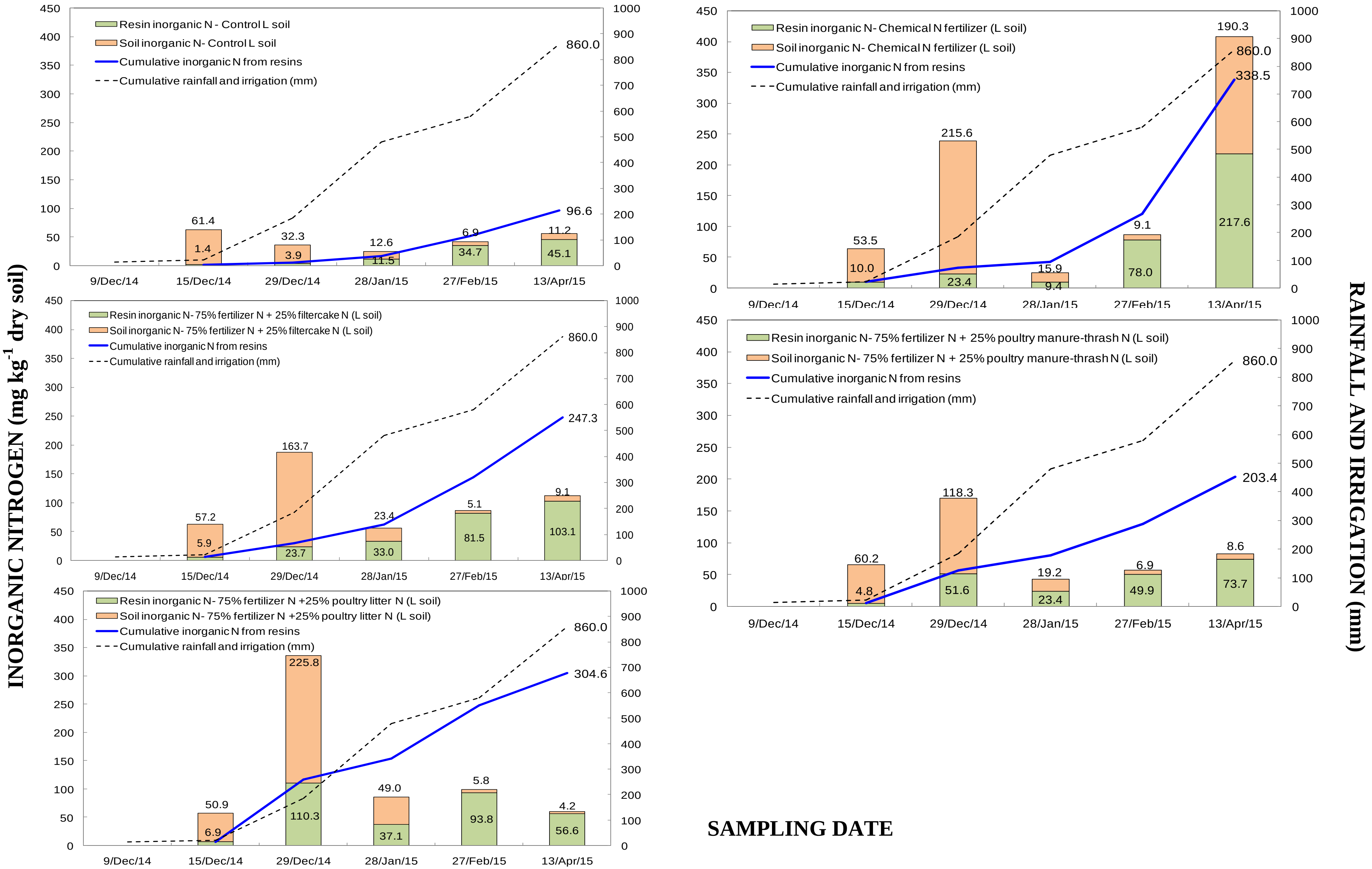


FIG. 3.2.7: Inorganic nitrogen in resins and Low Humic Latosol soil (L) of Chebel amended with combinations of inorganic nitrogenous fertilizer and compost

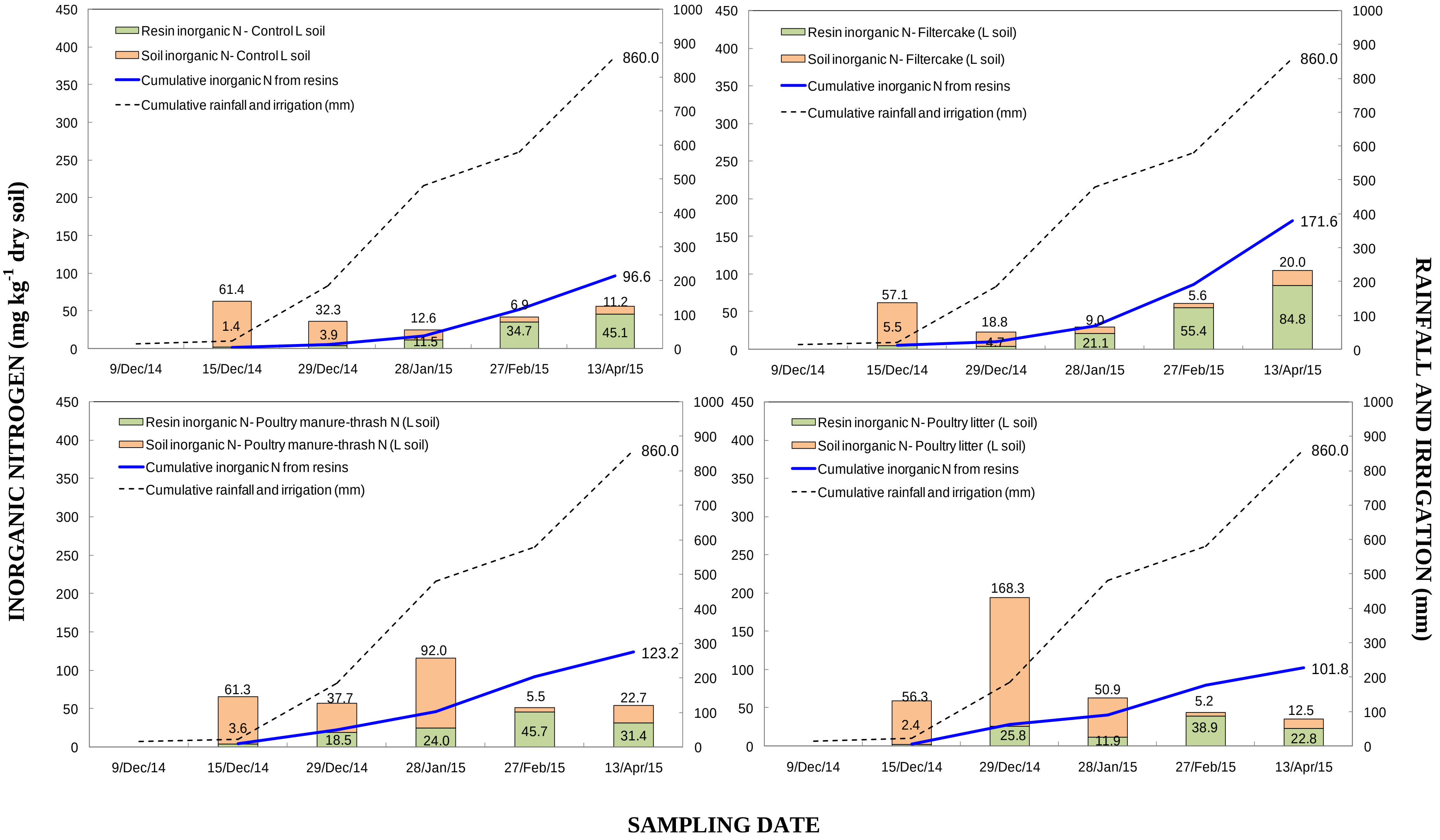


FIG. 3.2.8: Inorganic nitrogen in resins and Low Humic Latosol soil (L) of Chebel amended with compost

3.7 Effect of agricultural composts on sugarcane yield

3.7.1 Plant cane yield response to treatments at Pierrefonds, Britannia and Chebel

As shown by Figure 3.2.9, crop yield response to N fertilizers in plant cane ranged from 0.3% to 14% in the P soil of Pierrefonds, 8% to 25% in the H soil of Britannia, and from 5% to 32% at Chebel. Referring to the index of N availability (N_0K) determined in the laboratory incubation experiment (Chapter 2), it is interesting to note that yield response to N fertilizer was highest in the L soil group which had the lowest N mineralization potential(0.524 mg N kg^{-1} soil day^{-1}) of the three soil groups. Overall, yield response to applied fertilizers at planting was low and no significant differences ($P > 0.05$) were observed amongst the treatments of the same site (Appendix X).

Previous field studies done in Mauritius in the 1960s have shown that there were no significant yield differences between unfertilized and fertilized (with inorganic fertilizers) plots for a plant cane (Parish and Feillafé 1962). Indeed, at the three sites, the response of plant cane to N fertilizer was low, and the yields obtained for these plots were only 6% higher than the unfertilized plot at Pierrefonds, 8% higher at Britannia and 10% higher at Chebel. In practice, soil tillage precedes planting and during this operation, OM which was previously occluded becomes exposed to oxygen, and undergoes faster oxidation than it would have in an undisturbed state (Chen et al. 2009). Since SOM is the source of organic N in soil (Van Antwerpen et al. 2013), it may be deduced that the amount of N mineralized from SOM in the control soil was sufficiently high to produce cane yields comparable to the fertilized plots. This is consistent with the fact that 85% of N taken up by the crop originates from mineralized soil N (MSIRI 2001). In general, the highest cane yields were observed under irrigated conditions at Pierrefonds and Chebel and the lowest yields under rainfed conditions at Britannia.

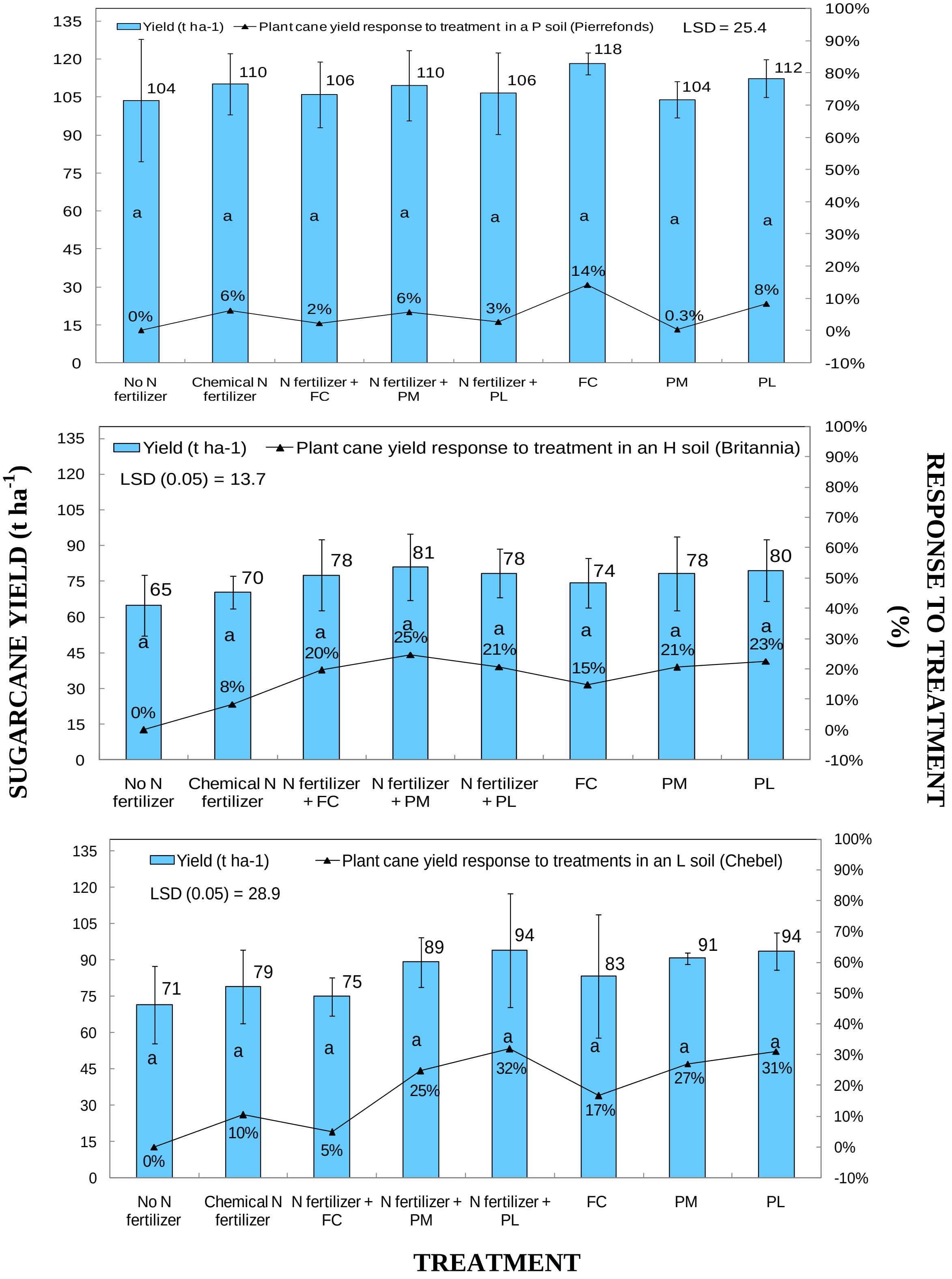


FIG. 3.2.9: Sugarcane yield response to treatments for the plant cane crop at Pierrefonds, Britannia and Chebel. Mean yields with the same letter are not statistically significant

A statistical analysis of the yields obtained at the three sites showed significant cane yield differences ($P < 0.001$) between the three soil groups which were located in different agro-climatic zones (Appendix X). Considering the distinct chemical and physical characteristics of the soils under study, and the prevailing climate at the trial sites, it was expected that the yield response to treatments would differ significantly. At Pierrefonds, it was surprising to note that out of the three composts, FC which had the lowest total N and OM contents achieved the highest yield, producing 14% more cane than the control although this was not statistically significant. Based on the monitoring of inorganic N concentrations in soil *in situ*, it was expected that PL-amended plots would out yield those treated with FC but this was not the case. In a study of Moberly and Meyer (1978), it was reported that the positive cane yield response to FC applied in the cane row could partly be explained by the fine texture and moisture content of FC. In the rocky soils of Pierrefonds where sett-soil contact may be poor, FC which had an initial moisture content of 59.7%, could have promoted germination and cane establishment. Indeed, at an application rate of 36 t ha^{-1}, and a planting width of 1.8 m, it can be assumed that 3.89 L of water were supplied to the cane setts on a linear meter basis. At Britannia and Chebel, a similar positive response of 15% and 17% respectively, to FC was noted, but unlike at Pierrefonds, the responses were relatively low compared to other treatments implemented at the same site.

At the three sites, PL compost which was applied at rates varying between 10 and 13 t ha^{-1} in the cane rows, sustained sugarcane growth and development to produce yields that were numerically higher than those achieved with inorganic fertilizer despite being statistically insignificant. The response was in the order L soil (31%) > H soil (23%) >P soil (8%). Although P and K were applied to be non-limiting according to soil analyses, the inherently low soil P and K of the L and H soil may also explain the greater response of these soils compared to the P soil, as PL compost contained appreciable amounts of P and K. The relative nutrient gain from compost could therefore have been higher in the H and L soils than in the P soil, and was translated into stronger yield responses. While positive responses of 27% and 21% were observed at Chebel and Britannia respectively when PM was applied in the cane row, a response of only 0.3% was noted at Pierrefonds. These observations are consistent with the results obtained in the laboratory incubation study whereby PM increased daily N mineralization in both L soils (from 0.524 to

0.667 mg N kg^{-1} day^{-1}) and H soils (0.975 to 1.327 mg N kg^{-1} day^{-1}), but had an inverse effect on the immature P soil, decreasing N mineralization from 0.637 to 0.454 mg N kg^{-1} day^{-1}.

Across the sites, reduced rates of inorganic N fertilizer with agricultural composts resulted in positive yield responses relative to the control soil. In the plant cane, the P soil of Pierrefonds was the least responsive to the blended treatments and the L soil of Chebel the most responsive. In general, responses to blends of inorganic N fertilizer and compost ranged from 2% to 6% at Pierrefonds, 20% to 25% at Britannia and 5% to 32% at Chebel. At Britannia, the three compost blends even produced higher yields than inorganic fertilizer only (response of 8%), although the differences were not statistically significant. The H soil which is naturally acidic may have reacted more strongly to the blend with PM which is highly alkaline (pH of 9.46) and might have improved the availability of nutrients which at low pH are only partially available. Neutralization of soil acidity by PM has been reported by Ano and Ubochi (2007).

3.7.2 Industrial recoverable sucrose response to treatments in plant cane crop at Pierrefonds (P group), Britannia (H group) and Chebel (L group)

In terms of industrial recoverable sucrose (IRSC), Figure 3.3 shows that in general, in the plant cane crop, the IRSC varied from 11.94% to 13.04% at Pierrefonds, 11.55% to 12.82% at Britannia and 10.97% to 12.48% at Chebel. The statistical difference between treatments of the same site was not significant despite the numerical variation observed (Appendix XII). Over and above fertilization treatments, temperature amplitudes between day and night, water supply and crop genetics are factors that have a direct impact on maturation, and explain the differences in IRSC across the sites. To measure the influence of N treatments on sucrose content, the IRSC in each treatment was therefore compared to control treatment that did not receive N fertilizer. The IRSC responses were highly variable from one site to another. While all the N treatments improved IRSC at Chebel, almost all the treatments (except PL compost and the blend of inorganic fertilizer with PM) depressed sucrose content at Pierrefonds. At Britannia, relative to the control treatment, positive responses to N fertilization were also noted, except when PM was applied. In the context of N fertilization, depressed sucrose concentration in sugarcane stalks is often explained by luxury N uptake by the crop (Muchow et al. 1996).

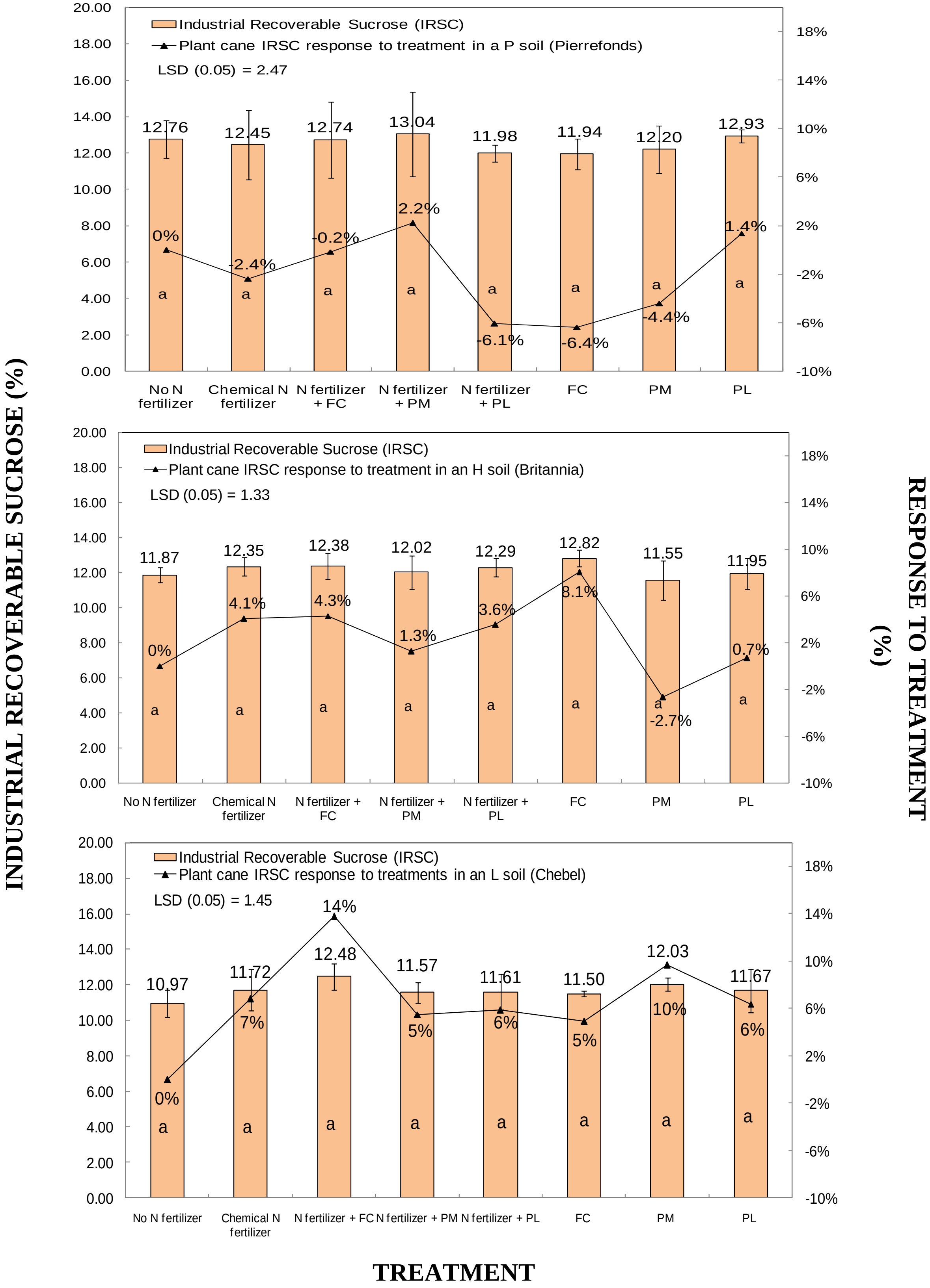


FIG. 3.3: Industrial recoverable sucrose (IRSC) in plant cane at Pierrefonds, Britannia and Chebel. IRSC means with the same letter are not statistically significant

In the L soil group of Chebel, it can be stated that additional sources of N applied were highly beneficial to sucrose content, relative to the control treatment. At this site, the highest IRSC response was achieved with the blend of inorganic fertilizer and FC (IRSC of 12.48%) and the lowest positive response with FC only (IRSC of 11.50%). The input of N may have potentially caused a shift in the ratio of clay to NH_4^+ ions which are known to be adsorbed on the surface of negatively-charged clay particles.

As shown by the laboratory incubation study, both the P soil group of Pierrefonds and the H soil group of Britannia had a higher daily N mineralization potential than the L soil group. At Pierrefonds, almost all the N treatments, including inorganic fertilizer, caused a numerical decrease in sucrose content, thereby indicating either luxury N uptake or delayed N mineralization. According to Muchow et al. (1996), high levels of N applied towards the end of the grand period of growth may result in lower sucrose content by promoting the diversion of dry matter to further growth rather than to storage in the stem. This could explain the low sucrose content in FC, PM, inorganic fertilizer-PL treated plots compared to other treatments in the P soil group. With regards to FC, Moberly and Meyer (1978) also reported a drop in IRSC when FC was applied at rates of 50 t ha^{-1} and above, the phenomenon being more marked in soils with high N mineralization power. It is suspected that OM-rich FCtriggered soil N mineralization in the P soil by providing sufficient moisture to sustain microbial activity in a rocky soil where water availability tends to be irregular. This aspect warrants further investigations. At Britannia, in the H soil group, IRSC improved with the all the N fertilizer treatments, except with PM, where IRSC was 2.7% lower than the control treatment.

The high peaks of inorganic N observed *in situ* upon incorporation of PL did not lower the IRSC relative to the control in any of the soil groups. As underlined by Muchow et al. (1996), only N spikes late in the season are susceptible to decrease IRSC by prolonging vegetative growth.However, at Chebel and Britannia where the yield responses to PL were more pronounced, less sugar was recovered in PL-amended plots compared to inorganic fertilizer.With the PM treatment,it was noted that compared to the control, IRSC was depressed at Pierrefonds and Britannia, but not at Chebel. While the spikes in inorganic N late during the cycle at Pierrefonds could explain the lowered sucrose content, an increased N mineralization and uptake at Britannia could have occurred. In general, the IRSC obtained where PM and PL blends were applied were lower than with inorganic fertilizer only, although not statistically significant. Across the three sites, FC blends resulted in a better IRSC than with inorganic fertilizer only.

3.7.3 First ratoon yield response to treatments at Pierrefonds, Britannia and Chebel

In general, the yields obtained in the first ratoon were lower than the plant cane, except at Chebel where recruiting was done just after harvest to fill the gaps caused by the heavy rainfall event that occurred immediately after planting. As shown by Figure 3.3.1, the yield response to inorganic N fertilization was more marked in the first ratoon than in the plant cane, ranging from 12% at Britannia, to 36% at Chebel, and 46% at Pierrefonds. Previous studies in Brazil indicated that while only 10% of the total accumulated N in the above-ground parts of plant cane at harvest came from the applied inorganic N fertilizer (Franco et al. 2011), the N use efficiency of sugarcane increased in ratoon cane as 30% of the accumulated N at harvest was found to originate from inorganic N fertilizer. This stronger N-yield response may be the result of an increased use efficiency of added inorganic N following the high use of newly mineralized N from SOM for the plant cane crop.

The difference between yields of the control plots of Britannia and Chebel was quite small from the plant cane to the first ratoon, indicating that more or less the same amount of N was being mineralized from SOM and acquired by the crop. However, at Pierrefonds, the yield of the unfertilized plot decreased by 44%, which suggests a sharp decrease in the amount of inorganic N mineralized in the P soil from the plant cane to the first ratoon. This could explain why the P soil was the most responsive to the different treatments. Only at Pierrefonds were differences in yield between treatments significant ($P < 0.001$), mostly due to the low yield for the control treatment (Appendix XI).

To evaluate the residual value of compost N, some plots were only amended with compost in the cane rows at planting following which compost application was discontinued. These treatments showed that agricultural composts had the lowest residual value at Britannia and the highest at Pierrefonds.

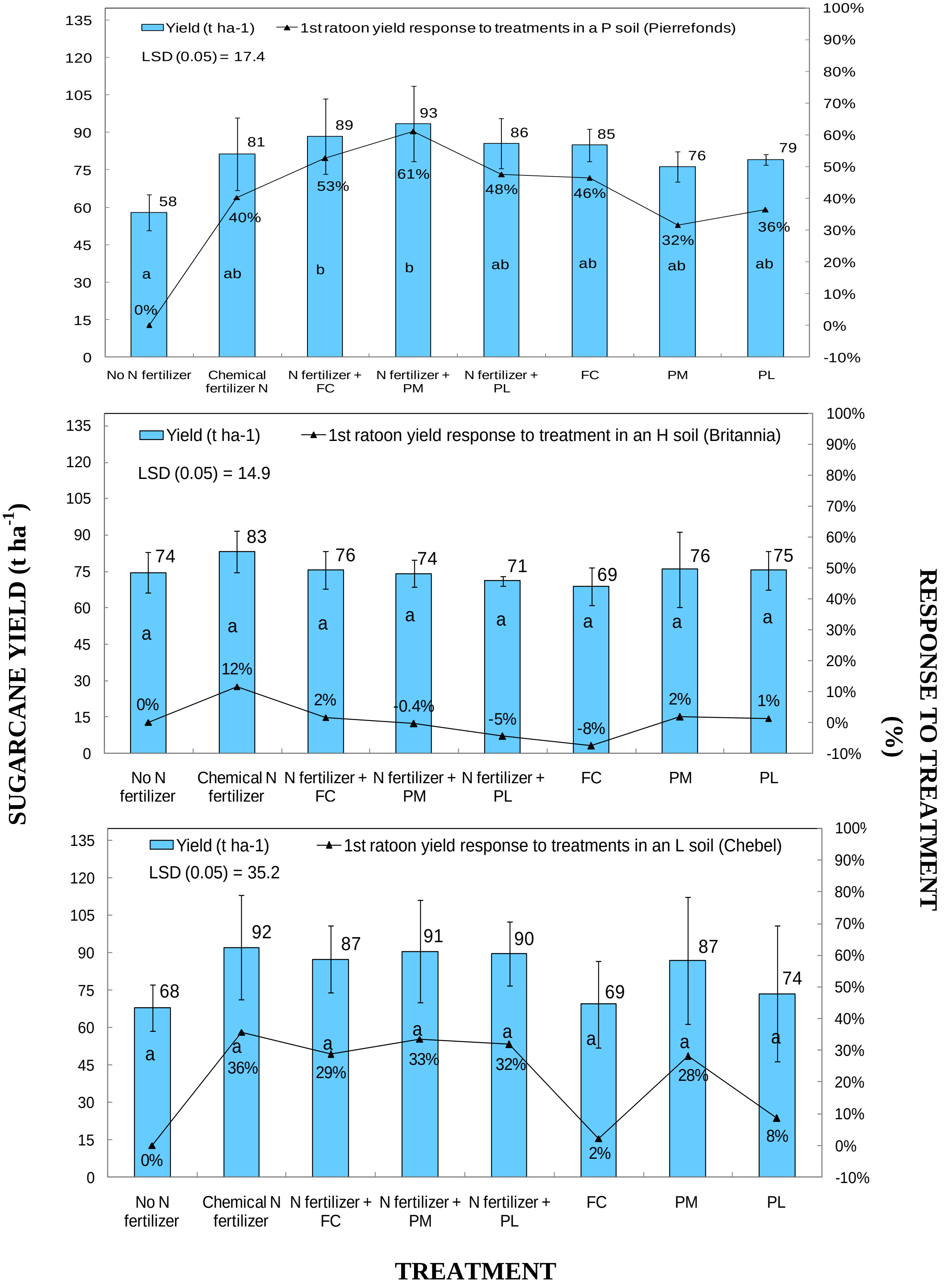


FIG. 3.3.1: Sugarcane yield and response to treatments in the first ratoon cane of Pierrefonds, Britannia and Chebel. Mean yields with the same letter are not statistically significant

Out of the three soil groups, the H group the widest C:N ratio (10.1), and it is generally accepted that incorporated materials with C:N ratios wider than 10 lead to N immobilization (Nicolardot et al. 1986). In this context, FC that had the highest C:N ratio of the three composts, may have depressed the inorganic N content of soil by promoting microbial assimilation, causing a negative yield response of -8% relative to the control in the first ratoon in the presence of cane thrash. However, in the L soil group, the cane yield response to FC, although weaker than in the plant cane, was still positive (2%) in the first ratoon. As noted earlier, FC had the strongest positive impact on cane yield at Pierrefonds, with a yield response of 46%. It was encouraging to see that the yield response to FC was even higher than with inorganic N fertilizer (40%). It is postulated that besides the residual N value of FC, the water retention capacity of this fine-textured compost may also have contributed to a strong positive yield response. The residual effects of FC on yield in the first ratoon were also reported by Moberly and Meyer (1978) and positive effects were noted in nine of the ten field experiments implemented.

In plots amended with PL and PM in the plant cane crop and in which the treatments were discontinued in the first ratoon, positive yield responses were observed at the three sites in the first ratoon. In both the H and L soils PM had a stronger residual effect on yield than PL. In the P soil, the inverse was true. Compared to inorganic fertilizers which are most often formulated to be immediately plant-available, composts have a heterogeneous composition and consist of different SOM fractions that vary in their turnover rates (Zech et al. 1997, Sohi et al. 2001). Consequently, it is plausible that inorganic N immobilized in plant cane mayhave become available by mineralization in the first ratoon.

Sugarcane yields obtained when reduced rates of inorganic fertilizer were applied with the three types of compost were statistically comparable to yields from plots fertilized with inorganic N fertilizer only. At Britannia, although a negative yield response relative to the control soil resulted from the application of blends with PL (-5%) and PM (-0.4%), the decrease in yield was not substantial enough for the yield differences to be significant. Only the FC blend produced a positive yield response at Britannia. However, after only two seasons, it is difficult to draw conclusive remarks about the blended treatments as the benefits of compost usage are mostly observed over the long term. In the high-clay soil of Chebel, the trends in yield with compost-inorganic fertilizer blends varied from 28% with PM, 29% with FC and 32% with PL. Some of the high standard deviations observed at Chebel were partly due to the slope of the land and to the fact that some plots were constantly affected by flowing rain water during heavy rainfall events which may have caused some run-off. The strongest responses were noted at Pierrefonds whereby all the three blends out-yielded the remaining treatments, with responses as high as 48% with PL, 53% with FC and 61% with PL blends.According to the results, it is clear that the dual use of inroganic fertilizers with compost produces statistically similar cane yields as inorganic fertilizer only, and that the residual N value of compost, particularly for PM and PL, in the first ratoonmay allow further reduction in inorganic N fertilizer consumption.

3.7.4 Sucrose response to treatments in first ratoon crop

In the first ratoon crop, IRSC at the different sites was higher than in the plant cane crop, being in the range of 12.59% to 13.26% at Pierrefonds, 11.80% to 12.53% at Britannia and 13.42% to 13.91% at Chebel (Figure 3.3.2). In the P soil group of Pierrefonds, the IRSC responded positively to all the treatments, although to a limited extent to FC. Overall, the blended treatments produced a higher IRSC than both the compost treatments and the inorganic fertilizer at Pierrefonds.

Relative to the control, the decrease in IRSC noted with PM at Britannia in the plant cane was also observed in the first ratoon. The remainingtreatments also resulted in IRSC levels lower than the control. Nevertheless, despite a numerically variable IRSC across the treatments, the differences observed were not statistically different. The negative IRSC responses recorded may indicate the capacity of the H soil to maintain a constant supply of inorganic N to the crop so that in the presence of exogenous sources of N, luxury N uptake is favoured.

In the L soil group of Chebel, the blended treatments (except that with PL) produced numerically higher concentrations of sucrose in the stalk compared to the both the compost treatments and the inorganic fertilizer treatment. Unlike in the plant cane crop, PL and PM resulted in lower sucrose concentrations than the control treatment in the first ratoon crop.

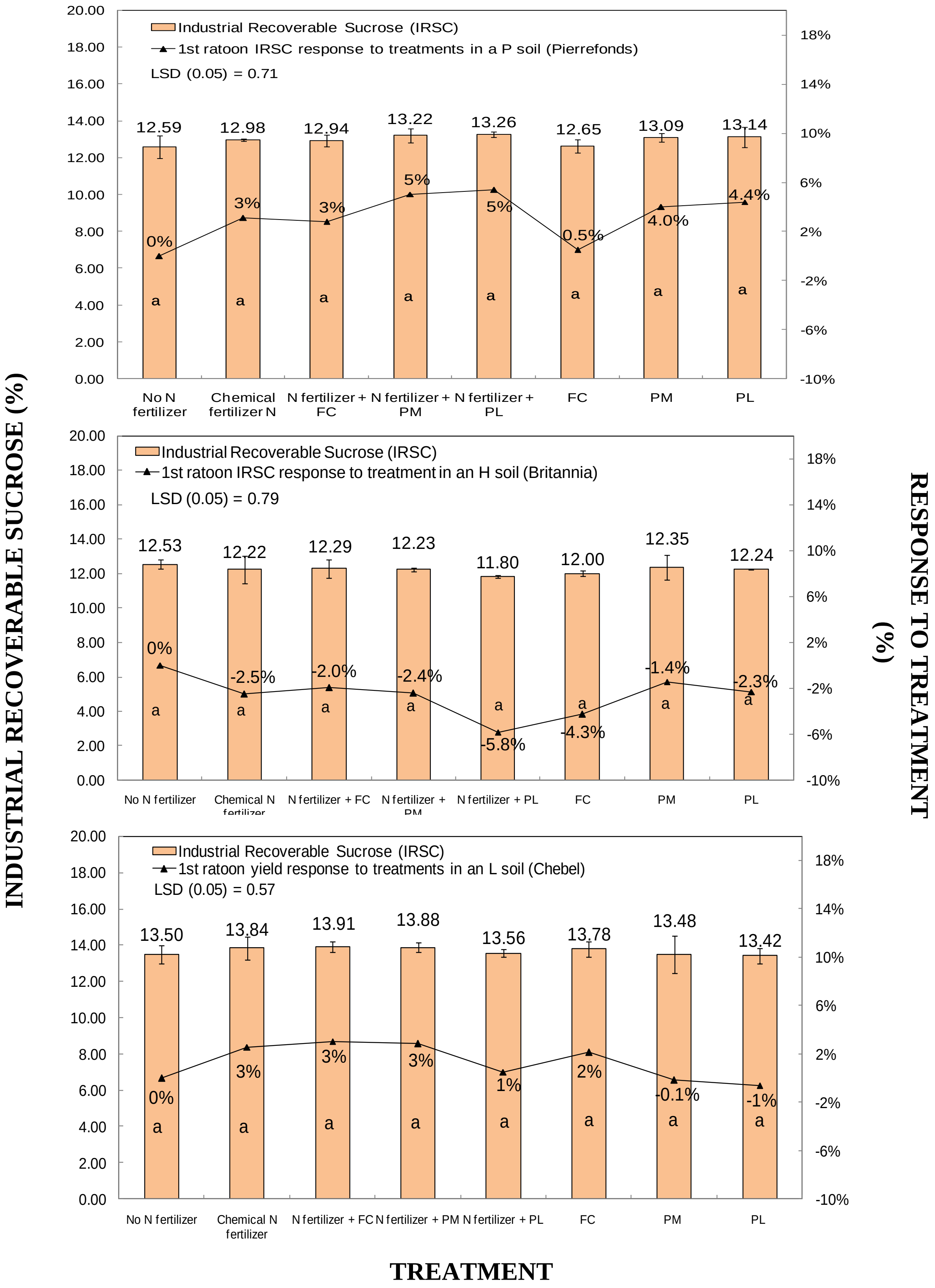


FIG. 3.3.2: Industrial recoverable sucrose (IRSC) in the first ratoon at Pierrefonds, Britannia and Chebel. IRSC means with the same letter are not statistically significant

Based on the assumption that 1.4 kg N is exported for every tonne of millable cane, the average yields of plots previously amended with compost only were converted into equivalent N amounts, and expressed as a percentage of the total amount of N that would need to be applied to achieve different cane yields. The figures presented in Table 3.1.1 are not recommendations, but have been worked out to extrapolate the potential of compost applied at planting as a source of N in the first ratoon. From the earlier graphs in Figure 3.3.1, the positive yield responses to compost showed clearly that compost had a residual value, and could potentially help growers to reduce the amount of inorganic N fertilizers applied. Henceforth, in Table 3.1.1, it can be seen that the residual N value of compost in the P soil ranged from 106.9 to 119.0 kg N ha^{-1}, and could possibly supply between 76 and 85% of the total N to apply for a targeted yield of 100 t ha^{-1}. At Pierrefonds, in the P soil group, FC had the greatest residual value of the three composts. In the H and L soil groups, the N contribution from compost varied from 96.1 to 106.0 kg N ha^{-1}, and 97.1 to 121.6 kg N ha^{-1} respectively. In both the H and L soil groups, PM had the greatest residual value. Overall, it was noted that FC and PL had the strongest residual value in the P soil while N recovery in PM was highest in the L soil.

TABLE 3.1.1: Estimate of the residual value of compost nitrogen in the first ratoon

		Expected yield (t ha^{-1})	120	110	100	90
		Total amount nitrogen to apply (kg ha^{-1}) †	168	154	140	126
Treatment	**Average yield (t ha^{-1})**	**Estimated N supplied (kg ha^{-1}) †**	**% of total nitrogen required supplied by compost**			
P soil + FC	85.0 ± 15.0	119.0	71	77	85	94
P soil + PM	76.3 ± 6.0	106.9	64.	69	76	85
P soil + PL	79.2 ± 15.1	110.8	66	72	79	88
H soil + FC	68.6 ± 7.8	96.1	57	62	69	76
H soil + PM	75.7 ± 15.4	106.0	63	69	76	84
H soil + PL	75.4 ± 7.9	105.5	63	69	75	84
L soil + FC	69.3 ± 17.5	97.1	58	63	69	77
L soil + PM	86.9 ± 25.5	121.6	72	79	87	97
L soil + PL	73.6 ± 27.4	103.0	61	67	74	81

† Based on the assumption that 1.4 kg nitrogen needs to be applied per ton of millable cane

3.7.5 Second ratoon yield response to treatments at Britannia

For the field experiments, yield data for the second ratoon could only be obtained for Britannia due to accidental firing in the Pierrefonds trial in January 2016, three months after harvest of the first ratoon.Due to delays in soil preparation at Chebel, the trial field was only planted in December 2014 instead of December 2013 as at Britannia and Pierrefonds.Owing to favourable weather conditions during the year preceding harvest of the second ratoon, the yields obtained at Britannia, as graphically presented in Figure 3.3.3, were above those of the plant cane and first ratoon. Compared to previous years, heavy lodging of the cane was also noted, and was translated into a higher tonnage of cane harvested.

The trends in yield in the second ratoon were inconsistent with those in the first ratoon, and it was interesting to note that in the unfertilized control soil, a yield as high as 96 ± 3 t ha^{-1} was achieved, and that in plots fertilized with inorganic N fertilizer, the averageyield was only 5% higher than the control. The laboratory incubation study showed that the H soil group had the highest daily N mineralization capacity of the five main soil groups of Mauritius. Henceforth,*in situ*, the soil N reserves may have sustained sugarcane growth, resulting in yields that were not significantly different from those achieved in fertilized plots, even in the second ratoon ($P = 0.214$). This further highlights soil as an important N reserve, and the need to adjust present N fertilization according to the different N mineralization capacities of soils.

Although a negative yield response (-2%) for FC applied at planting was observed, the residual effects of PM (6%) and PL (12%) were still positive when benchmarked against the control soil, although not statistically significant. Similarly, blends of inorganic N fertilizer with compost also had a positive impact on yield in the order of FC blend (13%) > PM blend (11%) > PL blend (8%). The blended treatments resulted in a better yield response than chemical fertilizer (5%). In the second ratoon, IRSC was lower than in both the plant cane crop and the first ratoon, being in the range of 11.04% to 11.77%. With an increased cane yield in the second ratoon, the IRSC response to treatments was further decreased relative to the control treatment, potentially showing enhanced N uptake by the crop.

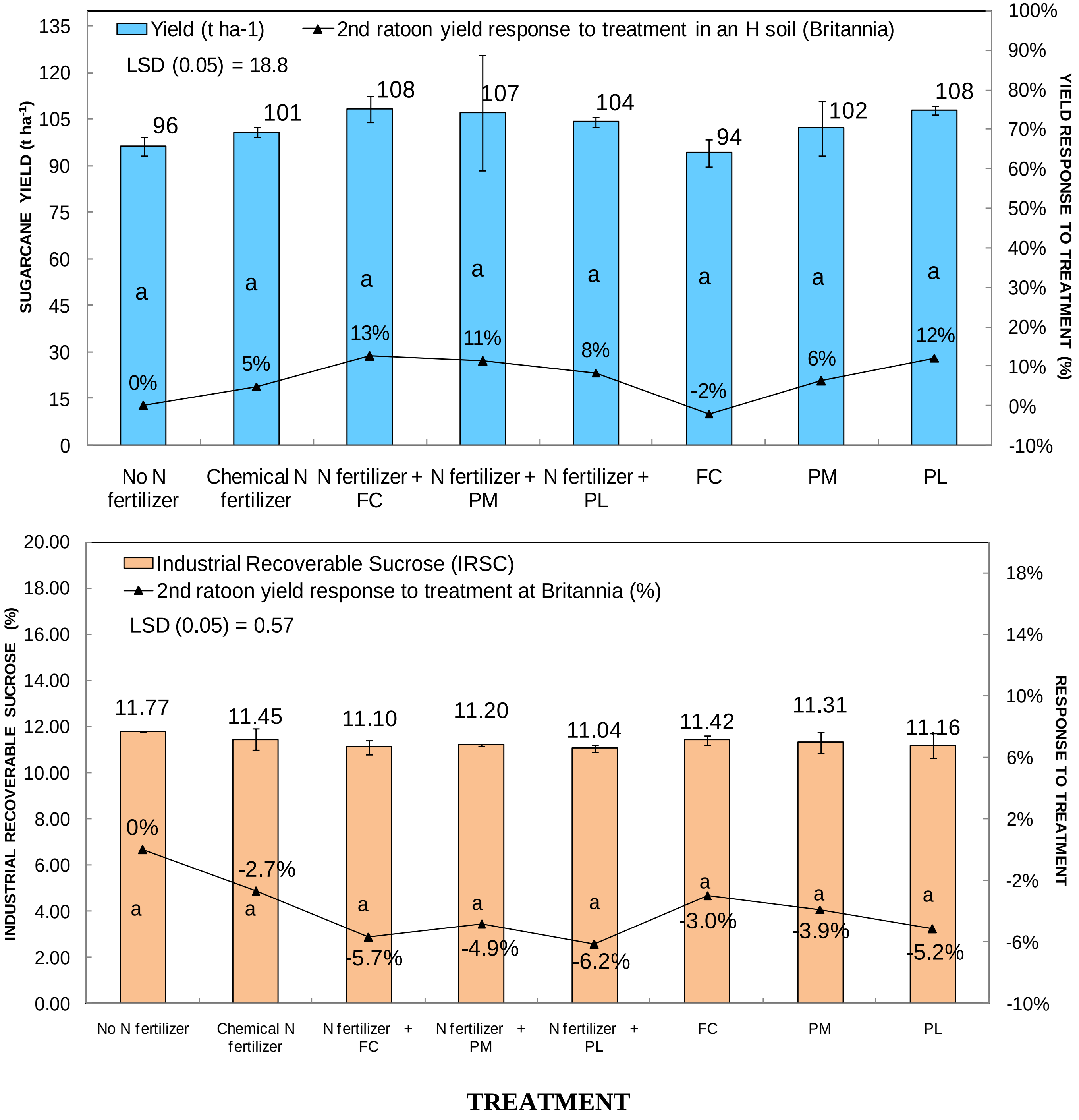


FIG. 3.3.3: Sugarcane yield and industrial recoverable sucrose (IRSC) in the second ratoon at Britannia. Mean yields and IRSC with the same letter are not statistically significant

3.8 Conclusion

Changes in soil bioavailable nitrogen

The *in situ* study in the three soil groups indicated that before fertilization, the inorganic N levels in soil were low, varying from 38mg N kg^{-1} soil at Britannia (H soil), to14 mg N kg^{-1} soil at Pierrefonds (P soil), and 20mg N kg^{-1} soil at Chebel (L soil). At the three sites, the input of inorganic fertilizers caused a spike in the concentration of bioavailable N six days following application. In this treatment, the highest spike was noted at Britannia (457 mg N kg^{-1} soil), followed by Chebel (239 mg N kg^{-1} soil), and was unexpectedly low at Pierrefonds (49 mg N kg^{-1} soil). At the latter site, it is suspected that the high temperatures recorded may have decreased the solubility of ammonia gas in the soil solution (Meisinger and Jokela 2000), the rocky soil promoting gaseous losses despite the immediate irrigation event after planting. The effect of high temperatures on ammonia volatilization in rocky soils may be further investigated. Because the lapse between the inorganic N spike and the drop to basal levels was short, occurring between day 6 and day 35, it is highly recommended to apply inorganic N fertilizers when the sugarcane root system has well developed both at planting and in subsequent ratoon crops. As from day 35 till harvest, basal inorganic N levels not exceeding 53 mg N kg^{-1}soil were observed.

Across the three experimental sites, in the plant cane crop, the blends of inorganic fertilizer with agricultural composts resulted in a positive priming effect six days following fertilization. Out of the three blends, only that with PL produced an inorganic N spike higher than inorganic fertilizer across the three soil groups. The highest inorganic N peak was obtained at Britannia, where 579 mg N kg^{-1} soil was recorded when the PL blend was applied. As with inorganic fertilizer, the levels of inorganic N in plots fertilized with blended treatments dropped on day 35, and with the boom in vegetative growth and increased N uptake, basal inorganic N levels were observed till harvest. In the first ratoon, although a similar trend was noted at the three sites, the inorganic N spikes measured were not as substantial as for the plant cane crop. Nevertheless, in both the plant cane and the first ratoon crops of Britannia and Chebel, the cane yields obtained with all the treatments were not statistically different.At Pierrefonds, the differences in cane yield were only statistically significant ($P < 0.001$) in the first ratoon because of the considerable drop in yield in the control treatment.

In the experimental sites, agricultural composts were applied in the cane rows at planting only at rates varying from 36 t ha^{-1}(FC), to 22 t ha^{-1} (PM), and 13 t ha^{-1} on a fresh weight basis. Across the sites, all the compost treatments resulted in positive priming effects, except in the L soil of Chebel where the concentration of inorganic N was lower than the control treatment during 97 days.In the first ratoon, compost application was discontinued to evaluate the residual effect of N on cane yield. From the trends in inorganic N concentrations observed in the first ratoon of the compost treatment, it was difficult to detect if there was any residual N from the compost applied at planting. Nevertheless, the cane yields obtained in the first ratoon strongly supported the residual value of compost N in the first ratoon.

Inorganic nitrogen trapped by cation and anion exchange resins

From an economic and environmental perspective, it is important to ensure that fertilizer inputs are absorbed optimally by the crop and that risks of N losses to groundwater (leaching) or the atmosphere (denitrification) are minimal. During a 125-day incubation period, 1499 mm of rainfall and 860 mm of rainfall and irrigation water was received in the mature H (Britannia) and L (Chebel) soils respectively. Even if N fertilizers were not applied in the control treatment, inorganic N was still detected at 0.20 m from the soil surface. In the high rainfall region of Britannia, losses of N from SOM mineralization can be more considerable than at Chebel and Pierrefonds (693 mm of rainfall and irrigation water). As in the H soil, L soils amended either partly or fully with compost lead to the least concentrations of N ions in the resins. These results indicate that the dual use of compost with reduced rates of inorganic N fertilizer can potentially decrease the risks of N losses by leaching. Composts are known to increase the cation exchange capacity (CEC) of soil which is linked to a greater availability of cation exchange sites for the adsorption of NO_3^- and NH_4^+, ions that are prone to leaching losses from the root zone to groundwater (Van Der Laan et al. 2013). In the immature P soil of Pierrefonds, compost-based treatments did not always lead to lower inorganic N concentrations in the resins when compared to plots fertilized with inorganic fertilizer only. It is suspected that soil and environmental conditions of this particular site may have promoted N losses by volatilization and denitrification.

Plant cane sugarcane yield and sucrose levels

Relative to the control treatment where no N was applied, cane yield response to inorganic fertilizer was as low as 6% at Pierrefonds, 8% at Britannia and 10% at Chebel. From these results, it can be inferred that SOM contributes substantially to N nutrition in the plant cane crop and that the present rates of inorganic N fertilizers applied at planting need to be adjusted. Nevertheless, since the soil fosters important, but not limitless N reserves, the soil N pool should be constantly recycled by the input of fertilizers. No significant differences ($P > 0.05$) were observed amongst treatments of the same site.It can therefore be stated that the combined use of compost with or without inorganic fertilizers produces comparable cane yields than just inorganic fertilizers for the plant cane crop. Accordingly, the hypothesis of no yield difference between the set treatments holds. As observed across the three sites, both the blended treatments and the compost treatments constituted a valuable source of N at planting, and in many cases, lead to numerically higher cane yield responses than inorganic fertilizer only. Relative to the control treatment, the strongest yield responses were obtained with FC at Pierrefonds (14%), PM-inorganic fertilizer at Britannia (25%) and PL-inorganic fertilizer at Chebel (32%). The yields obtained *in situ* potentially reflect the adverse effect of PM on N mineralization noted in the laboratory incubation, implying that it would be risky from an agronomic perspective to apply PM as the only source of N in a P soil. In general the IRSC responded positively to all the treatments at the three sites, except at Pierrefonds where PM and FC caused a decline in sucrose to levels below those of the control. At Britannia, a decrease in IRSC was only noted with PM.

It is clear that the dual use of reduced rates of N fertilizers with compost represents an interesting approach to guarantee a sufficient supply of N to sugarcane, and maintain at the same time soil fertility. A reduction in the N rate (1.4 kg per tonne of expected millable cane) by 25% was compensated by the application of compost at rates varying from 9.0 t ha^{-1} for FC to 5.5 t ha^{-1} for PM and 3.5 t ha^{-1} for PL in the cane row at planting. These amounts of compost can be applied mechanically, and for a more cost-effective and efficient application, an appropriate equipment capable of localizing both inorganic fertilizers and compost simultaneously on the cane row should be evaluated. The economic aspect of compost application warrants further investigation, but could be a worthy option for Estates involved in both sugar cultivation and rearing activities that generate organic waste products.

First ratoon sugarcane yield and sucrose levels

From a general perspective, it was observed that cane yield responses to fertilization were greater in the first ratoon than in the plant cane. This is consistent with the studies of Franco et al. (2011) in Brazil that showed increased N use efficiency in ratoon cane, whereby 30% instead of 10% (in plant cane) of the accumulated N at harvest originated from applied inorganic N fertilizer. At Pierrefonds, the sharp yield decline from plant cane to the first ratoon in the unfertilized, control plot highlights the importance of N fertilization to ensure the recycling of nutrients in soil. In this context, N fertilization should be maintained in the plant cane crop, although, the N rates applied at planting would need re-adjustment to consider the substantial amount of N mineralized from SOM after soil preparation. For the compost treatments, compost was applied at planting only and discontinued in the following ratoon. The residual N effect on cane yield was strongest in the P soil of Pierrefonds whereby FC resulted in a numerically higher yield response (46%) than inorganic fertilizer (40%), relative to the control. Cane yield responses obtained with both PM (32%) and PL (36%) were also non-negligible. In the L soil of Chebel and the H soil of Britannia, although, agricultural composts still produced higher cane yields than the control treatment, the responses were less important than in the P soil. At Chebel, the yield responses to compost treatment were only 2% to 25% higher than the control treatment, while at Britannia, the responses did not exceed 2%. Still, since compost treatments do have a residual N effect, the rates of inorganic N fertilizer applied in the first ratoon can potentially be lowered. Reducing the recommended N rate (1.4 kg N ha^{-1}) by 25% and complementing N fertilization with compost successfully sustained sugarcane growth and development, particularly in the P soil where numerically higher yields than inorganic fertilizer were achieved, though the differences were not statistically significant. These results provide insights to growers wishing to reduce dependence on chemical fertilizers, enhance SOM and minimize the risks of soil acidication. The IRSC levels indicate that in the P soil, the sucrose levels did not decline with respect to the control. However, in the L soil, the PL and PM treatments lead to a decrease in sucrose content. At Britannia, owing to the inherently high N mineralization potential of soil, exogeneous N supplied by the treatments may potentially have lead to luxury N uptake as relative to the control treatment, the IRSC levels were of all treatments were lower.

Second ratoon sugarcane yield and sucrose levels

In the second ratoon of Britannia, it was interesting to note that in the unfertilized control soil, a yield as high as 96 ± 3 t ha^{-1} was achieved, and that in plots fertilized with inorganic N fertilizer, the average yield was only 5% higher than the control. The yields recorded were not significantly different even in the second ratoon ($P = 0.214$), and the residual value of PM and PL were confirmed by the positive yield responses of 6% and 12% respectively (relative to the control). All the blended treatments resulted in a better yield response than inorganic fertilizer (5%). In the second ratoon, IRSC was lower than in both the plant cane crop and the first ratoon, being in the range of 11.04% to 11.77%.

CHAPTER 4: MODELLING THE EFFECTS OF COMPOST APPLICATION ON NITROGEN MINERALIZATION DYNAMICS AND SOIL ORGANIC MATTER

The Soil Water Balance (SWB) model is a process-oriented, generic crop model initially developed for irrigation scheduling purposes (Annandale et al. 1999). With time, the model has evolved into a predictive tool with broader applications for the study of crop response to irrigation with gypsiferous mine water (Annandale et al. 2001, Annandale et al. 2002), nitrogen (N) dynamics in soils amended with organic materials (Tesfamariam et al. 2012), and the study of leaching losses in agricultural systems (Van Der Laan et al. 2010). The inclusion of an N sub-routine into the SWB-Sci (research version) model is quite recent (Van Der Laan 2009) and was partly motivated by the need to simulate nitrogen (N) dynamics in soils amended with biosolids and inorganic fertilizer, and forecast any non-point source (NPS) pollution that could result from this practice.

The soil fosters important, but not limitless N reserves in the organic form. Provided that the soil organic N pool is constantly replenished by the application of fertilizers, the soil may contribute appreciable amounts of N to a sugarcanecrop. Although figures on the natural N-supplying capacity of soils in Mauritius have been reported previously (Anthony 1998), the effects of agricultural composts on Nbioavailability in soil still need to be studied to allow the integration of composts in sugarcane fertilization. Therefore, to investigate the potential use of SWB-Sci at simulating N mineralization in Mauritian soils, a laboratory incubation study was done to generate datasets against which the model was compared. For calibration and testing purposes, only the N mineralization dataset for the immature soil, Latosolic Reddish Prairie (P) soil was used. To meet the first objective of the study, the SWB-Sci model was parameterized, and the simulated N mineralization in a P soil amended with agricultural composts wascompared tomeasured laboratory data. In the field trial described in Chapter 4, compost was localized in the cane rows only. Because this mode of compost application could not be modeled by SWB-Sci, the field dataset was not used for testing.The second objective was to simulate the impact of long-term organic and inorganic fertilization on total N and soil organic matter (SOM) in a P soil.

Hypotheses

(a) SWB-Sci model can be used to predict N mineralization from organic fertilizers.

Major chapter objectives

(a) To explore the use of the SWB-Sci model to predict N mineralization under different fertilization regimes.

(b) To simulate the impact of long-term organic and inorganic fertilization on SOM, total N, and inorganic N in soils under sugarcane cultivation.

4.1 Materials and Methods

4.1.1 Laboratory incubation experiment

A laboratory incubation experiment was conducted with the P soil, and three types of agricultural composts that included filtercake (FC), poultry litter (PL) and poultry manure-thrash (PM). The treatments were composed of mixtures of soil with compost, and soil only as control. Each treatment was replicated twice. For the establishment of anactive soil microbial community, the dried soil samples were pre-incubated for seven days at field capacity and room temperature in the laboratory of the Mauritius Sugar Industry Research Institute (MSIRI) at Réduit. During the incubation period, the average temperature varied from 24.6 °C in the morning and 25.9 °C in the afternoon. On the seventh day (Day zero), the samples were leached with 150ml 0.01M $CaCl_2$ before the application of compost. The leachates were then analyzed for total inorganic N, ammonium- N (NH_4-N) and nitrate- N (NO_3-N). The three types of compost were then added to the pre-incubated soils in sintered Büchner funnels and were left to incubate at room temperature under controlled moisture content over a period of 30 weeks. During the incubation period, leaching episodes were carried out on pre-determined days.

Following leaching on Day zero, sieved and dried composts were mixed with soil. Compost was added to the soil to supply 140 kg N ha^{-1}, the recommended rate of inorganic N fertilizer in Mauritius for a sugarcane yield of 100 t ha^{-1}. The application rate of compost was based on the assumption that only 50% of the total N in compost would become available during the first crop season (Chabalier et al. 2006), therefore, 280 kg N ha^{-1} was effectively applied to soil via the compost in the laboratory experiment. The soil and compost mixing ratios were calculated according to the measured bulk density of the P soil, to a plough layer depth of 0.25 m, assuming that compost was broadcasted over one hectare (10000 m^2).

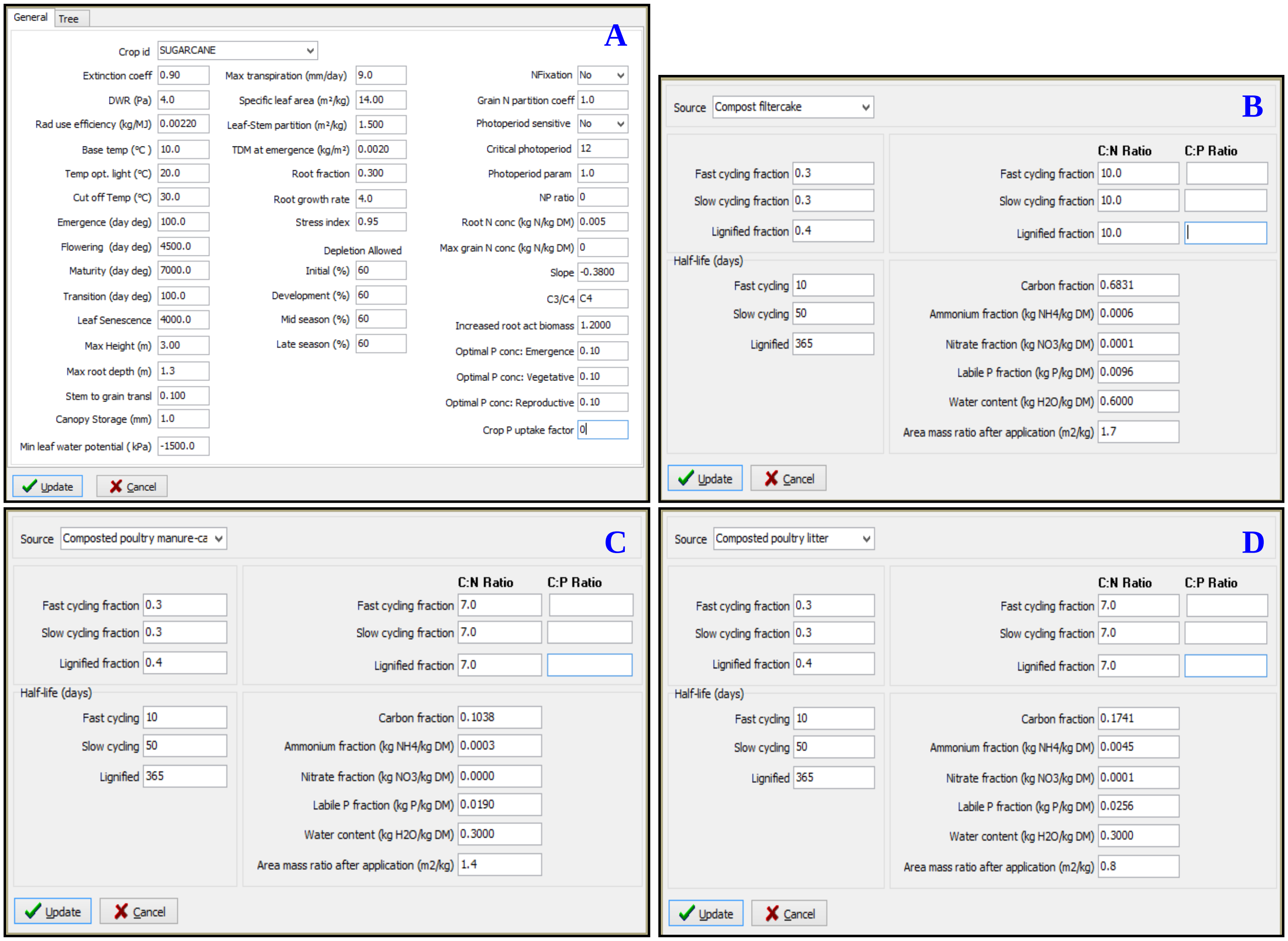
The chemical and physical profile of the P soil and three types of agricultural composts used for the laboratory incubation experiment were also determined. These chemical and physical parameters measured are further described in Chapter 2.

4.1.2 Model set up

To parameterize the model, the chemical and physical properties of soil and compost were obtained from the laboratory incubation study. A calibration exercise using historical cane and sugar yields recorded at Pierrefonds from year 2006 to 2014 was also done for the purpose of accurately simulating sugarcane growth. Since the cane stalk yields were on a fresh mass basis, the assumption that sugarcane stalk has a dry matter content of 30% (Bakker 1999) was used to convert the historical yields to a dry matter basis, as simulated by the model. The historical total aboveground dry matter (TDM) used in the model excludes cane tops and leaves as during mechanical harvest of sugarcane, these plant parts are left in the field, and constitute crop residue blanket. Urea was used as inorganic fertilizer, simulated to be broadcasted at a rate of 140 kg N ha^{-1}.

The crop parameters for sugarcane (Figure 4.1) were obtained from both the SWB-Sci model database, and the calibration exercise. During calibration, because the harvestable dry matter HDM (sucrose) was overestimated by the model, the default flowering day degrees of 4000 was increased to 4500 to lengthen the vegetative phase of the crop and delay sucrose accumulation in the stalk. The initialization parameters used for the agricultural composts under study were obtained from the chemical characterization done during the laboratory incubation experiment.In addition to the soil, compost and crop parameters, weather data specifically, minimum and maximum temperatures, and rainfall for the Pierrefonds region were also loaded into the model.Daily reference evapotranspiration (ET_o) was estimated by the SWB-Sci model using the Penman-Monteith equation (Annandale et al. 1999).

To compare the effects of yearly applications of an inorganic N fertilizer versus agricultural composts on soil total N, inorganic N and SOM, a simulation of ten years was ran (2006 to 2015). It was assumed that all other nutrients were non-limiting. The SWB-Sci was set up to apply composts on a dry weight basis, eight days after harvest every year. The rates applied varied from 16.5 t ha^{-1} for FC,13.4 t $ha^{-1}$for PM, and 7.5 t ha^{-1} for PL, supplying a total 280 kg N ha^{-1}. The N rate was based on the assumption that only 50% of this amount would be available during the crop season (Chabalier et al. 2006). The inorganic fertilizer urea (46% N) was simulated to be applied at arate of 305 kg ha^{-1} to supply 140 kg N ha^{-1}. As discussed in Chapters 3 and 4, the immature/less weathered P soil is relatively shallow and rocky. For this reason, only the simulated changes in total N, inorganic N and OM occurring to a depth of 0 to 0.25 m were considered.



Crop id	SUGARCANE
Extinction coeff	0.90
DWR (Pa)	4.0
Rad use efficiency (kg/MJ)	0.00220
Base temp (°C)	10.0
Temp opt. light (°C)	20.0
Cut off Temp (°C)	30.0
Emergence (day deg)	100.0
Flowering (day deg)	4500.0
Maturity (day deg)	7000.0
Transition (day deg)	100.0
Leaf Senescence	4000.0
Max Height (m)	3.00
Max root depth (m)	1.3
Stem to grain transl	0.100
Canopy Storage (mm)	1.0
Min leaf water potential (kPa)	-1500.0
Max transpiration (mm/day)	9.0
Specific leaf area (m²/kg)	14.00
Leaf-Stem partition (m²/kg)	1.500
TDM at emergence (kg/m²)	0.0020
Root fraction	0.300
Root growth rate	4.0
Stress index	0.95
Depletion Allowed	
Initial (%)	60
Development (%)	60
Mid season (%)	60
Late season (%)	60
NFixation	No
Grain N partition coeff	1.0
Photoperiod sensitive	No
Critical photoperiod	12
Photoperiod param	1.0
NP ratio	0
Root N conc (kg N/kg DM)	0.005
Max grain N conc (kg N/kg DM)	0
Slope	-0.3800
C3/C4	C4
Increased root act biomass	1.2000
Optimal P conc: Emergence	0.10
Optimal P conc: Vegetative	0.10
Optimal P conc: Reproductive	0.10
Crop P uptake factor	0

Source Compost filtercake

Fast cycling fraction	0.3
Slow cycling fraction	0.3
Lignified fraction	0.4

	C:N Ratio	C:P Ratio
Fast cycling fraction	10.0	
Slow cycling fraction	10.0	
Lignified fraction	10.0	

Half-life (days)

Fast cycling	10
Slow cycling	50
Lignified	365

Carbon fraction	0.6831
Ammonium fraction (kg NH4/kg DM)	0.0006
Nitrate fraction (kg NO3/kg DM)	0.0001
Labile P fraction (kg P/kg DM)	0.0096
Water content (kg H2O/kg DM)	0.6000
Area mass ratio after application (m2/kg)	1.7

Source Composted poultry manure-ca

Fast cycling fraction	0.3
Slow cycling fraction	0.3
Lignified fraction	0.4

	C:N Ratio	C:P Ratio
Fast cycling fraction	7.0	
Slow cycling fraction	7.0	
Lignified fraction	7.0	

Half-life (days)

Fast cycling	10
Slow cycling	50
Lignified	365

Carbon fraction	0.1038
Ammonium fraction (kg NH4/kg DM)	0.0003
Nitrate fraction (kg NO3/kg DM)	0.0000
Labile P fraction (kg P/kg DM)	0.0190
Water content (kg H2O/kg DM)	0.3000
Area mass ratio after application (m2/kg)	1.4

Source Composted poultry litter

Fast cycling fraction	0.3
Slow cycling fraction	0.3
Lignified fraction	0.4

	C:N Ratio	C:P Ratio
Fast cycling fraction	7.0	
Slow cycling fraction	7.0	
Lignified fraction	7.0	

Half-life (days)

Fast cycling	10
Slow cycling	50
Lignified	365

Carbon fraction	0.1741
Ammonium fraction (kg NH4/kg DM)	0.0045
Nitrate fraction (kg NO3/kg DM)	0.0001
Labile P fraction (kg P/kg DM)	0.0256
Water content (kg H2O/kg DM)	0.3000
Area mass ratio after application (m2/kg)	0.8

FIG. 4.1: Soil Water Balance (research version) parameters for sugarcane (A) and the agricultural composts filtercake, poultry manure with sugarcane thrash, and poultry litter (B to D)

4.1.3 Testing model performance

The accuracy of SWB-Sci at predicting N mineralization is generally based on a set of statistical criteria proposed by Wilmot (1982) and De Jager (1994). For a simulation to be accurate, the square of correlation coefficient (r^2), the mean absolute error (MAE) and index of agreement (D) should meet the criteria shown in Table 4.1. However, since soil inorganic N levels are highly variable, this parameter was not subjected to statistical validation. Instead, the goodness-of-fit was judged visually.

TABLE 4.1: Reliability criteria to evaluate simulated data against measured data

Statistical parameter	Reliability criteria
Square of correlation coefficient (r^2)	> 0.8
Index of agreement (D)	> 0.8
Mean absolute error (MAE)	< 20

4.2 Results and Discussion

4.2.1 Simulated and measured soil inorganic nitrogen, ammonium and nitrate

Soil inorganic N ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) in a P soil amended with agricultural composts was modeled and ran against soil inorganic N measured in a laboratory incubation. Figure 4.1.1 shows that the model predicted only moderately well the changes in soil inorganic N following the application of compost. The measured data clearly shows that compared to the control treatment which had not been fertilized with an N fertilizer, FC and PM application resulted in a negative initial priming effect, hampering N mineralization through increased microbial assimilation (Kuzyakov et al. 2000). An inverse effect was observed in the PL-amended soil where there was a relative increase in inorganic N through enhanced microbial activity. However, the N immobilization occurring upon application of FC and PM was not modeled by SWB-Sci. Instead, a peak in inorganic N was observed immediately after amendment. The positive priming effect in soil treated with PL was also overestimated. Generally, the rates and pattern of conversion of organic N into its inorganic forms rely on the C:N ratio of the decomposing pool that acts as a sink for the OM resulting from decomposition (Van Der Laan 2009). Although the C:N ratio of the three types of agricultural compost was specified, SWB-Sci considers compost OM as being composed of three fractions having different C:N ratios.Because the fractionation of OM into different pools involves complex analysis techniques (Kader et al. 2010) that were beyond the scope of this study, similar C:N ratios were set for the three fractions of each type of compost. This could explain the rapid initial mineralization of organic N from compost. In a study of Probert et al. (2005) using the Agricultural Production Systems Simulator (APSIM), it was found that the simulation of N mineralization patterns were improved by setting different C:N ratios for the three OM pools of manure. Similar findings were also reported by Mohanty et al. (2010) when using APSIM to model N mineralization of farmyard manure. More realistic half-lives based on laboratory analyses could also be plugged in for the different fractions for a better goodness-of-fit. This could represent a research avenue to improve the performance of SWB-Sci at simulation levels of inorganic N in soils. As pointed out by Van Der Laan (2009), the point wise sampling of measured data could also have to the mis-detection of changes in soil inorganic N.

A visual assessment of the goodness- of- fit of the simulated data to the measured data outlines a tendency of the model to underestimate soil inorganic N in soil amended with PM and PL, 68 and 52 days following compost application. Considering the fact that SWB-Sci integrates the different soil and climatic conditions prevalent *in situ,* this observation is not surprising. In literature, studies are consistent that the rates of N mineralization are overestimated in laboratory incubation; lower mineralization values for *in situ* trials were explained by the increased prevalence of immobilization and conditions of precipitation and temperature that may enhance losses of N by denitrification (Adams and Attiwil 1986, Weinhold 2007, Sistani et al. 2008). However, to a depth of 0 to 25 cm, the effect of FC on soil inorganic N, 68 days after application was better simulated by the model compared to PM and PL.

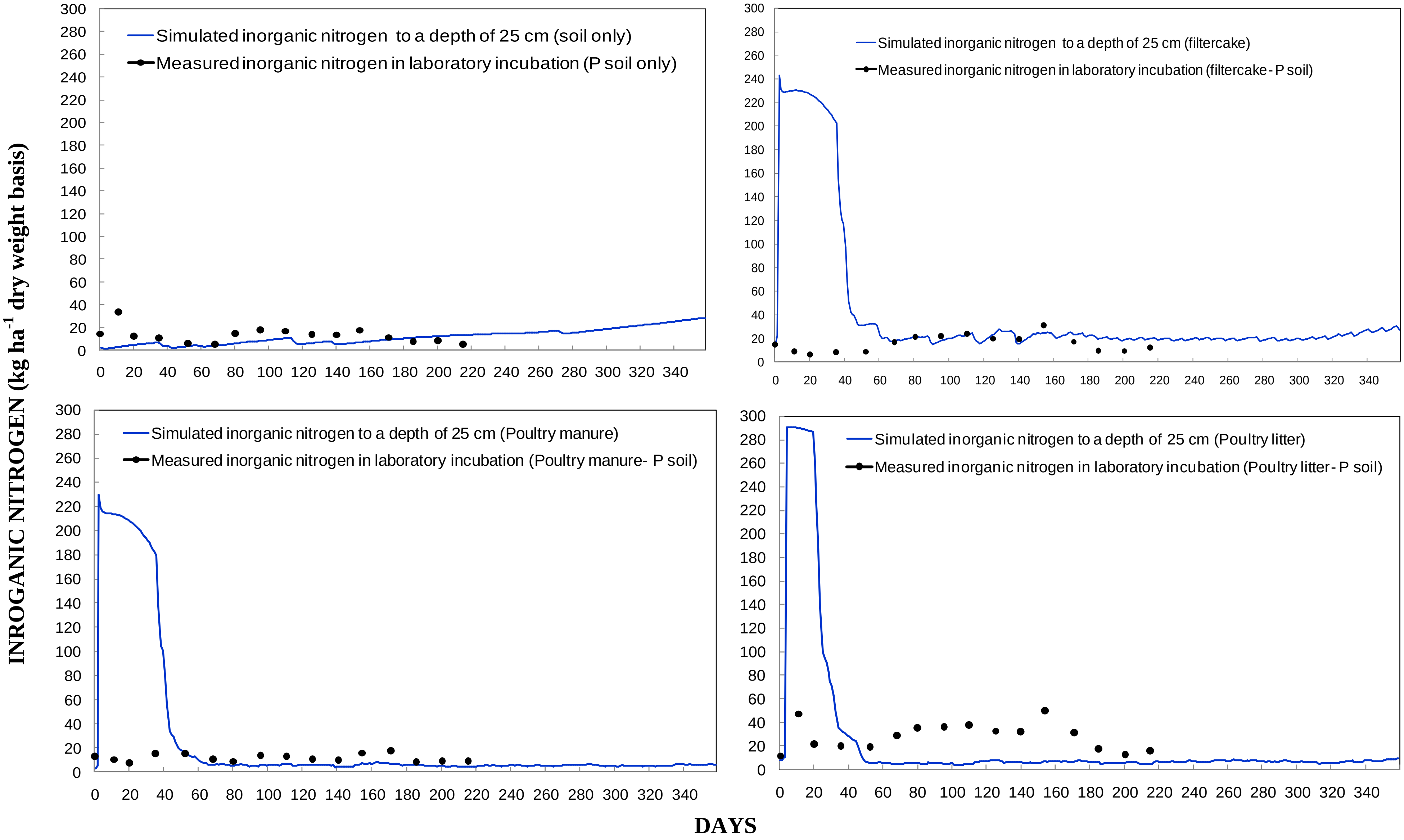


FIG. 4.1.1: Simulated and measured soil inorganic nitrogen at a depth of 0 to 25 cm in a latosolic reddish prairie soil (P) amended with agricultural composts

As illustrated by Figure 4.1.2, the modeled process of ammonification was overestimated for soil amended with the three types of agricultural composts, particularly during the first forty days of application. After this period, the measured and simulated data were visually similar. In the control treatment where no N fertilizer was applied, the model correctly showed that there was no peak in the concentration of ammonium.

Nitrificationfrom N-NH_4^+ to N-NO_3^- (Figure 4.1.3) was also overestimated by the model during the days following compost application. This process occurred almost simultaneously as ammonification, and basal levels of nitrate achieved after approximately forty days. Except for the FC treatment where there was a close fit between the simulated and measured data after 40 days, the nitrate concentrations modeled in PM- and PL-amended soil remained below the measured dataset.

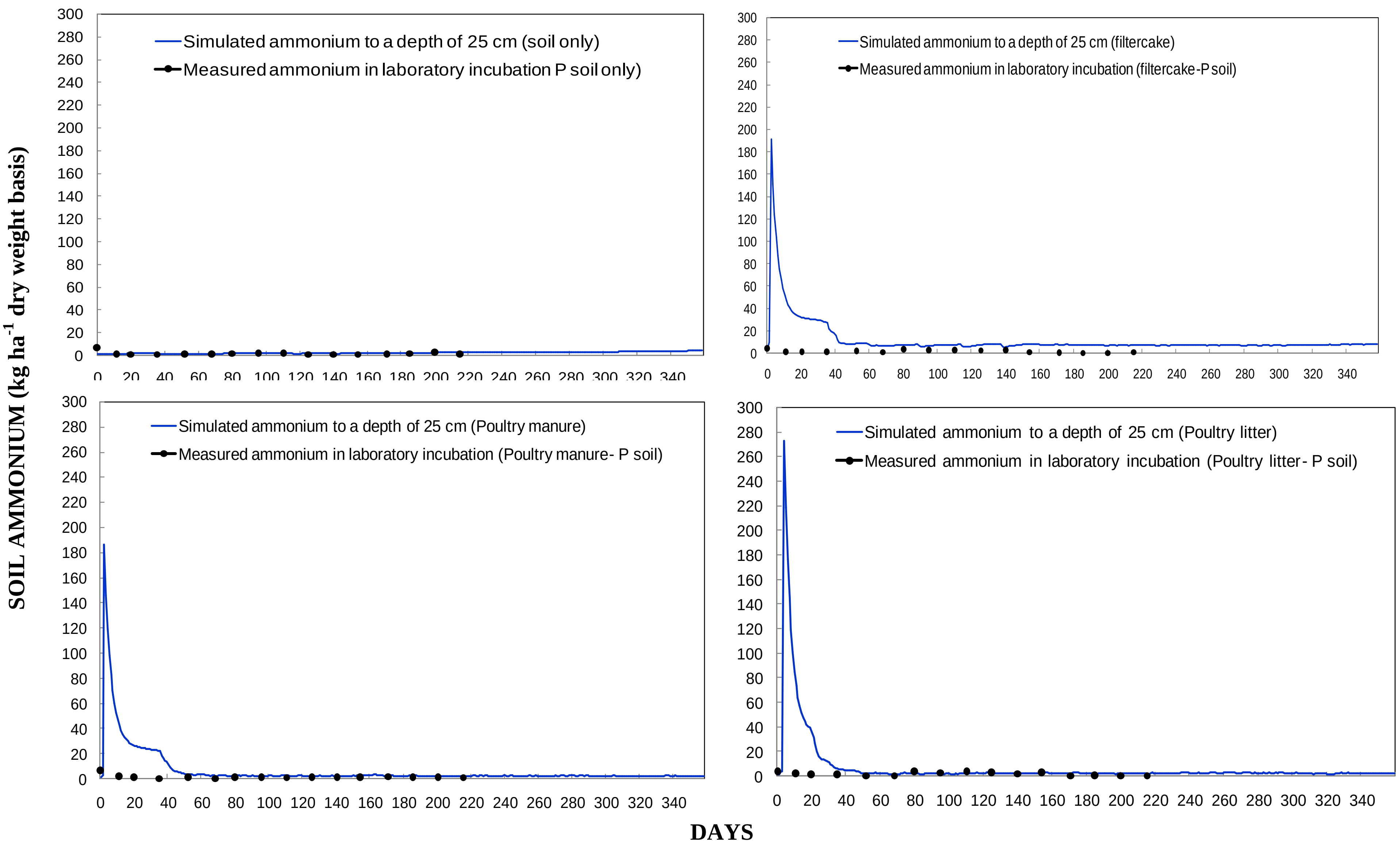


FIG. 4.1.2: Simulated and measured soil ammonium at a depth of 0-25 cm a in a latosolic reddish prairie soil amended with agricultural composts compared to a control

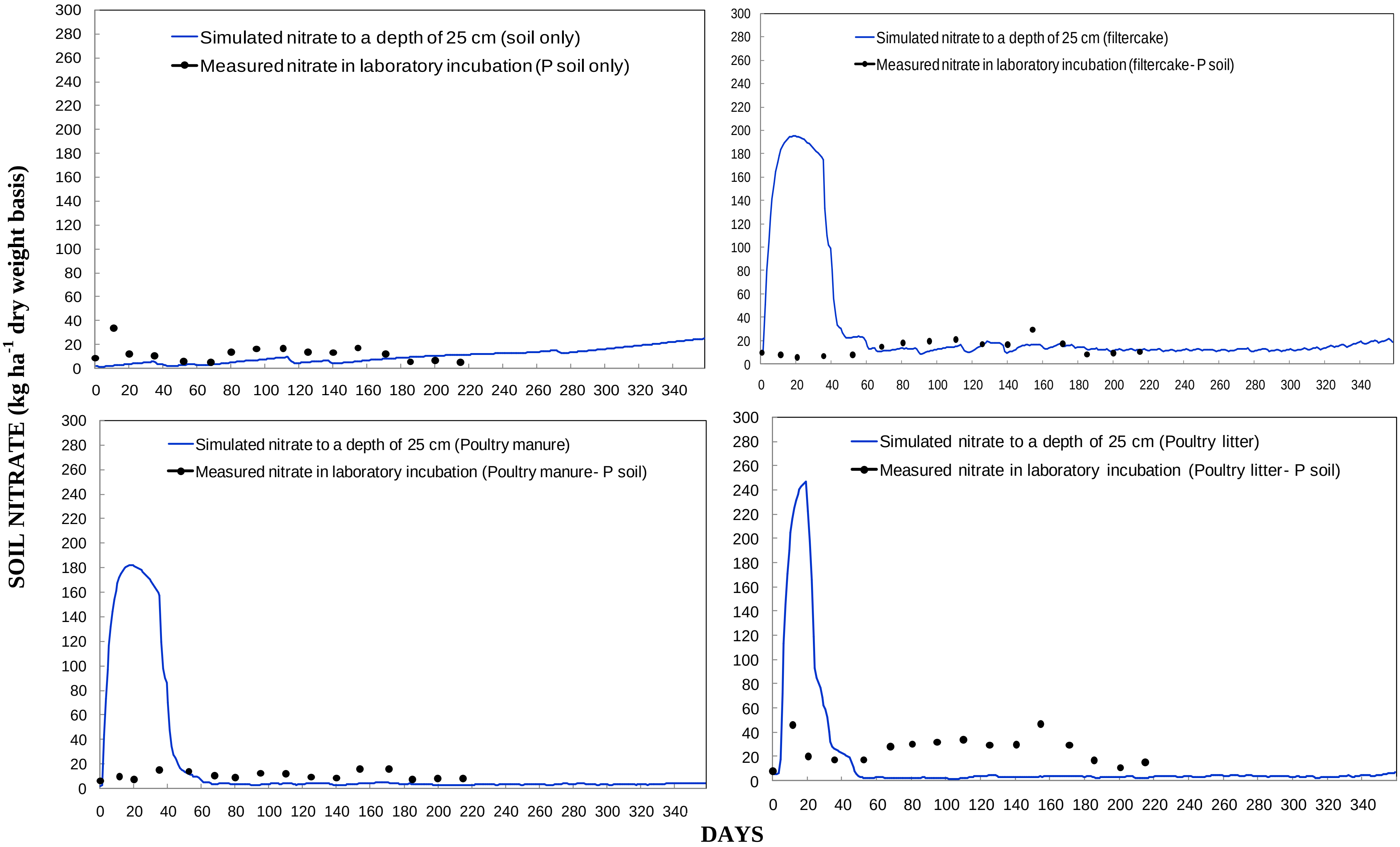


FIG. 4.1.3: Simulated and measured soil nitrate at soil depth of 0-25 cm in a latosolic reddish prairie soil amended with agricultural composts compared to a control

4.2.2 Evolution of total nitrogen, inorganic nitrogen and organic matter in a P soilfertilized with inorganic fertilizer and agricultural compost over ten years

The model showed that the continuous application of inorganic fertilizer (urea) over a period of ten years had a limited impact on the total N content of a P soil, when compared to the control treatment where no N had been applied (Figure 4.1.4). Therefore, even if part of the N from an inorganic source becomes at some point in time integrated in the soil N fraction through microbial assimilation or immobilization (Rasmussen et al. 1998, Chowdary et al. 2004), the model supports that the contribution of inorganic fertilizers to soil total N, relative to the control treatment, might not be significant in the P soil.However, according to Franco et al. (2010), only 30% of the total N accumulated in the above-ground parts of sugarcane at harvest originates from applied inorganic N fertilizer, suggesting that a major portion is either immobilized or subjected to gaseous losses or leaching. Because the model was set up to broadcast urea, volatilization losses may have occurred, decreasing the amount of N recycled in the organic N pool. It is known that the broadcasting of urea on soil surface or thrash can lead to N volatilization losses as high as 26% in Mauritius (MSIRI 2005). However, inorganic fertilizers had a major impact on the concentration of inorganic N in the soil solution, which would have otherwise remained as low as in the control. During ten years of urea application, there was a clear decline in SOM from 2.92% to 1.91%, roughly 32% less OM. Because the long-term simulation considered the crop residues left in the field after green harvest, this may imply that sources of OM, over and above crop residues left-over, would be needed to conserve SOM and soil fertility in the long term.

Since the model was parameterized and ran according to different fertilization regimes during a few months before year 2006, the initial total N content of soil varied from one treatment to another. According to the model, although the difference in total N was not very marked between the inorganic fertilizer and compost treatments during the first three years (2006 to 2008), the trends in total N accumulation were distinct after this period. Relative to both the control and urea treatments, yearly applications of the three types of agricultural compost mitigated the drop in soil total N that occurred in a P soil under sugarcane cultivation.

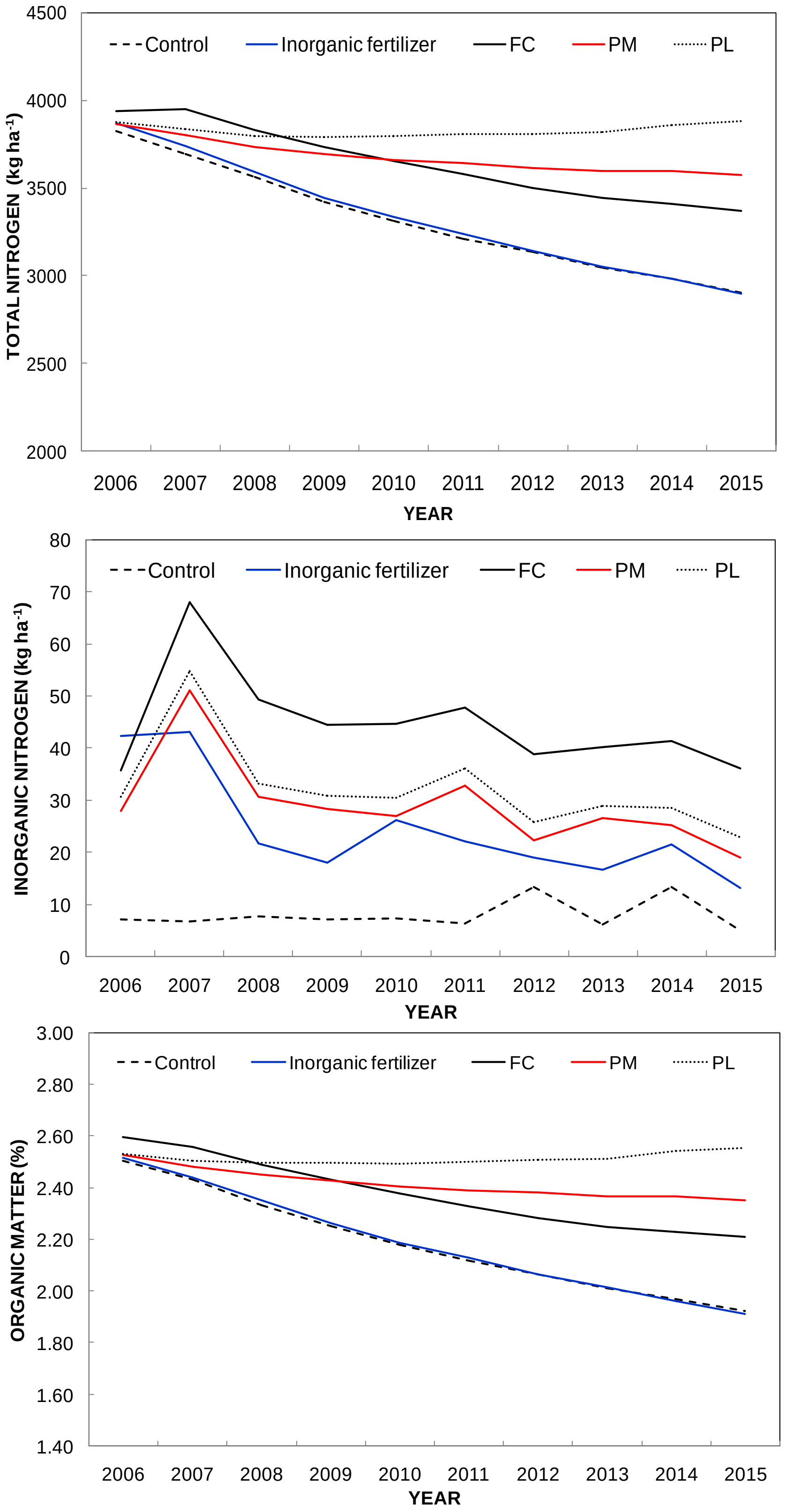


FIG. 4.1.4: Evolution of total nitrogen, inorganic nitrogen and organic matter to a depth of 0 to 25 cm in soil fertilized with inorganic fertilizer, filtercake (FC), poultry manure-thrash (PM), and poultry litter (PL), as compared to a control

Out of the three composts, PL that had the highest OM content, 43.02 ± 26.09%, not only maintained the soil's total N reserves, but also started to increase those reserves after a ten-year application period. Filtercake and PM, that had an OM content of 28.89 ± 9.15% and 24.45 ± 1.30%respectively, also attenuated the drop in total N compared to inorganic fertilizer, although to a lesser extent than PL. The study of Gutser et al. (2005) corroborate these observations as it was found that regular application of organic residues resulted in an accumulation of soil organic N, from which increasing concentrations of mineralized N could be expected throughout the years. Following the application of composted cattle manure over five years (a yearly rate of 15 t ha^{-1}), Whalen et al. (2008) also suggested the major impact of compost application remained increased levels of total N, as a result of a gain in stabilized N compounds. Indeed, the concentration of soil inorganic N from compost increased to levels higher than with urea following continuous yearly applications. Recently, Chalhoub et al. (2013) also supported the contribution of compost to increased availability of N through continuous yearly application. Application rates to supply 200 kg N ha^{-1} were proposed.

From Figure 4.1.4, it can be seen that a noteworthy contribution of yearly inputs of agricultural composts is the conservation of SOM reserves. As the OM matter reserves in soils fertilized yearly with urea decline sharply over ten years, those amended with compost decrease only slightly. Where PL was applied, the SOM were even higher than the initial SOM levels after eight years of continuous application. Through the long term simulation, the model highlights the potential of agricultural composts to restore, conserve, and enhance soil fertility over the long term for a sustainable sugarcane production system.

4.2.3 Evolution of total nitrogen at different soil depths in a P soil fertilized with inorganic fertilizer and agricultural compost over ten years

The long term simulation showed that in general, changes in total N resulting from different fertilization regimes were most detectable in the 0 to 5 cm soil layer (Figure 4.1.5). The amount of total N decreased down the soil profile, and was lowest at a depth of 25 cm across all the treatments. The impact of the inorganic fertilizer treatment on total N content was so insignificant that there was only a small difference in the amount of total N between the upper (0 to 5 cm) and lower (10 to 15 cm) soil layers.

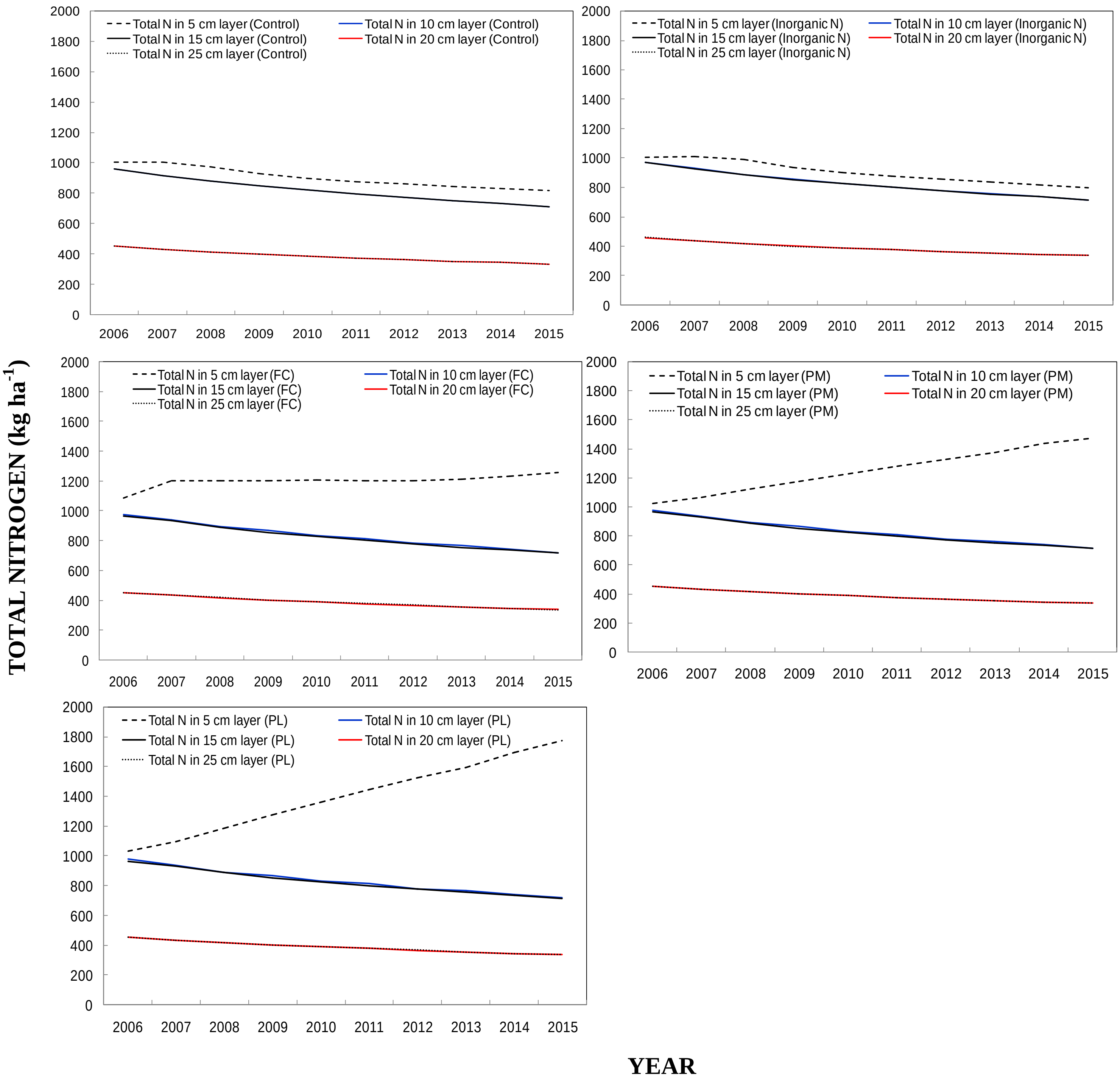


FIG. 4.1.5: Simulated total nitrogen from 2006 to 2015 in soils treated every year with inorganic fertilizer, filtercake (FC), poultry manure-thrash (PM), and poultry litter (PL)

The trend in the average annual total N noted in plots fertilized with inorganic N fertilizer only was also similar to that of the control treatment. With the low contribution of inorganic fertilizer to the soil total N stock, and the crop's consumption of nutrients from OM breakdown, a constant decline in the total N curve occurred over a ten-year period.

In soil amended with agricultural composts, a considerable increase in total N in the upper 5 cm layer was noted throughout the years. Compost may have contributed predominantly to the organic N pool as a major portion of N in compost is organically-bound (Brady 1999). The magnitude of the increase observed seemed to be proportional to the initial total N content of compost; PL that had a higher total N content (3.7%) than PM (2.1%) and FC (1.7%) resulted in the highest accumulation of total N over ten years of amendment.

4.2.4 Evolution of inorganic nitrogen at different soil depths in a Latosolic Reddish Prairie soil fertilized with inorganic fertilizer and agricultural compost over ten years

Across the treatments, the amount of inorganic N was highest in the 0 to 10 cm layer, except for the control where the amount of inorganic N was comparable at different depths (Figure 4.1.6). The average yearly amount of inorganic N for the urea treatment was unusually low compared to the compost treatments. Therefore, it is again suspected that considerable N losses via volatilization might have occurred due to the broadcasting of urea. Although composts are also exposed to risks of N volatilization when surface-applied, most of the N is in the organic form, and only mineralizes gradually (Rasmussen et al. 1998). Compared to total N content, the inorganic N levels in soil were highly variable from year to year, with no distinct trend. The main point of this simulation is the difference in inorganic N amounts between fertilized soils compared to the control treatment that highlights the importance of fertilization for crop production.

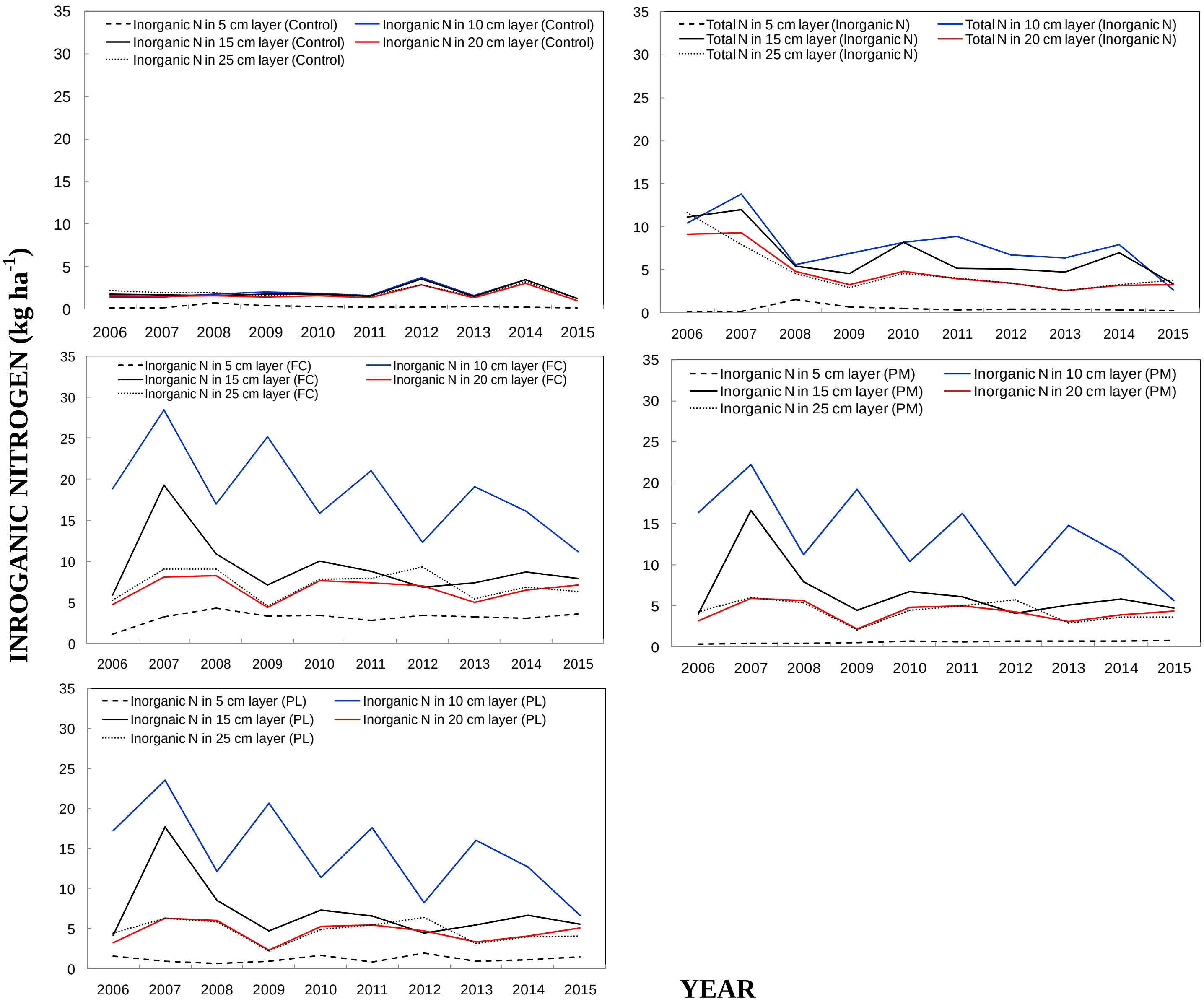


FIG. 4.1.6: Simulated inorganic nitrogen from 2006 to 2015 in soils treated every year with inorganic fertilizer, filtercake (FC), poultry manure-thrash (PM), and poultry litter (PL)

4.2.5 Evolution of organic matter at different soil depths in a Latosolic Reddish Prairie soil fertilized with inorganic fertilizer and agricultural compost over ten years

As for total N, the trends in OM content at different depths shows that the changes in OM resulting from compost application occur primarily to a depth of 0 to 5 cm (Figure 4.1.7). The model showed the OM content of the control treatment was not different from that fertilized with inorganic fertilizer only, even to a depth of 0 to 5 cm where changes in SOM are generally more marked. In both treatments, SOM followed a similar declining trend. Across the compost treatments, the SOM content was higher than the initial levels, PL having a higher impact than PM and PL. The natural decrease in OM modeled down the plough layer, up to a depth of 20 cm, is consistent with the observation of Ros et al. 2009.

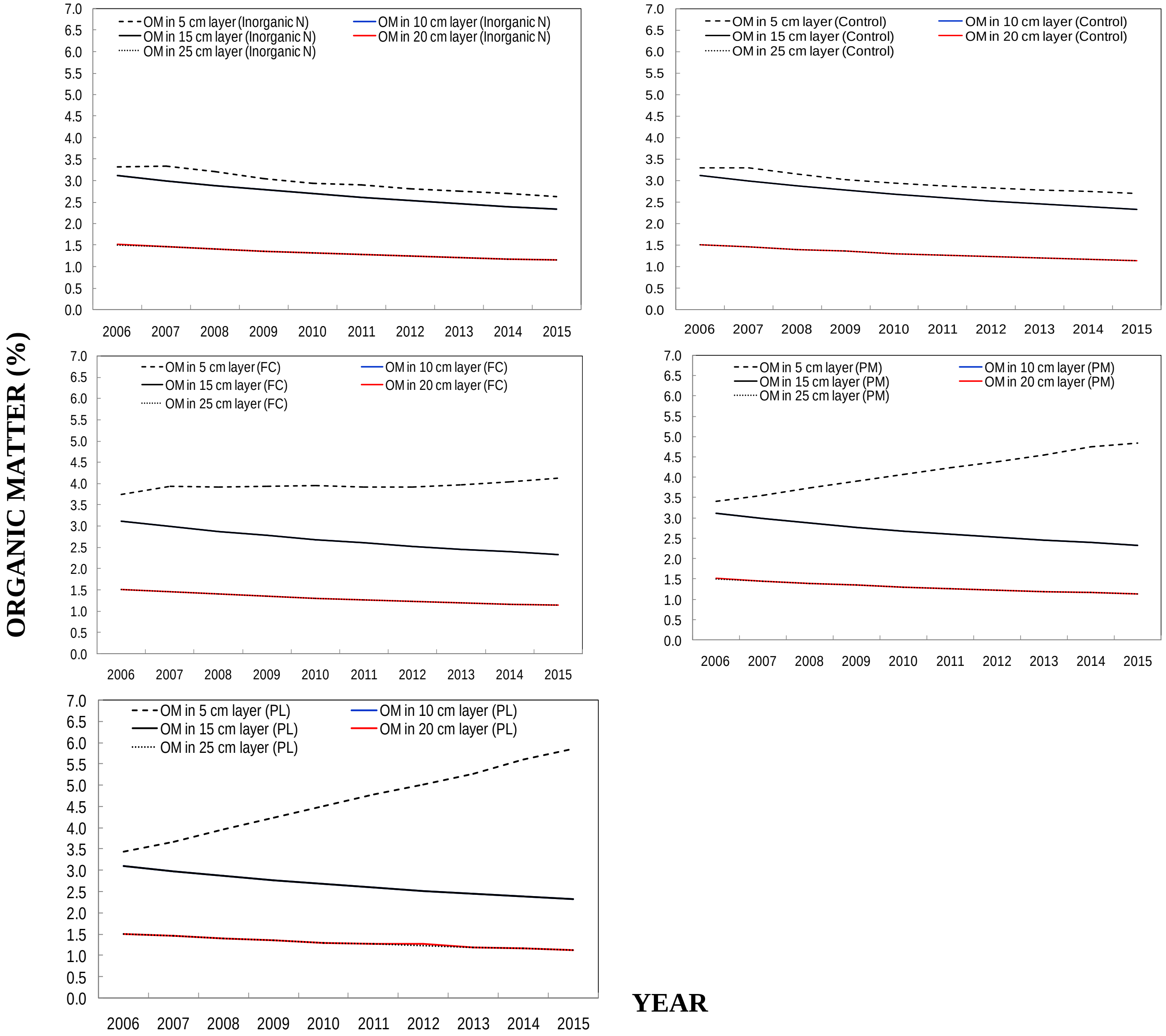


FIG. 4.1.7: Simulated soil organic matter from 2006 to 2015 in soils treated every year with inorganic fertilizer, filtercake (FC), poultry manure-thrash (PM), and poultry litter (PL)

4.3 Conclusion

The model predicted only moderately well the changes in soil inorganic N following the application of compost, overestimating the concentration of inorganic N in amended soil during the first 40 days. The initial quick organic N mineralization was mainly attributed to the fact that similar C:N ratios and generic half-lives were attributed to the three OM fractions of compost.

The model simulation of different fertilization practices over 10 years showed that compared to a soil that had not been fertilized with N, yearly fertilization with inorganic fertilizer had a higher concentration of inorganic N, and was therefore necessary to maintain a source of available N to the crop. However, there is much concern about the impact of yearly inputs of only inorganic fertilizer on soil total N and OM content, both of which decline constantly throughout the years. This observation raises questions about the ability of inorganic fertilizer to conserve soil fertility over the long-term because OM constitutes an important source of organic N that supplies the crop with a substantial amount of inorganic N (Zech et al. 1997), and is also related to improved soil structure, water-holding capacity and microbial flora (Hongwei et al. 2012). The drop in the average sugarcane yield in Mauritius during the last decade was linked to soil impoverishment (MSIRI undated). The decline in OM modeled in soil fertilized with inorganic fertilizer only also supports soil impoverishment over the long term. In this respect, yearly applications of agricultural composts such as FC, PM and PL mitigated the drop in total N and OM reserves that occurs naturally in soils under crop cultivation. These observations corroborate with studies done on the effect of organic residues on soil organic N (Gutser et al. 2005, Whalen et al. 2008, Chalhoub et al. 2013). Poultry litter that had the highest OM content of three composts even increased SOM to levels higher than the initial soil level after 10 years of application. The simulation therefore highlighted the potential of exogenous sources of OM such as agricultural composts to conserve soil fertility in the long run for sustainable crop production.

The impact of fertilization practices on total N and SOM were most detectable to a depth of 0 to 5 cm and followed a clear trend over 10 years. With regards to inorganic N, the 0 to 10 cm layer contained the highest concentration of inorganic N across the treatments. Because the concentrations of inorganic N from agricultural composts were generally higher than inorganic fertilizer, this may indicate considerable N losses occurring as a result of broadcasting. However, it was challenging to draw clear-cut conclusions from the simulated inorganic N curve because of the high variability of the results from one year to another.

5.0 SUMMARY

To maintain profitable sugarcane yields and soil fertility, it is important to ensure that fertilization practices are sustainable. Henceforth, organic sources that have a stronger residual nitrogen (N) than inorganic fertilizers in soil are advocated to mitigate the mining of the existing soil N pool. In Mauritius, agricultural composts such as filtercake (FC), poultry manure with sugarcane thrash (PM), and poultry litter (PL) are commonly available sources of organic N. To quantify N mineralization in five major soil groups under sugarcane cultivation amended with agricultural compostsin Mauritius, a laboratory incubation experiment under controlled conditions of soil moisture and room temperature was carried out. The objectives of the study were to determine the pattern and rate of ammonium (NH_4^+) and nitrate (NO_3^-) release in compost-amended soils, and to evaluate the impact of soil and compost chemical and physical properties on the N mineralization potential of soils.

The chemical and physical characterization of the five major soil groups of Mauritius showed that in general, the soil groups were slightly acidic to near neutral, with a pH (H_2O) range of 5.30 to 6.36. The organic matter (OM) content was between 2.63% and 6.35%, the immature soils having a higher OM content than the mature soils. The C:N ratios of the five soil groups under study varied from 8.9 to 11.9. Across the soil groups, the Latosolic Reddish Prairie (P) soil had the highest concentration of total N, extractable phosphorus (P) and available potassium (K).The proportion of clay in Mauritian soils ranged from 23.7% to 68.8%, and the sand content from 5.5% to 23.3%. The soil texture varied from silty clay loam to silty clay to clay.

Out of the three agricultural composts analyzed, PL contained the highest amounts of the main elements, N (3.66%), P (2.56%) and K (10.0%), that are essential for plant nutrition. The composts contained appreciable amounts of OM that varied from 24.45% to 43.02%, PL having the highest OM content. In terms of C:N ratio, FC had a wider C:N ratio (9.2) than both PM (6.2) and PL (6.2). With regards to pH (H_2O), PL was near neutral (pH 6.2), while FC was more acidic with a pH of 5.68 and PM highly alkaline with a pH of 9.46.

Quantification of inorganic N during a 215-day laboratory incubation showed that the net amount of N mineralized in the five major soil groups (control) of Mauritius ranged from 65.2 to 87.8 mg N kg^{-1} dry soil. The monthly N mineralization varied from 26.4 to 36.8 mg N kg^{-1} dry soil across the soil types tested. There were no significant differences ($P > 0.05$) in the cumulative net N mineralized between the five soil groups (control). In general, the immature (latosolic) soils mineralized greater amounts of N than the mature (latosol) soils, at the exception of the Humic Latosol (H).

The addition of compost to soils caused a significant variation ($P < 0.05$) in the magnitude of N mineralization in all soil groups. In FC-amended soils, the cumulative N mineralized ranged between 53 and 137 mg N kg^{-1} dry soil, and was greater than that of all control soils, except in the Low Humic Latosol (L). In FC-amended soils, variable periods of N immobilization were also observed. Poultry manure-thrashincreased the native inorganic N mineralized from soil, the cumulative net N mineralized varyingfrom 62.6 to 194.6 mg N kg^{-1} dry soil. Compared to the mitigated effect of FC on N mineralization in the L soil, PM enhanced N mineralization despite an initial immobilization period of 52 days. However, PM had a mitigated effect on N mineralization in the immature P soil, and may not ensure a regular N supply to sugarcane during the growing phase.In PL-amended soils, the cumulative net N mineralized ranged from 58.2 to 180.1 mg N kg^{-1} dry soil, and positive effects on N mineralization were observed in all soils, except in the L group. In general, the NO_3^- form was dominant in all the treatments across the soil groups. Only in the H soil amended with PM and PL was the NH_4^+ form pre-dominant.

The Spearman’s correlation coefficient showed a slight positive correlation (0.300) between inorganic N mineralized in control soils and SOM, implying that the amount of inorganic N mineralized will increase with increasing SOM levels. The negative correlation (-0.100) between C:N ratio and inorganic N mineralized indicates that the greater the C:N ratio of soil, the lower the N mineralized from native soil organic N. The index of N availability (N_0k) showed that in control soils, the daily N availability (mg N kg^{-1} soil day^{-1}) was in the order Latosolic Brown Forest (B) (1.242) > H (0.975) >Humic Ferruginous Latosol (F) (0.674) > P (0.637) > L (0.524). The relatively high N availability in the B may explain why sugarcane cultivated in this soil is lowly responsive to increments in N fertilizers (MSIRI 1986). Across the soil groups, FC resulted in a mitigated N availability, mostly due to a relatively slower rate of N mineralization. This could have been attributed to the initially low total N content (1.65%), and wider C:N ratio (9.2) of FC compared to the other types of compost. However, in soils treated with PL and PM, despite a reduced rate of N mineralization, the increases in N mineralization potential, N_0,lead to higher daily N availability than the control soil.

In general, the percentage of N mineralization from native soil organic N in control soils, varied from 2% to 4%. In FC-amended soils, between 2% and 5% of the total N from soil and compost mineralized during the 215-day laboratory incubation. Nevertheless, in the clayey L soil, FC depressed N mineralization relative to the non-amended control soil. Applied in the weathered soil groups (H, L and F), PM resulted in an appreciable increase in organic N mineralized that varied between 6% and 9%. However, in the immature soils, PM had a relatively mitigated effect, with 1% of total N mineralization in the amended P soil, and 3% in the B soil. Across the soil groups amended with PL, from 4% to 8% of the total organic N mineralized. Only in the L soil did N immobilization occur when PL was applied.

While laboratory studies were conducted to estimateN_0k, field trials were implemented to determine the changes in soil inorganic N in three major soil groups (P, L and H groups) under sugarcane cultivation in Mauritius amended with FC, PM and PL. In the field experiments, the hypothesis that the combined use of inorganic fertilizer with compost will produce equal cane and sugar yields as inorganic fertilizers only was tested.

The three field experiments showed that in the plant cane, the input of inorganic N fertilizers caused a spike in the concentration of soil inorganic N six days following application. The highest spike was recorded at Britannia (457 mg N kg^{-1} soil), followed by Chebel (239 mg N kg^{-1} soil), and was unexpectedly low at Pierrefonds (49 mg N kg^{-1} soil). In the blended treatments, the rate of inorganic N fertilizer was reduced by 25% and complemented with compost at rates varying from 9.0 t ha^{-1} for FC to 5.5 t ha^{-1} for PM and 3.5 t ha^{-1} for PL in the cane row at planting. Out of the three blends, only PL produced an inorganic N spike greater than inorganic fertilizer in the three soil groups, withthe highest inorganic N peak being obtained at Britannia (579 mg N kg^{-1} soil) when PL blend was applied. As with inorganic fertilizer, the levels of inorganic N in plots fertilized with blended treatments dropped on day 35; with the boom in vegetative growth and increased N uptake, basal inorganic N levels persisted until harvest. In the first ratoon, although a similar trend was noted at the three sites, the inorganic N spikes measured were not as substantial as for the plant cane crop.

In the experimental sites, agricultural composts were applied in the cane rows at planting only at rates varying from 36 t ha^{-1}(FC), to 22 t ha^{-1} (PM), and 13 t ha^{-1} (PL) on a fresh weight basis.In the plant cane, the compost treatments across the sites resulted in positive priming effects, except in the FC-amended L soil of Chebel where the concentration of inorganic N was lower than the control treatment during the first 97 days.

The hydrogen (H^+)-saturated cation (Dowex 50WX8 50-100; Manufacturer) and chloride (Cl^-)-saturated anion resins (Dowex 1X8 50-100)placed at the base of Poly vinyl Chloride (PVC) corers to a depth of 0.2 mindicate that in the H and L soil groups, plots amended either partially or fully with compost lead to the lowest concentrations of N ions in the resins (over 125 days).In the immature P soil of Pierrefonds, compost-based treatments did not always lead to lower inorganic N concentrations in the resins. Even if N fertilizers were not applied in the control treatment, inorganic N was still detected at 0.20 m from the soil surface. The concentration of inorganic N trapped by the resins indicates that in the high rainfall region of Britannia, losses of N from SOM mineralization could be more considerable than at Chebel and Britannia.

In the plant cane, the relatively low cane yield responses to N fertilization across the three sites suggest that SOM contributes substantially to N nutrition in the plant cane crop and that the present rates of inorganic N fertilizers applied at planting need to be adjusted. No significant cane yield differences ($P > 0.05$) were observed amongst treatments of the same site. Relative to the control, the strongest yield responses were obtained with FC at Pierrefonds (14%), PM blend at Britannia (25%) and PL blend at Chebel (32%). The differences in Industrial Recoverable Sucrose (IRSC) between treatments of the same site were not statistically different ($P > 0.05$).

Cane yield responses to fertilization were greater in the first ratoon thanin the plant cane. At Pierrefonds, the yield of the unfertilized plot decreased by 44%, which suggests a sharp decrease in the amount of inorganic N mineralized in the P soil from the plant cane to the first ratoon. This could explain why the P soil was the most responsive to the different treatments. Cane yields obtained when reduced rates of inorganic fertilizer were applied with composts were statistically comparable to yields from plots fertilized only with inorganic N fertilizer. In plots where compost was applied at planting and discontinued in the following ratoon, the residual N effect on cane yield was strongest in the P soil of Pierrefonds whereby FC resulted in a numerically higher yield response (46%) than inorganic N fertilizer (40%), relative to the control. Cane yield responses obtained with both PM (32%) and PL (36%) were also appreciable. At Chebel, the yield responses to compost treatments were only 2% to 25% greater than the control treatment, while at Britannia, the responses did not exceed 2%. In the first ratoon, the differences in IRSC detected between treatments of the same site were not statistically significant.

The process-oriented Soil Water Balance model (SWB) used to parameterize, and simulate N mineralization in a P soil amended with agricultural composts was compared to measured laboratory N mineralization data. The impact of long-term organic and inorganic fertilization on total N and SOM in a P soil was also investigated.The model predicted only moderately well the changes in soil inorganic N following the application of compost, overestimating the concentration of inorganic N in amended soil during the first 40 days. The initial quick organic N mineralization was mainly attributed to the fact that similar C:N ratios and generic half-lives were attributed to the three OM fractions of compost.The point wise sampling of measured data could also haveled to the mis-detection of changes in soil inorganic N.

The modeled process of ammonification was overestimated for soil amended with the three types of agricultural composts, particularly during the first 40 days of application. After this period, the measured and simulated data were visually similar. In the control treatment where no N fertilizer was applied, the model correctly showed that there was no peak in the concentration of NH_4^+. Nitrification from NH_4^+ to NO_3^- was also overestimated by the model during the days following compost application.

The model simulation of different fertilization practices over 10 years showed that compared to a soil that had not been fertilized with N, yearly fertilization with inorganic fertilizer had led to a higher concentration of inorganic N, and was therefore necessary to maintain a source of available N to the crop. During ten years of urea application, there was a clear decline in SOM from 2.92% to 1.91%, roughly 32% less OM. In this respect, relative to both the control and urea treatments, yearly applications of compost mitigated the drop in soil total N that occurred in a P soil under sugarcane cultivation. Poultry litter which had the highest OM content of the three composts even increased SOM to levels higher than the initial soil level after 10 years of application. The simulation therefore highlighted the potential of exogenous sources of OM such as agricultural composts to conserve soil fertility in the long run for sustainable crop production.

Study Recommendations

Laboratory incubation experiment

- In each soil group, only specific types of agricultural composts may significantly ($P < 0.05$) increase cumulative N mineralized, relative to the control: PM in the L group, PM and PL in the H group, PL in the F group, PL in the P group, and FC and PL in the B group.

- The mitigated effect of PM in the P soil may be linked to the alkalinity of PM, and an enhanced conversion of NH_4^+ into NH_3 in rocky soils that favoured gaseous exchanges between the soil and the atmosphere. This assumption could be further tested in laboratory experimentations by monitoring the emission of NH_3 in compost-amended soils.

- Out of the three agricultural composts, only PM enhanced N mineralization in the L soil. The relatively lower lignin content of PM compared to FC and PL can be a plausible explanation for this observation. Further studies on the biochemical composition of agricultural composts and its impact on N mineralization are therefore suggested.

- The first order kinetics exponential equation of Stanford and Smith (1972) was unsuitable when FC and PL composts containing 22.6% and 22.8% lignin respectively, were used in specific soil groups. Other first order kinetics models with two organic N pools could provide improved estimates of potentially mineralizable N.

- Because, of the peaks in NH_4^+ and NO_3^- levels upon application of agricultural composts to specific soil groups, it is highly recommended to incorporate compost instead of broadcasting on the soil surface to prevent heavy volatilization losses.

- In compost-amended soils, the potential risks of N losses to groundwater through leaching could be investigated by implementing lysimeter experiments.

Field trials

- Due to the short lapse between the inorganic N spike and the drop to basal levels, it is highly recommended to apply inorganic N fertilizers when the sugarcane root system is well developed, at planting and in subsequent ratoon crops.

- Since no significant differences ($P > 0.05$) were observed amongst treatments of the same site, it can be stated that the combined use of compost with or without inorganic fertilizers produces comparable cane yields than just inorganic fertilizers for the plant cane crop, and first ratoon cane.

- The H^+-saturated cation and Cl^--saturated anion resins placed at the base of PVC corers to a depth of 0.2 m indicated that, the use of FC, PM or PL alone, or in combination reduced rates of inorganic N fertilizer, could potentially decrease the risks of N losses by leaching.

Modelling

- Because the long-term simulation considered the crop residues left in the field after green harvest, this may imply that sources of OM, over and above crop residues left-over, would be needed to conserve SOM and soil fertility in the long term.

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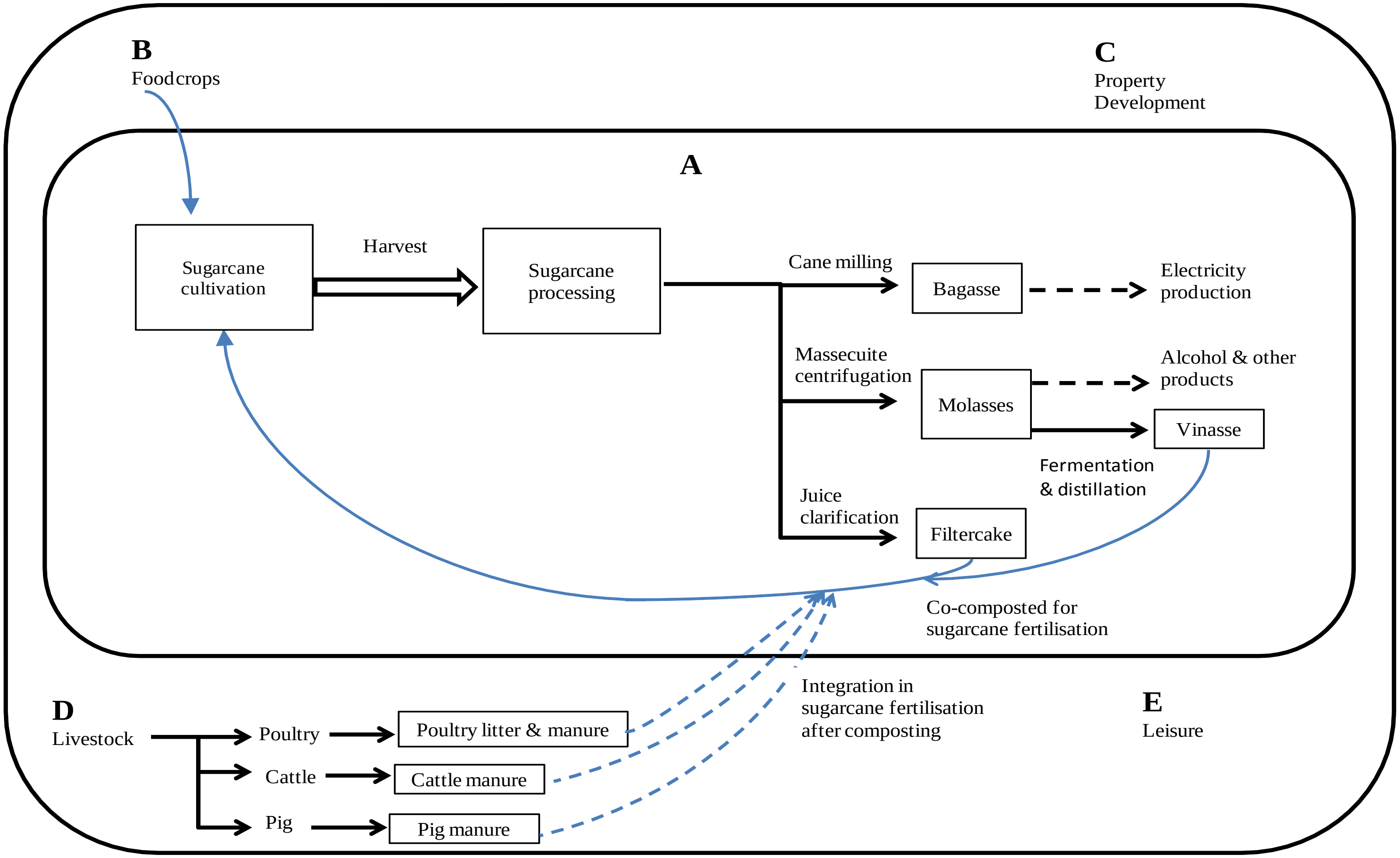
APPENDIX I

- **Position of a sugar-producing unit in a multi-cluster company and proposed synergy between clusters**



APPENDIX II

- **Nitrogen recommendations from 1981 to 2011 (compiled from MSIRI recommendation sheets No 7, 38, 48, 87, 149, 163, 169, and 181)**

Year	Recommendations	Inorganic nitrogenous fertilizer
1981	N to be applied 6-8 weeks after planting	Sulphate of ammonia: 115-126 kg N ha^{-1} for short season cane, and 131-149 kg N ha^{-1} for long season cane. CAN: 117-130 kg N ha^{-1} for short season cane, and 130-143 kg N ha^{-1} for long season cane
1986	N applied 6-8 weeks after planting is just as effective as when applied at a later date.	Complex fertilizers 17-8-25 and 17-2-27 can be applied to supply 115-127 kg N ha^{-1}for short season cane, and 127-145 kg N ha^{-1} for long season cane
1988	13-20-20	For short season cane apply 117-130 kg N ha^{-1}, and for long season cane apply 130-143 kg N ha^{-1}
1995	Fertilizer rates have to be raised to increase net revenue under favourable sugar price. Either use 17-8-25 or 17-2-27	<u>Plant cane</u>: *high response soil* apply 145-160 kg N ha^{-1} for short season, and 160-180 kg N ha^{-1} for long season canes. *low response soil* apply 120-145 kg N ha^{-1} for short season, and 145-160 kg N ha^{-1} for long season canes. <u>Ratoon cane</u>: *high response soil* apply 145-160 kg N ha^{-1} for both short and long season canes. *low response soil* apply 120-145 kg N ha^{-1} for both short season and long season canes.
2005	Blended fertilizers now available such as 20-8-28, 23-0-30, 34-0-16, 16-22-22, 28-0-24, 19-20-20	1.4 kg N to produce 1 ton millable cane
2008		1.1 kg N to produce 1 ton millable cane
2010	Fertilizer N rates revised due to drop in sugar price and in fertilizer cost	1.4 kg N to produce 1 ton millable cane
2011		1.2 kg N to produce 1 ton millable cane

APPENDIX III

- **Spearman correlation coefficient to test the relationship between cumulative inorganic nitrogen in control soils (laboratory incubation) and selected chemical and physical properties of soil**

Correlation matrix

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                         Carbon_%  1   1.000
                  Clay_content_%  2  -0.900   1.000
                              pH  3   0.000  -0.100   1.000
                       Total_N_%  4   1.000  -0.900   0.000   1.000
                       C_N_ratio  5   0.100  -0.300  -0.600   0.100   1.000
                            OM_%  6   1.000  -0.900   0.000   1.000   0.100
Cumulative_inorganic_N_mineraliz  7   0.300   0.100  -0.300   0.300  -0.100
                                          1       2       3       4       5


                            OM_%  6   1.000
Cumulative_inorganic_N_mineraliz  7   0.300   1.000
```

Exact probabilities

```
                        Carbon_%  1       *
                  Clay_content_%  2   0.004       *
                              pH  3   0.237   0.196       *
                       Total_N_%  4   0.000   0.004   0.237       *
                       C_N_ratio  5   0.196   0.129   0.058   0.196       *
                            OM_%  6   0.000   0.004   0.237   0.000   0.196
Cumulative_inorganic_N_mineraliz  7   0.129   0.196   0.129   0.129   0.196
                                          1       2       3       4       5


                            OM_%  6       *
Cumulative_inorganic_N_mineraliz  7   0.129       *
                                          6       7
```

APPENDIX IV

- **Analysis of Variance for the cumulative nitrogen mineralized (mg kg^{-1} dry soil) in control soils of the laboratory incubation**

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replicate stratum	1	60.7	60.7	0.32	
Replicate.*Units* stratum					
Main_treatment	4	769.4	192.4	1.00	0.498
Residual	4	766.2	191.5		
Total	9	1596.3			

$F_{0.05}$ (4, 4) = 6.39

F 0.498 < 6.39

Difference in N mineralized between five soil groups is not significant

- **Analysis of Variance for the cumulative N mineralized (mg kg^{-1} dry soil) in amended soils of the laboratory incubation**

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replicate stratum	1	1081.0	1081.0	4.01	
Replicate.*Units* stratum					
Soil_type	4	23592.8	5898.2	21.90	<.001
Type_of_compost	2	16900.0	8450.0	31.38	<.001
Soil_type.Type_of_compost	8	19585.7	2448.2	9.09	<.001
Residual	14	3770.0	269.3		
Total	29	64929.5			

APPENDIX V

- **Test of significance, coefficient of variation (CV) and least significance difference (LSD) of the effect of individual compost on the net cumulative nitrogen mineralized across the different soil groups incubated during 215 days. The same letter in the same column indicates no significance difference**

	Mean net cumulative nitrogen mineralized (mg kg^{-1} soil)							
Treatment	**Latosolic reddish prairie (P)**	**Latosolic brown forest (B)**	**Low humic latosol (L)**	**Humic latosol (H)**	**Humic ferruginous latosol (F)**	**ANOVA**	**CV (%)**	**LSD (0.05)**
Control	74.2 ± 13.4a	87.8 ±17.5a	69.8 ± 8.9a	85.4 ±8.3a	65.2 ± 13.9a	$P = 0.498$	4.6	38.42
Filtercake	89.4 ± 22.7ab	136.8 ± 6.4b	53.3 ± 0.1a	97.0 ± 11.8ab	101.6 ± 31.7ab	$P < 0.05$	15.2	35.36
Poultry manure-thrash	66.5 ± 0.9a	109.2 ± 23.6a	110.7 ± 18.6a	197.0 ± 10.1b	120.6 ± 7.4a	$P < 0.05$	2.2	44.45
Poultry litter	167.4 ± 0.3b	198.4 ± 10.5b	74.8 ± 3.8a	178.4 ± 36.1b	149.0 ± 25.7ab	$P < 0.05$	8.9	47.24

APPENDIX VI

- **Phosphorus and potassium fertilization of sugarcane according to soil analyses**

Recommendations for phosphorus fertilization at planting (STASM 2003)

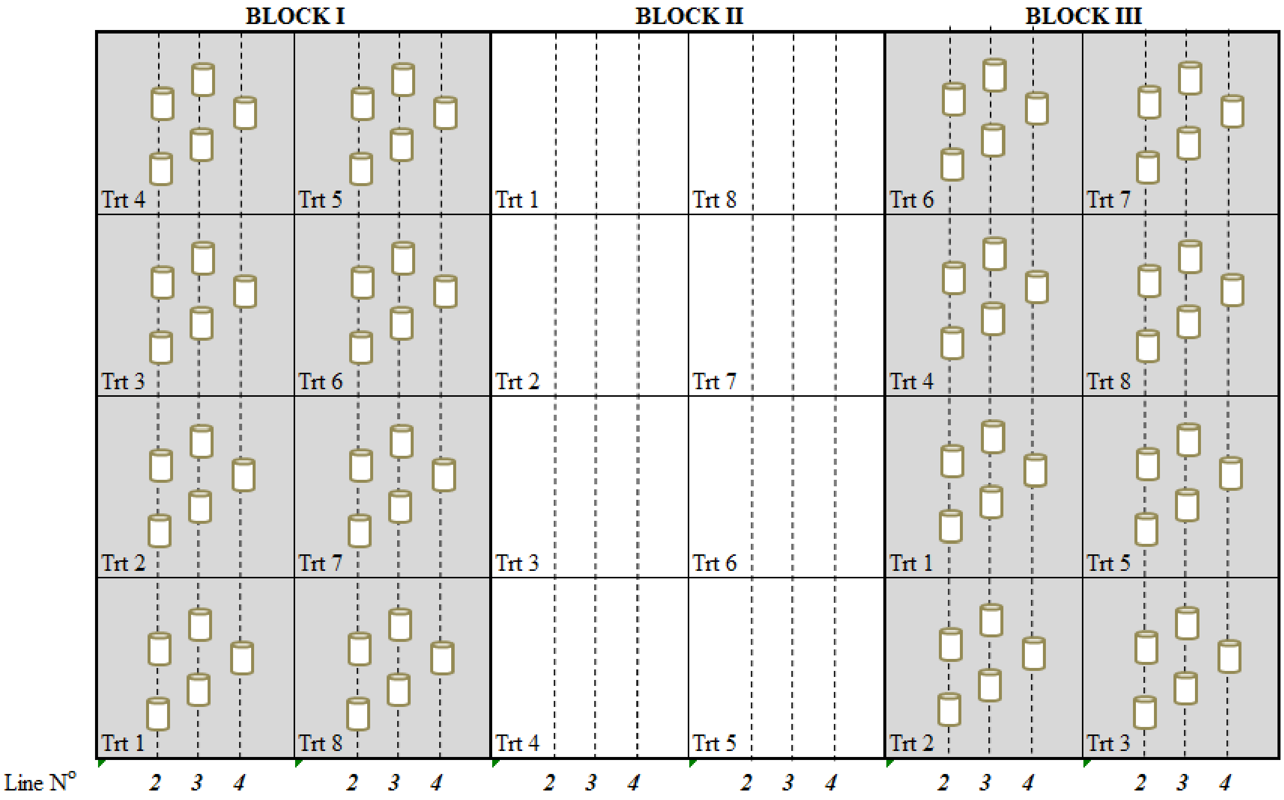
Soil test value (ppm P)	P_2O_5 to apply at planting (Kg ha^{-1})
15	750
20	700
25	650
30	600
35	525
40	475
45	425
50	375
55	325
60	275
65	200
70	125
75	50
80	0

Recommendations for K fertilization (STASM 2003)

Soil test value (m.e %)	Muriate of potash (Kg $ha^{-1}year^{-1}$)
< 0.3	200
0.3 – 0.4	150
0.4 – 0.5	100
> 0.5	0

APPENDIX VII

- **Display of soil corers at the three experimental sites**



APPENDIX VIII

- **Calendar of field operations**

	Plant cane	First ratoon	Second ratoon
BRITANNIA			
Planting date	11 December 2013		
Fertilization date	11 December 2013	05 December 2014	26 October 2015
Tiller count	30 September 2014	17 September 2015	08 August 2016
Stalk sampling	09 October 2014	23 September 2015	17 August 2016
Gap assessment	30 September 2014	07 September 2015	
Harvest date	29 October 2014	29 September 2015	30 August 2016
PIERREFONDS			
Planting date	17 December 2013		
Fertilization date	17 December 2013	28 November 2014	17 November 2015
Tiller count	16 October 2014	09 September 2015	
Stalk sampling	11 November 2014	09 October 2015	
Gap assessment	_	_	
Harvest date	20 November 2014	23 October 2015	
CHEBEL			
Planting date	09 December 2014		
Fertilization date	09 December 2014	10 December 2015	
Tiller count	05 November 2015	13 August 2016	
Stalk sampling	09 November 2015	29 September 2016	
Gap assessment	09 November 2015	13 August 2016	
Harvest date	13 November 2015	07 October 2016	

APPENDIX IX

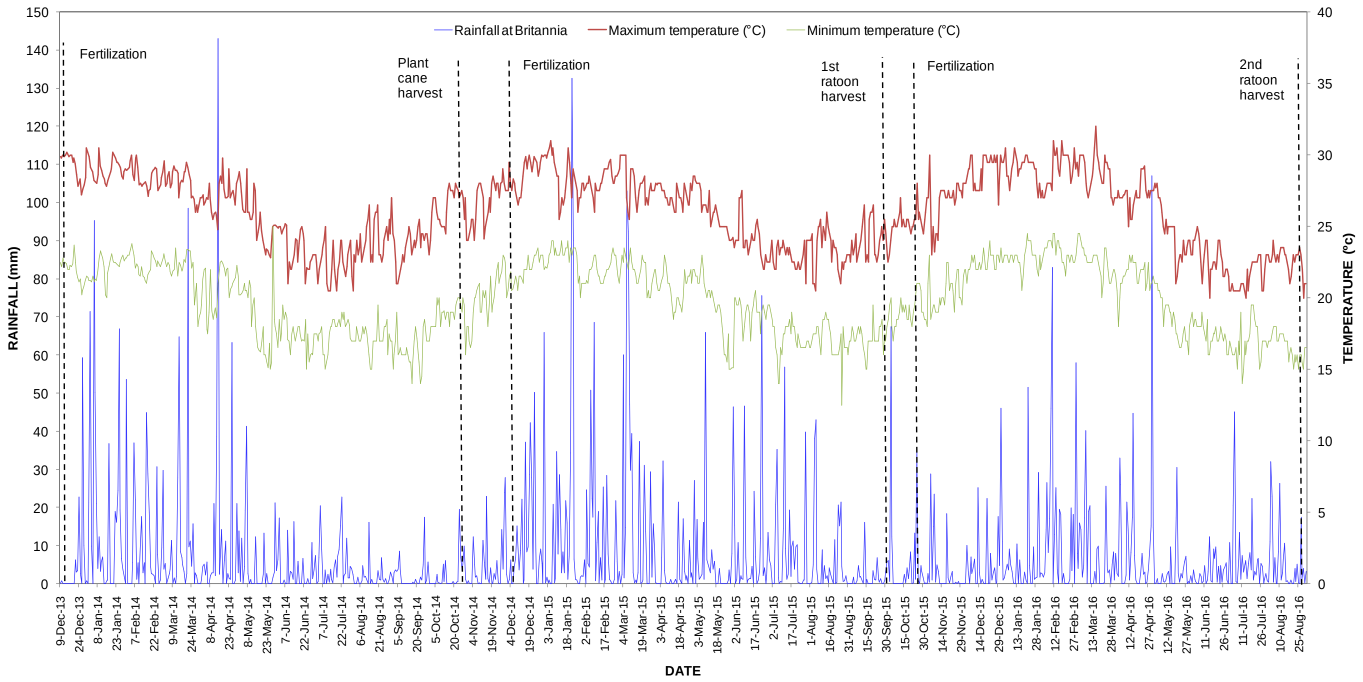
- **Soil temperature readings in the field trial of Britannia**

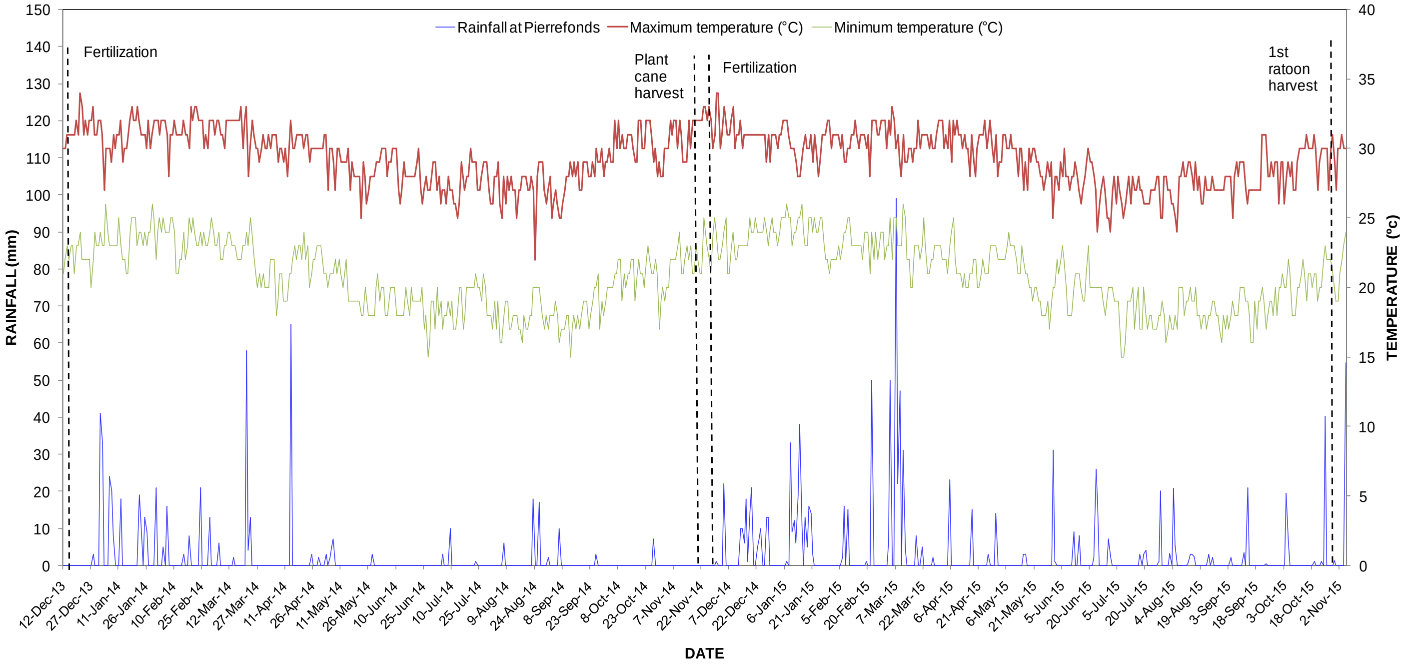
			5 cm-depth		10 cm-depth	
Date	**Month**	**Season**	**Morning (a.m)**	**Afternoon (p.m)**	**Morning (a.m)**	**Afternoon (p.m)**
12-Dec-13	December	Summer	24.5	33.5	25.5	29.5
13-Dec-13	December	Summer	25.5	32.5	26.5	29.0
14-Dec-13	December	Summer	25.5	26.5	26.0	29.0
15-Dec-13	December	Summer				
16-Dec-13	December	Summer	25.5	34.5	26.5	30.0
17-Dec-13	December	Summer	26.5	34.5	27.0	30.5
18-Dec-13	December	Summer	27.0	32.0	27.5	31.5
19-Dec-13	December	Summer	26.5	27.0	27.0	33.0
20-Dec-13	December	Summer	28.5	30.0	28.0	29.5
21-Dec-13	December	Summer	27.0	30.0	26.5	29.5
22-Dec-13	December	Summer				
23-Dec-13	December	Summer	27.0	31.0	28.5	28.0
24-Dec-13	December	Summer	27.5	30.0	27.0	31.5
25-Dec-13	December	Summer				
26-Dec-13	December	Summer	25.5	31.5	26.0	32.0
27-Dec-13	December	Summer	24.0	26.5	24.5	28.0
28-Dec-13	December	Summer				
29-Dec-13	December	Summer				
30-Dec-13	December	Summer	25.0	27.0	25.5	27.5
31-Dec-13	December	Summer	25.0	27.0	26.0	27.5
Average			26.0	30.2	26.5	29.7
Standard deviation			1.2	2.9	1.0	1.7

Soil temperature readings in the field trial of Pierrefonds

			5 cm-depth		10 cm-depth	
Date	**Month**	**Season**	**Morning (a.m)**	**Afternoon (p.m)**	**Morning (a.m)**	**Afternoon (p.m)**
18-Dec-13	December	Summer				
19-Dec-13	December	Summer				
20-Dec-13	December	Summer				
21-Dec-13	December	Summer				
22-Dec-13	December	Summer				
23-Dec-13	December	Summer	23.0	40.0	25.0	34.0
24-Dec-13	December	Summer	26.0		27.0	
25-Dec-13	December	Summer				
26-Dec-13	December	Summer	24.5	37.0	26.0	33.0
27-Dec-13	December	Summer	24.0	34.5	26.5	32.5
28-Dec-13	December	Summer	25.5		27.0	
29-Dec-13	December	Summer				
30-Dec-13	December	Summer				
31-Dec-13	December	Summer				
Average			24.6	37.2	26.3	33.2
Standard deviation			1.2	2.8	0.8	0.8

- **Climatic conditions during the field trials of Britannia and Pierrefonds**





APPENDIX X

- **Analysis of variance of mean sugarcane yields of the plant cane crop of the different treatments set at Pierrefonds, Britannia and Chebel**

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replicate stratum	2	1850.6	925.3	5.84	
Replicate.*Units* stratum					
Main_treatment	2	14235.6	7117.8	44.96	<.001
Sub_treatment	7	1598.5	228.4	1.44	0.212
Main_treatment.Sub_treatment	14	1126.2	80.4	0.51	0.916
Residual	46	7282.2	158.3		
Total	71	26093.0			

APPENDIX XI

- **Summary of cane yield in experimental fields from plant cane to second ratoon**

	Plant cane yield (t ha^{-1}; harvest 2014)		
Treatment	**Pierrefonds**	**Britannia**	**Chebel**
No N fertilizer	103.7 ± 24.1	64.7 ± 11.4	71.5 ± 16.0
Chemical N fertilizer	110.1 ± 12.1	71.9 ± 9.1	78.9 ± 15.1
Chemical N fertilizer + FC	106.1 ± 13.0	77.7 ± 14.9	75.0 ± 7.9
Chemical N fertilizer + PM	109.6 ± 13.9	80.6 ± 9.7	89.1 ± 10.3
Chemical N fertilizer + PL	106.4 ± 16.2	78.6 ± 12.5	94.2 ± 23.5
FC only	118.4 ± 4.3	74.4 ±10.3	83.4 ± 25.6
PM only	104.0 ± 7.2	78.3 ± 15.6	90.8 ± 2.4
PL only	112.3 ± 7.5	79.6 ± 12.9	93.7 ± 7.7
ANOVA	P = 0.936	P= 0.259	P= 0.575
CV (%)	7.5	12.7	2.5
LSD (0.05)	25.4	13.7	28.9
Treatment	**First ratoon yield (t ha^{-1}; harvest 2015)**		
No N fertilizer	58.0 ± 7.2 a	74.4 ± 8.3	67.9 ± 9.4
Chemical N fertilizer	81.4 ± 10.0ab	83.0 ± 8.4	92.1 ± 20.9
Chemical N fertilizer + FC	88.6 ± 2.1b	75.6 ± 5.6	87.4 ± 13.4
Chemical N fertilizer + PM	93.5 ± 6.5 b	74.1 ± 5.4	90.6 ± 20.4
Chemical N fertilizer + PL	85.6 ± 14.5ab	71.0 ± 1.9	89.5 ± 12.8
FC only	85.0 ± 15.0 ab	68.6 ± 7.8	69.3 ± 17.5
PM only	76.3 ± 6.0ab	75.7 ± 15.4	86.9 ± 25.5
PL only	79.2 ± 15.1ab	75.4 ± 7.9	73.6 ± 27.4
ANOVA	P < 0.05	P= 0.657	P=0.629
CV (%)	6.3	3.5	5.4
LSD (0.05)	17.4	14.9	35.2
Treatment	**Second ratoon yield (t ha^{-1}; harvest 2016)**		
No N fertilizer	-	96.2 ± 3.0	-
Chemical N fertilizer	-	95.2 ± 9.9	-
Chemical N fertilizer + FC	-	108.3 ± 4.4	-
Chemical N fertilizer + PM	-	107.1 ± 1.86	-
Chemical N fertilizer + PL	-	104.1 ± 1.5	-
FC only	-	94.2 ± 4.4	-
PM only	-	102.1 ± 9.0	-
PL only	-	107.8 ± 1.4	-
ANOVA	-	P= 0.524	-
CV (%)		2.7	
LSD (0.05)	-	18.8	-

Except for Chebel trial that was harvested in 2015 (plant cane) and 2016 (first ratoon)

Treatment means that share the same letter are not statistically different

APPENDIX XII

- **Summary of sugar recovery in experimental fields from plant cane to second ratoon**

	Plant cane sugar recovery (harvest 2014)		
Treatment	**Pierrefonds**	**Britannia**	**Chebel**
No N fertilizer	12.8 ± 0.6	11.9 ± 0.4	11.0 ± 0.8
Chemical N fertilizer	12.5 ± 1.0	12.3 ± 0.5	11.7 ± 1.1
N fertilizer + FC	12.9 ± 1.1	12.4 ± 0.7	12.5 ± 0.7
N fertilizer + PM	13.1 ± 1.2	12.0 ± 1.0	11.6 ± 0.6
N fertilizer + PL	12.2 ± 0.2	12.3 ± 0.5	11.6 ± 1.0
FC only	11.9 ± 0.5	12.8 ± 0.5	11.5 ± 0.2
PM only	12.3 ± 0.7	11.6 ± 1.1	12.0 ± 0.4
PL only	13.0 ± 0.2	12.0 ± 0.9	11.7 ± 1.2
ANOVA	P= 0.947	P= 0.611	P= 0.589
CV (%)	2.1	2.0	2.5
LSD (0.05)	2.47	1.33	1.45
Treatment	**First ratoon sugar recovery (harvest 2015)**		
No N fertilizer	12.6 ± 0.6	12.5 ± 0.3	13.50 ± 0.50
Chemical N fertilizer	13.0 ± 0.1	12.2 ± 0.8	13.84 ± 0.65
N fertilizer + FC	12.9 ± 0.3	12.3 ± 0.1	13.91 ± 0.31
N fertilizer + PM	13.2 ± 0.4	12.2 ± 0.1	13.88 ± 0.25
N fertilizer + PL	13.3 ± 0.1	11.8 ± 0.1	13.56 ± 0.20
FC only	12.7 ± 0.4	12.0 ± 0.1	13.78 ± 0.40
PM only	13.1 ± 0.2	12.4 ± 0.7	13.48 ± 1.02
PL only	13.1 ± 0.6	12.2 ± 0.0	13.42 ± 0.42
ANOVA	P= 0.384	P = 0.653	P=0.817
CV (%)	0.1	1.1	1.9
LSD (0.05)	0.71	0.79	0.86
Treatment	**Second ratoon sugar recovery (harvest 2016)**		
No N fertilizer	-	11.77 ± 0.01	-
Chemical N fertilizer	-	11.45 ± 0.46	-
N fertilizer + FC	-	11.10 ± 0.31	-
N fertilizer + PM	-	11.20 ± 0.06	-
N fertilizer + PL	-	11.04 ± 0.14	-
FC only	-	11.42 ± 0.20	-
ANOVA	-	P = 0.214	-
CV (%)	-	1.1	-
LSD (0.05)	-	0.57	-